United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/8-80-028
August 1980

Research and Development

Design Handbook for Automation of Activated Sludge Wastewater Treatment Plants

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the "SPECIAL" REPORTS series. This series is reserved for reports targeted to meet the technical information needs of specific user groups. The series includes problem-oriented reports, research application reports, and executive summary documents. Examples include state-of-the-art analyses, technology assessments, design manuals, user manuals, and reports on the results of major research and development efforts.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/8-80-028
August 1980

DESIGN HANDBOOK FOR AUTOMATION OF ACTIVATED SLUDGE WASTEWATER TREATMENT PLANTS

by

Alan W. Manning
David M. Dobs

EMA, Inc.
St. Paul, Minnesota 55101

Contract No. 68-03-2573

Project Officer

Irwin J. Kugelman
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U. S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is the necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This manual is intended to serve as a systems engineering handbook to assist wastewater treatment plant design engineers in the application of automation in activated sludge wastewater treatment processes.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

This report is a systems engineering handbook for the automation of activated sludge wastewater treatment processes. Process control theory and application are discussed to acquaint the reader with terminology and fundamentals. Successful unit process control strategies currently in use are discussed. Alternative methods of control and implementation are presented where other considerations such as reliability or flexibility are important. A method for preparing a cost effective analysis is detailed through the use of examples. Currently available instrumentation is reviewed to serve as a guide for the selection of instruments for specific applications. The design guide section reviews some of the aspects of control system design and includes examples of documentation required to convey the engineer's and user's requirements. The concluding section presents recommendations for further studies which will advance the application of automation in wastewater treatment.

This report was submitted in fulfillment of Contract No. 68-03-2573 by EMA, Inc. under the sponsorship of the Environmental Protection Agency. Work was completed as of January, 1979.

CONTENTS

Foreword iii
Abstract iv
Figures vi
Tables ix
Abbreviations and Symbols x
P&ID Legend of Symbols xi
Instrument & Device Identification xii
Acknowledgment xiii

1. Introduction and Purpose 1
2. Process Control 6
3. Control Strategies 30
   Interceptor Storage 36
   Flow Equalization 40
   Plant Lift Stations 44
   Bar Screening 47
   Grit Removal 50
   Primary Clarification and Sludge Pumping 54
   Hydraulic Flow Control 59
   Dissolved Oxygen & Blower Control 64
   Cryogenic Oxygen Generation 68
   Return Activated Sludge 74
   Waste Activated Sludge 83
   Chemical Feed 89
   Post-Chlorination 94
   Ozonation 103
   Gravity Thickening 110
   Flotation Thickening 115
   Anaerobic Digestion 120
   Vacuum Filtration 128
   Centrifugation 134
   Roll Press Dewatering 139
   Plate Press Dewatering 145
   Incineration 151
   Return Liquors 161
4. Alternate Control Approaches 167
5. Cost Effective Analysis 206
   Appendix-Cost Effective Analysis Tables 254
6. Available Instrumentation 292
7. Design Guide 346
8. Recommended Future Activities 386

Glossary 403

FIGURES

Number		Page
2-1	Open-loop control	7
2-2	Closed-loop control	8
2-3	Flow control loop	9
2-4	Typical control loop element response	10
2-5	Pressure control loop	11
2-6	On-off control	12
2-7	Differential gap on-off control	13
2-8	Proportional control input-output relationship, gain = 1	14
2-9	Effect of gain adjustment on input-output relationship	15
2-10	Proportional control offset	16
2-11	Proportional mode control response	17
2-12	Elimination of offset by manual reset	18
2-13	Integral mode controller action	19
2-14	Integral plus proportional mode controller action	20
2-15	Proportional plus integral mode control response	20
2-16	Proportional plus derivative mode controller action	22
2-17	Proportional plus integral plus derivative control response	22
2-18	Direct control of dissolved oxygen	25
2-19	Cascade control of dissolved oxygen	26
2-20	Feedforward control	27
2-21	Feedforward (ratio) control of chlorination	28
3-1	Lift station control for interceptor storage	37
3-2	Flow equalization control	42
3-3	Lift station wet well level control	46
3-4	Bar screen control	49
3-5	Aerated grit chamber control	52
3-6	Primary clarification and sludge pumping	55
3-7	Flow control	61
3-8	Flow control, MOV method	62
3-9	Dissolved oxygen and blower control	66
3-10	Cryogenic oxygen generation	70
3-11	Activated sludge process flow diagrams	75
3-12	RAS control	77
3-13	WAS control	85
3-14	Chemical feed control-flow pacing	91
3-15	Chemical feed control-mass flow pacing	92
3-16	Chlorine feed control-flow proportional	96
3-17	Chlorine feed control-compound loop	98
3-18	Chlorine feed control-double compound loop	99

FIGURES (Continued)

Number		Page
3-19	Chlorine feed control-ratioed feedback	101
3-20	Ozonation control	106
3-21	Gravity thickener control	112
3-22	Flotation thickening control	117
3-23	Digester control	123
3-24	Vacuum filter control	130
3-25	Centrifuge control	136
3-26	Roll press control	141
3-27	Plate press process diagram	147
3-28	Incineration controls	153
3-29	Incineration offgas handling	154
4-1	Dewatering feed system	172
4-2	Manual control	173
4-3	Analog control characteristics	175
4-4	Local analog control	176
4-5	Distributed analog control	178
4-6	Central analog control	179
4-7	Central digital configurations	182
4-8	Central digital control	183
4-9	Distributed digital configurations	184
4-10	Distributed digital control	185
4-11	Hybrid control systems	187
4-12	Analog control with digital data logging	188
4-13	Digitally directed analog control (DDAC)	189
5-1	Conventional activated sludge with drying beds	208
5-2	Conventional activated sludge with incineration	209
5-3	Liquid train P&ID - 5 mgd	211
5-4	Solids train P&ID - 5 mgd	212
5-5	Liquid train P&ID - 10 to 300 mgd	213
5-6	Solids train P&ID - 10 to 300 mgd	214
5-7	Control system panel comparison	217
5-8	General central digital system configuration	221
5-9	Alternative control system costs	225
5-10	Chemical feed control methods	242
5-11	Power demand control	245
5-12	Material and energy costs, June 1978	247

FIGURES (Continued)

Number		Page
7-1	Typical constant speed pump interface (maintained contact control)	353
7-2	Typical constant speed pump interface (momentary contact control)	354
7-3	Secondary clarification and RAS piping schematic	356
7-4	Control system configuration	357
7-5	Secondary clarification and RAS P&ID	360
7-6	P&ID Symbol Legend	361
7-7	Variable speed pump interface	365
7-8	Typical incremental controller interface	366
7-9	Typical mounting detail-sludge density analyzer	372
7-10	RAS local control panel	373

TABLES

Number		Page
2-1	Summary of Control Functions	24
3-1	Unit Process or Control Strategy Utilization	33
3-2	Steady State Modulation	71
4-1	Control Comparison Summary	191
5-1	Control Equipment and Wiring Capital Cost Summary	228
5-2	Operations Annual Manhours - Conventional Control	230
5-3	Process Operator Tasks	231
5-4	Operating Attendant II Tasks	231
5-5	Operating Attendant I Tasks	232
5-6	Operational Manpower Assignments	233
5-7	Operator Staffing Comparison - Conventional vs. Centralized Control	235
5-8	Maintenance Requirements per Component	236
5-9	Central Analog Maintenance Requirements	237
5-10	Central Digital Control Maintenance Requirements	238
5-11	Maintenance Manpower-Conventional Control	239
5-12	Annual Operations & Maintenance Manpower Costs	240
5-13	Annual Material and Energy Costs	248
5-14	Present Worth Analysis	249
5-15	Annual Cost Analysis	251
7-1	RAS Input/Output List	363
7-2	Instrumentation Summary List	368
7-3	Magnetic Flowmeter and Transmitter	371

ABBREVIATIONS AND SYMBOLS

PIPING AND INSTRUMENTATION SYMBOLS

The legend of symbols on page xi was derived from Instrument Society of America "Instrument Symbols and Identification," (ISA - S5.1, 1973). These symbols are used extensively in Section 3 - Control Strategies.

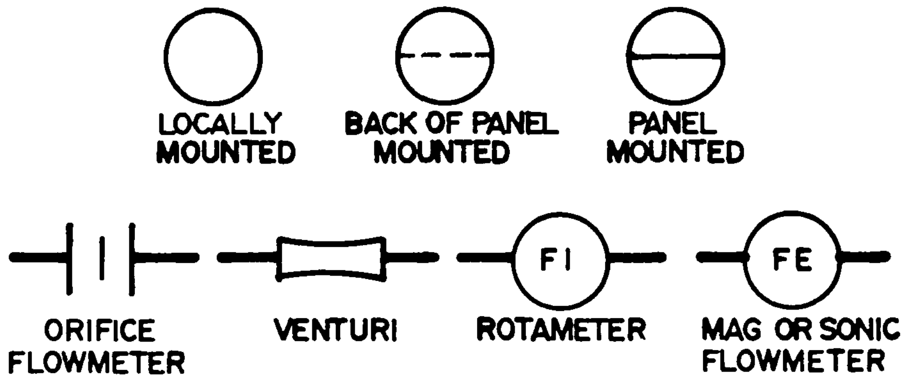
INSTRUMENT AND DEVICE IDENTIFICATION LETTERS

A list of instrument letter codes is provided on page xii. These letter codes appear in the so-called "balloons" on the piping and instrumentation drawings (P&ID's). For example, the designation FIC is decoded as follows: The first letter is identified as "flow" from the first column; the succeeding letters represent "indicate" and "control" from the second column. Additional gramatical modifiers must be added to form a complete designation, "flow indicating controller."

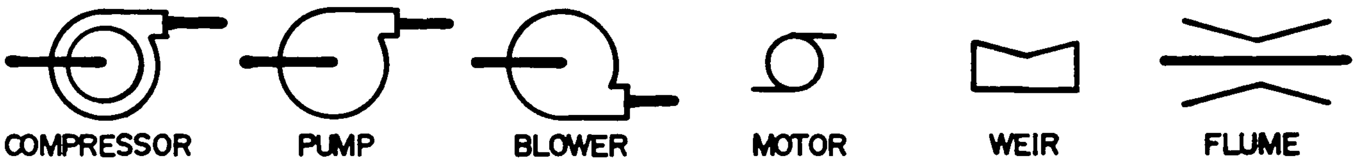
MISCELLANEOUS ABBREVIATIONS AND SYMBOLS

CL_2	chlorine
CPU	central processor unit (computer)
CRT	cathode ray tube
C/S	constant speed
DO	dissolved oxygen
FB	feedback
I/F	interface
I/P	current to pneumatic converter
LEL	lower explosive limit
MUX	multiplexer
O_2	oxygen
SEQ	sequence control
SP	setpoint
V/S	variable speed
Δ	differential
x	multiply
÷	divide
$\sqrt{\ }$	extract square root

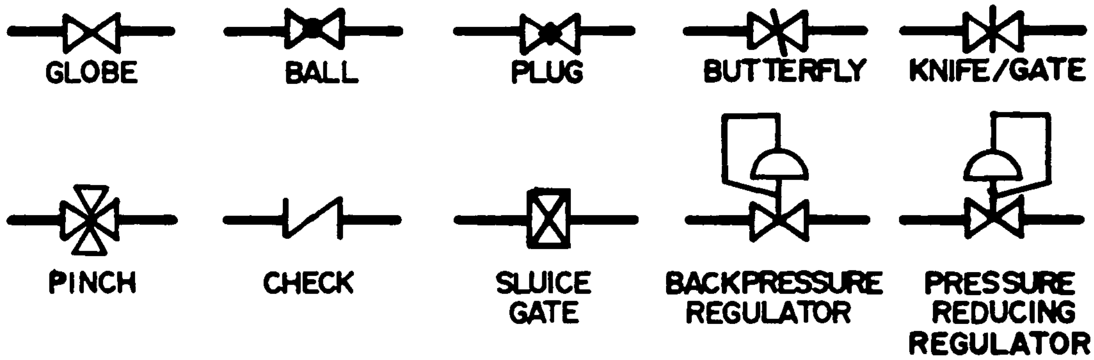
P & ID LEGEND OF SYMBOLS



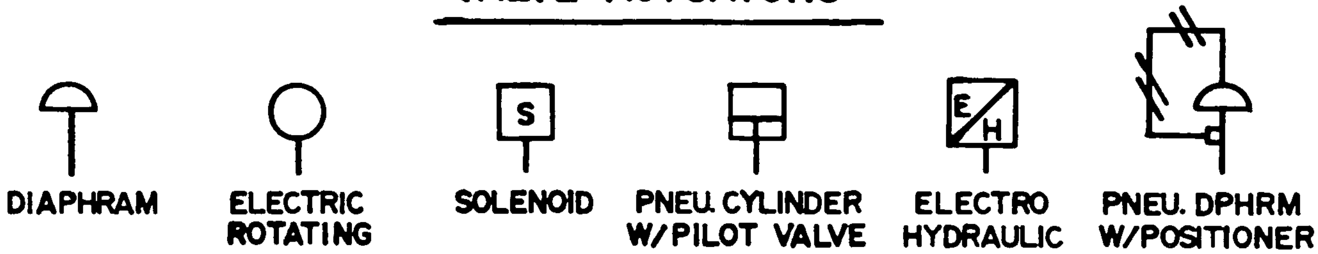
EQUIPMENT SYMBOLS



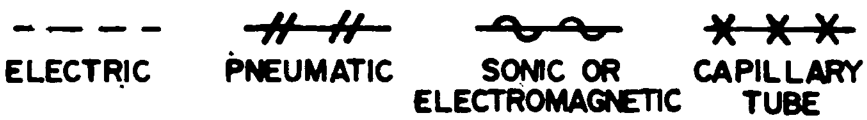
VALVE BODY SYMBOLS



VALVE ACTUATORS



SIGNAL LINE SYMBOLS



INSTRUMENT & DEVICE IDENTIFICATION

LETTER	FIRST LETTER	SECOND AND SUCCEEDING LETTERS
A	Analysis	Alarm
B	Burner Flame	Close or Decrease
C	Conductivity	Control
D	Density	Open or Increase
E	Voltage (EMF)	Primary Element
F	Flow Rate	Failure
G	User Choice	
H	Hand (Manual)	High
I	Current Elec)	Indicate
J	Power	Light
K	Capicator	Control Station
L	Level	Low
M	Motor	Operate or On/Off
N	Moisture	Start/Stop or Open/Close
O	Torque	Overload
P	Pressure or Vacuum	
Q	Quantity or Event	Totalize
R	Radioactivity	Recorder
S	Speed or Frequency	Switch
T	Temperature	Transmitter
U	Multivariable	Multifunction
V	Valve or Damper	Valve or Damper
W	Weight or Force	
X	Vibration, Motion	Excess
Y	Computer	Relay or Compute
Z	Position	Drive Actuate or Final Control Element

ACKNOWLEDGMENTS

Sincere thanks is offered to the management and operating staffs of the treatment plants visited for the purposes of gathering information utilized in this report. During the execution of this report, over seventy-five facilities were visited. It would be impossible to acknowledge each group individually. Certain people and organizations did contribute an inordinately large amount of time and information. The contributions of the following individuals in particular are gratefully acknowledged.

Mr. Dale Bergsted and Ms. Joanne Hart of the Metropolitan Minneapolis-St. Paul Wastewater Treatment Plant.

Mr. Timothy McAloon, Mr. Richard Fries and Mr. Edward Pytel of the Metropolitan Chicago Sanitary District.

Mr. John Nelson of the Metropolitan Denver Sewage Disposal District.

Mr. Stanley LeSeur, Mr. John Warren and Mr. Michael Mathews of the Hillsboro, Oregon Unified Sewerage Agency.

Mr. Gerald Seymour of the Metropolitan Cincinnati Sewer District.

Mr. Andy Letterman of the Springfield, Missouri Waste Treatment Plant.

Mr. Paul Papke of the Central Contra Costa Sanitary District.

Mr. Edward Becker of the San Jose-Santa Clara Water Pollution Control Plant.

Mr. Phillip Habrukowich of the Ocean County Utilities Authority.

In addition to all of those mentioned above, the authors wish to acknowledge the guidance and assistance provided by Joseph Roesler, project officer during the initial part of the activity.

SECTION 1

INTRODUCTION AND PURPOSE

A primary method for achieving cost effective abatement of water pollution is optimization of process and system control in wastewater treatment plants. Process control on a real-time basis is of vital concern because the quantity and quality characteristics of municipal wastewater exhibit significant time variation.

In the past, the overall economic framework of the water pollution control industry has not favored the same methods of achieving process control optimization as have been utilized in the chemical process industries. Historically the water pollution control industry has favored high capital expenditure for oversized or redundant units, and employment of relatively large operational staffs of low to semi-skilled operators. Recent tightening of effluent discharge standards, and the relative cost of materials, construction labor, opertional labor, electronic equipment, chemicals and power have forced a reassessment of the traditional techniques. Cost effective process control can now be best achieved by the techniques of the chemical process control industry, i.e., design of process unit capacity "close to the limit," and the use of small highly skilled operational staffs, aided by the extensive use of instrumentation and automation.

The key factor in this new process control optimization philosophy is the effective application of instrumentation and automation techniques. Unfortunately, in many cases initial applications of instrumentation and automation in the water pollution control field were less than roaring successes. Many reasons for significant failures in these initial installations have been identified (1) and much activity is now underway to correct these situations. However, the damage has been done such that instrumentation and automation for process control suffers from a poor reputation in the water pollution control industry.

Among the major problems identified as the cause of failures in highly instrumented and automated wastewater treatment plants are:

1. Lack of knowledge of and experience with the application of instrumentation equipment and automation in the sanitary engineering profession.

2. Lack of understanding of the correct techniques of process control on the part of design engineers and users.

3. Misapplication of otherwise acceptable sensors and instruments.

4. Lack of acceptable instruments and sensors.

5. Improper maintenance of instrumentation and automation equipment.

6. Lack of identified proven control strategies for some processes.

7. Poor coordination between the control engineers and the other engineering disciplines involved in design of wastewater treatment systems.

In fact, it is possible with the present level of technology and engineering knowledge to successfully design, construct and operate a highly instrumented and automated cost effective wastewater treatment plant, capable of meeting virtually all discharge standards. Indeed there have been several such plants put on stream in the last few years. A basic problem is putting the information about this technology and these engineering techniques in the hands of the user community.

The USEPA has actively pursued this educational goal by supporting the development of three previous publications on instrumentation and automation. In October of 1976, a report (2) was issued as a result of a comprehensive survey of wastewater treatment plants which documented the status of treatment plant instrumentation and automation. In December of 1976, a second report (3) was issued which analyzed potential applications of instrumentation and automation at wastewater treatment plants. Various proposed automated strategies were evaluated with respect to their technical and economic validity. In June of 1977, a third report (4) was issued which completely examined dissolved oxygen control. The last two reports are written as technical documents for instrument and control system engineers. In that these reports are the first of a kind, one can conclude that this process industry is just beginning to realize the benefits of instrumentation and automation.

This document is the fourth in this educational series. Its specific aim is to present to the sanitary design engineer the up-to-date information required to adequately cope with the design of activated sludge plants which will be equipped with cost effective instrumentation and automation. The objectives of this document are to provide a base of information, procedures and reference material to designers, users and regulatory agencies in an easily referenced handbook to aid them in making decisions regarding equipment selection or specification for automation.

The manual is divided into seven sections organized to guide the consulting engineer in control "system" design for wastewater treatment plants. The objective for each section of this manual is as follows:

PROCESS CONTROL

This is a discussion of basic concepts of automatic process control. The objective is to acquaint the reader with terminology and fundamentals, and to provide examples of control relevant to wastewater treatment.

CONTROL STRATEGIES

This section is a compilation of documented process control strategies that are currently in use. The objective is to summarize the generally accepted, successful and field verified control strategies for specific unit processes and varying plant capacities.

ALTERNATE CONTROL APPROACHES

The objective of this section is to introduce the consulting engineer to the alternate methods of control implementation. Various manual and automatic equipment configurations are described and important features such as reliability, flexibility and expandability are discussed in each case.

COST EFFECTIVE ANALYSIS

Cost is a consideration in every selection process. The objective of this section is to detail a method for preparing a cost effective analysis by performing such an analysis on three alternate control systems for seven plant sizes.

AVAILABLE INSTRUMENTATION

The common element of each alternate control system is measurement of the process variable. Flow, pressure, temperature, etc. must be sensed and converted to a signal representative of the measured variable for transmission to the devices controlling the process. The objective of this section is to establish an appreciation for the capabilities and limitations of instrumentation and to serve as a guide for the selection of instruments for specific applications. For each instrument, a minimum preventive maintenance program is suggested to ensure the instrument will remain operational.

DESIGN GUIDE

The objective of this section is to consolidate the information presented in the preceeding sections into a procedural guide demonstrating some of the aspects of control system design for wastewater treatment processes. The guidelines are intended to be used by design engineers, users and regulatory agencies in the proper approach for control system design. Attention to detail is stressed. Examples are included with special emphasis on explaining the documentation and drawings which are necessary to convey the engineer's and the user's requirements and desires. Checklists are provided for guidance.

RECOMMENDED FUTURE ACTIVITIES

The objective of this section is to present recommendations for further studies and research which will advance the application of instrumentation and automation in the wastewater treatment industry. The goal is to multiply the benefits of previous research by performing additional work which will broaden the use and value of this and other reports dealing with automation of wastewater treatment facilities.

SECTION 1
REFERENCES

1. Research Needs for Automation of Wastewater Treatment Systems, Proceedings of a workshop held at Clemson, SC, Sept. 23-25, 1974.

2. Instrumentation and Automation Experiences in Wastewater-Treatment Facilities, EPA-600/2-76-198. October, 1976.

3. Selected Applications of Instrumentation and Automation in Wastewater-Treatment Facilities, EPA-600/2-76-276. December, 1976.

4. Design Procedures for Dissolved Oxygen Control of Activated Sludge Processes, EPA-600/2-77-032. June, 1977.

SECTION 2

PROCESS CONTROL

INTRODUCTION

This section will introduce basic concepts of automatic process control including specific application examples relevant to wastewater treatment. No control theory background is assumed in the presentation. A formal approach to the subject requires the use of differential equations and Laplace transform techniques, but this is beyond the scope of this discussion. A major objective of this section will be to provide an understanding of commonly used control terminology. Formal definitions of the terms used in this section are listed in the glossary at the end of this manual.

REASONS FOR PROCESS CONTROL

Control can be considered as some action taken to maintain the objectives of operation by balancing the supply and demand of a process over a period of time. Variations in operating conditions can take many different forms and can occur at any point within a process. A few examples of these variations, more commonly referred to as "disturbances," include supply and demand load changes, changes in flowstream quality, and changes in ambient conditions. Satisfactory operation can sometimes be achieved with only minor and infrequent adjustments to correct or limit the deviation of measured values from some selected reference. In this situation, observation and manual corrective adjustment is often satisfactory. In most cases, however, it becomes impractical or impossible to manually control the process within acceptable tolerances due to factors such as operator fatigue, quantity and complexity of control decisions required, and the inability of an operator to make adjustments quickly and in a consistent manner. An automatic controller is required to overcome these problems. The controller is a device that accepts a signal representing the variable to be regulated, compares it with a setpoint which is a reference source representing the desired level of operation, and generates an output to a control device that influences the variable to be regulated.

CONTROL LOOPS

Open-Loop Control

A generalized block diagram of an open-loop control system is shown in Figure 2-1. The final control element (modulating valve, variable speed pump, etc.) is set at one point within its operating range or operated according to a fixed program (time clock operation of primary sludge pumping, for example). The distinguishing feature of open-loop control is that a continuous measurement of the variable to be controlled is not available or is not connected to the controls so that there is no assurance that the control objective is actually being achieved. Control will be satisfactory only if the control element is properly set or programmed for a particular set of process conditions and the conditions remain unchanged during operation. If the original conditions are disturbed, operator intervention will be required to make the necessary adjustments to maintain balance within the process. Open-loop control is satisfactory for noncritical applications where conditions do not vary significantly and close regulation of the process is not required.

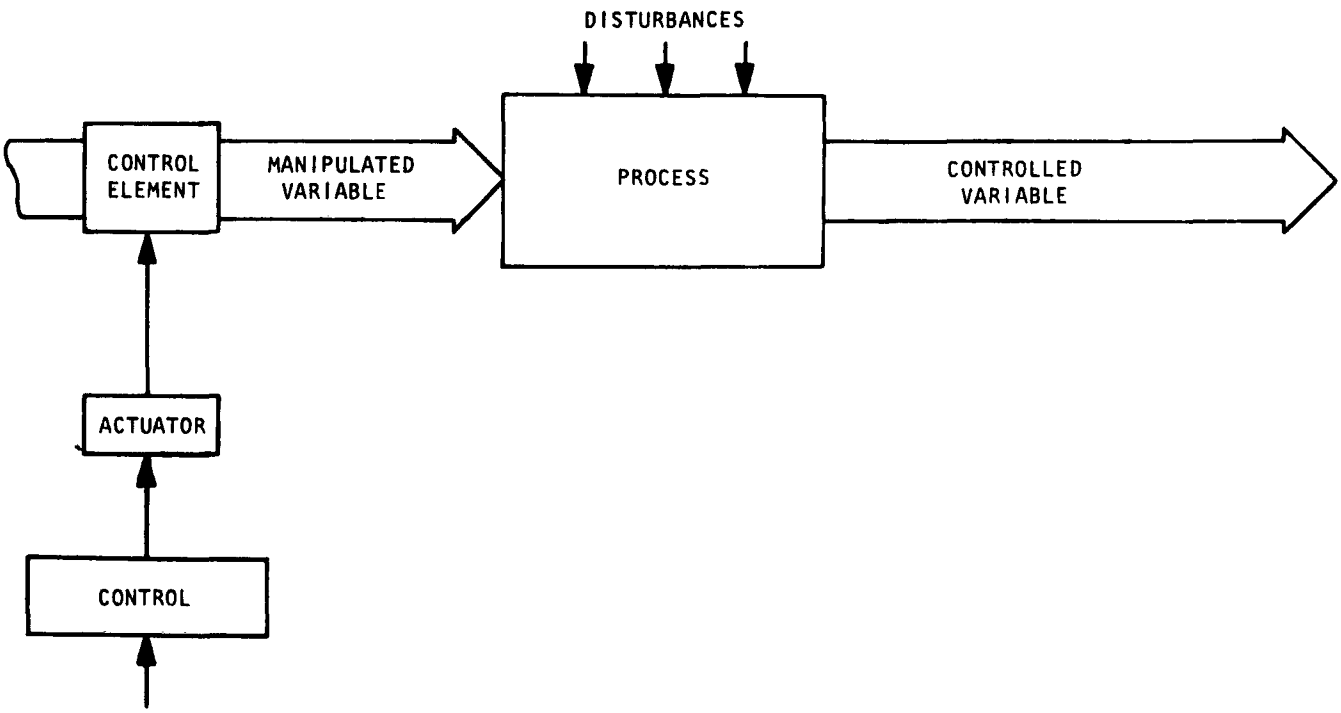


Figure 2-1. Open-loop control.

A manually adjusted variable speed pump control is an example of open-loop control because typically the actual speed is not monitored to provide correction to the control if a change in suction or discharge head should cause the pump speed to drift from the speed setting selected.

Closed-Loop Control

Figure 2-2 depicts a block diagram of a closed-loop control system. In this case, a continous measurement of the controlled variable is made and routed to the controller. The controller compares this measurement or feedback signal with the setpoint and any resulting deviation or error is used by the controller to generate an output to apply corrective action to the final control element. The term "closed-loop" describes the path that is formed about the process by the controlled variable measurement, the controller, and the output to the control element. The affects of any change in the system propagate around the loop. A change in the measurement causes the controller output to change, the output change causes some condition of the process to change, the change in the process affects the controlled variable, and so on.

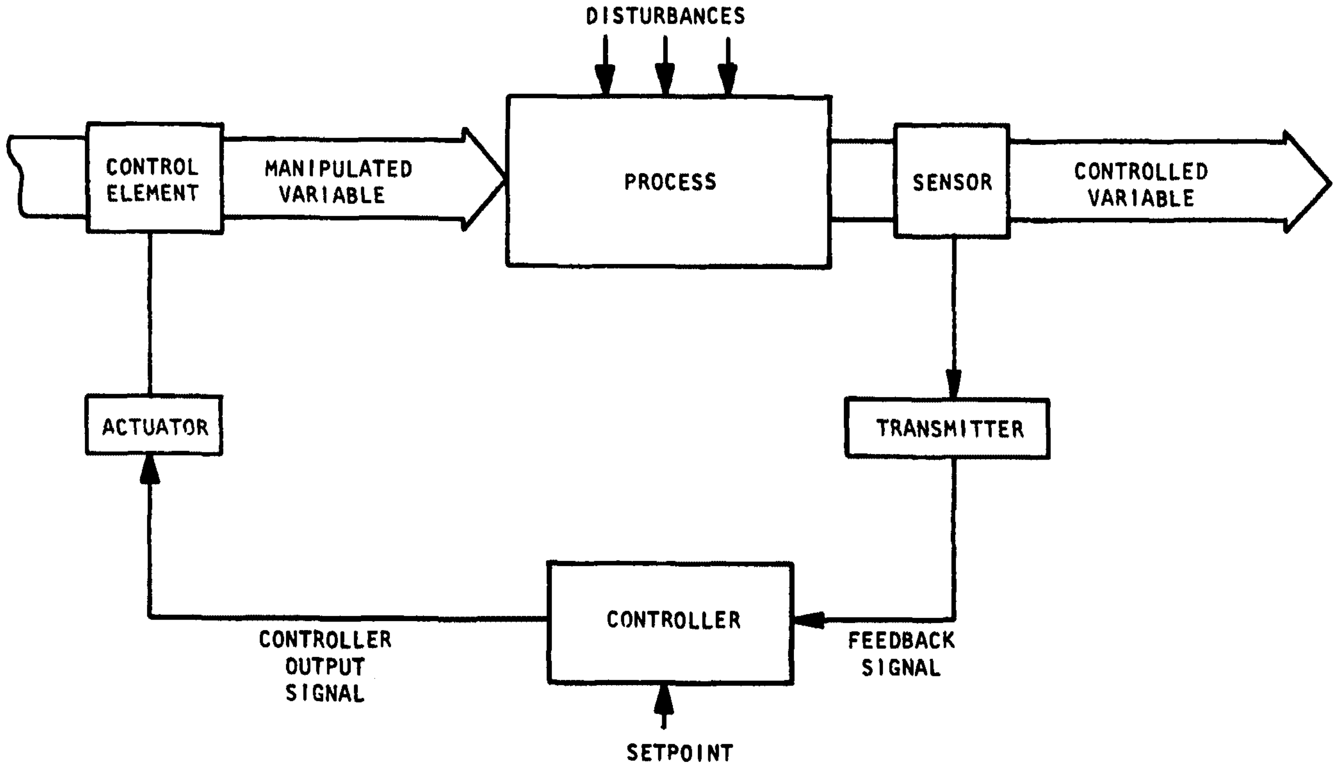


Figure 2-2. Closed-loop control.

The flow control system shown schematically in Figure 2-3 is an example of closed-loop control. The objective is to maintain the flow rate at some desired value by adjustment of the modulating valve. In this example, flow is the controlled variable used as feedback to the controller. The valve position is manipulated by the controller to reduce or eliminate any deviation of the flow from the setpoint value. The valve position is therefore referred to as the manipulated variable.

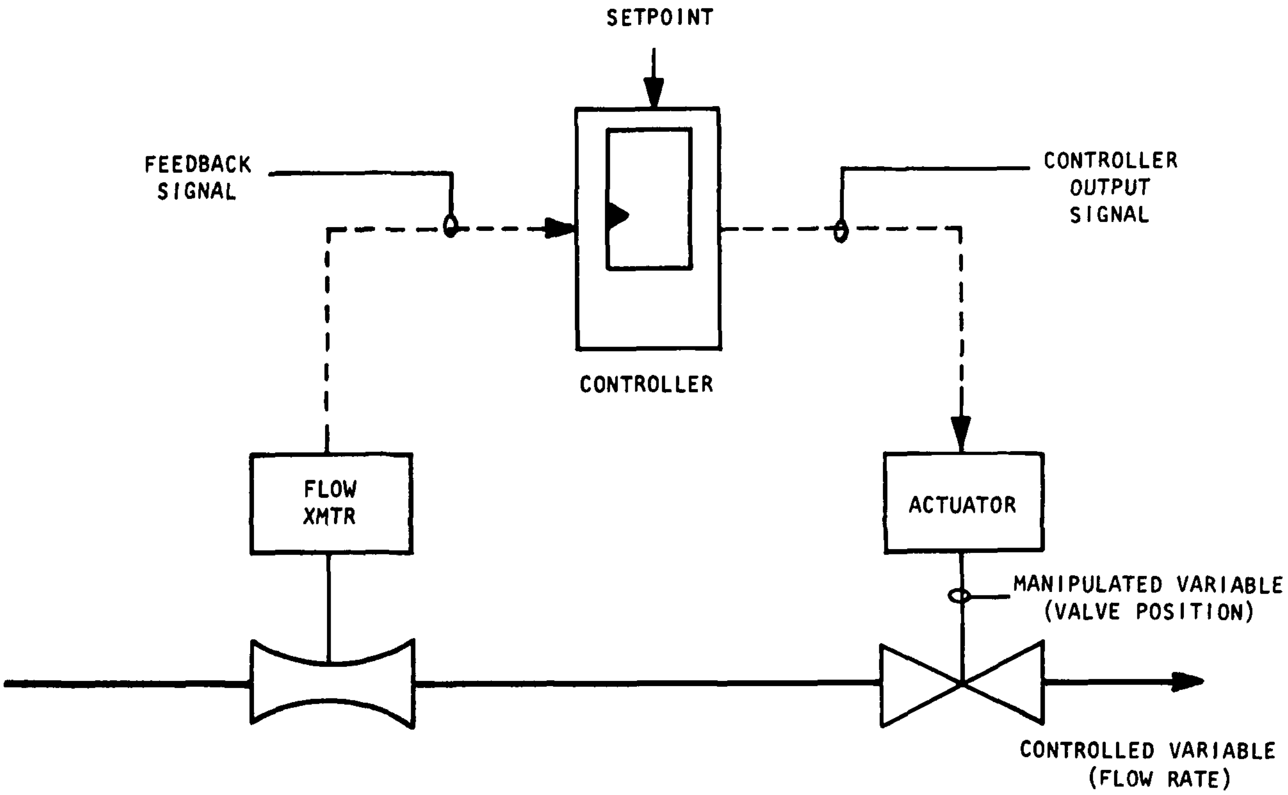


Figure 2-3. Flow control loop.

There is the potential for instability (cycling or oscillation of the controlled variable with increasing amplitude) in closed-loop control. The system will become unstable if the controller acts to augment an imbalance in the system rather than oppose it. This condition can occur if the characteristics of the controller are improperly matched with the characteristics of the control loop.

Dynamic Characteristics of Control Loops

Each element of a control loop including the sensor, transmitter, controller, actuator, control element and largely the process itself, requires time to react to a change in its input. The response of the complete control loop will be the sum of the responses of all elements in the loop. It is necessary to understand two basic types of time elements in order to correctly match the controller characteristics with those of the process.

Deadtime is that period of time which elapses between the moment a change is introduced into an element and the moment a response begins to occur. Absolutely no response can be detected during this time period. An example of deadtime in a process is that which is present in a chlorine contact chamber. If chlorine is injected into the influent at the chamber entrance and the chlorine residual is measured in the chamber effluent, there will be a period during which a change in the chlorination rate is undetectable. This is due to the time it takes for the affected portion of the flow to traverse the length of the chamber. Control of the chlorination rate based on the residual measurement will be poor at best because there is always a lack of current sensor information to direct the control device metering the chlorine. This illustrates the control problems typically encountered in any process where significant deadtime exists in the control loop.

A more common type of time lag is that due to capacity involving the storage of material or energy. A wet well is a simple example of the occurrence of capacity within a process. Unlike the previous example involving deadtime, an increase in flow into or from a wet well results in an immediate though small change in the rate at which the level rises or falls. This system is considered to have a delay due to capacity because the level is slow to respond as compared to the immediate change in flow rate that was introduced. Another example of the effect of capacity is evident in the control of dissolved oxygen in an aeration basin by regulating the aeration air flow supply. The DO in the large volume contained in the basin will change very slowly even if a large change is made in the air flow rate.

An index called a time constant is used to characterize the capacitive response of a control loop element. The time constant is defined as the time it takes after a step change is made in an element's input for the response of the element to reach 63.2% of its final equilibrium value. The response indicated in Figure 2-4 could represent the behavior of a process variable, a sensor or a control device.

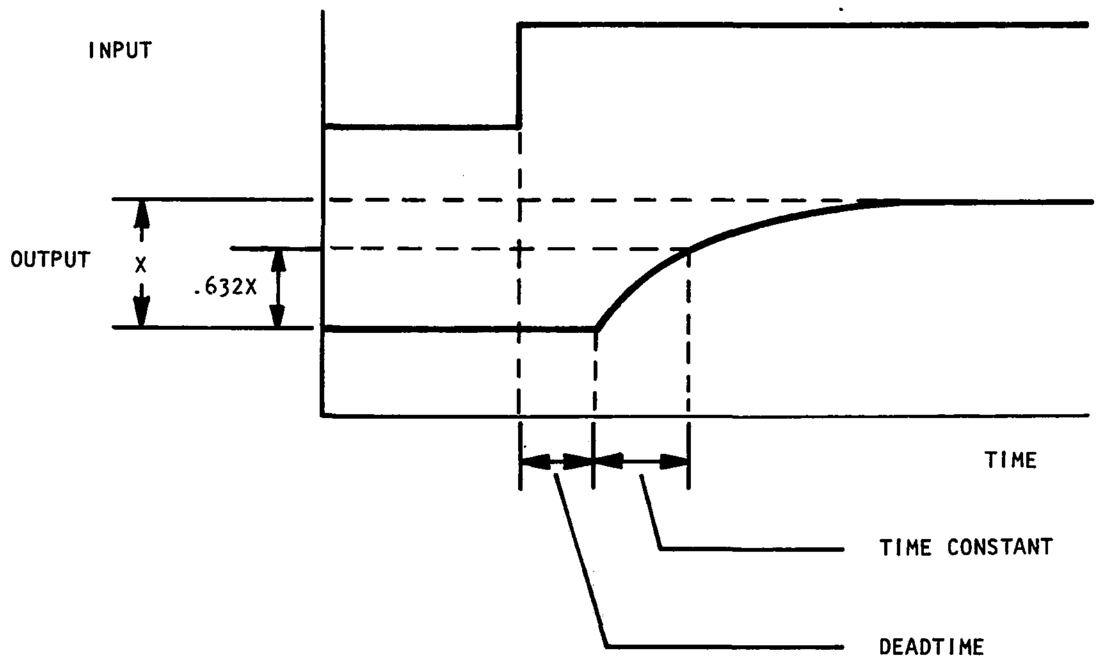


Figure 2-4. Typical control loop element response.

AUTOMATIC CONTROLLERS

The pressure control system shown in Figure 2-5 will be used as an example to explain the operation of an automatic controller in more detail. The objective of the control system is to maintain a tank pressure of 60 psi by adjusting the high pressure air inlet valve. We will assume that strict regulation of the tank air pressure is required for proper operation of the processes using the air supply.

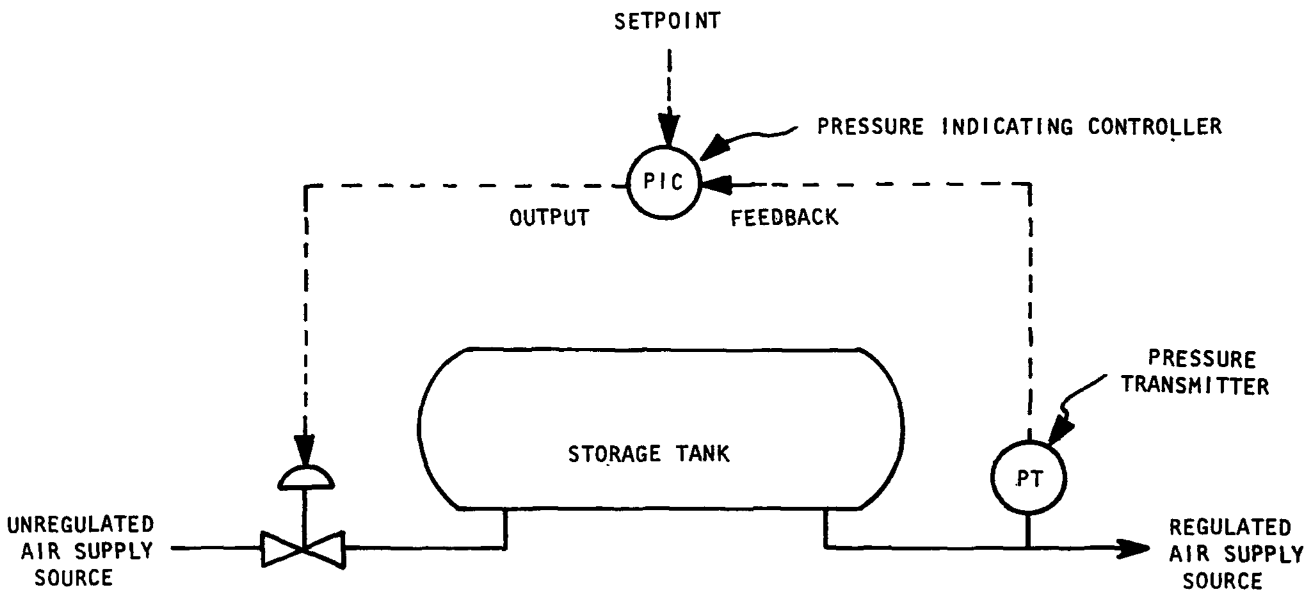


Figure 2-5. Pressure control loop.

On-Off Control

The simplest controller action that we might apply in this example would be to fully open or close the air supply valve, depending on whether the tank pressure is below or above 60 psi. When the final control element is driven to one extreme or the other in response to a comparison of the controlled variable with a setpoint, this is an example of two-position or on-off control. Using on-off control, the pressure control system responds as indicated in Figure 2-6. When the pressure falls below the setpoint, the controller opens the valve. The tank pressure builds up to 60 psi and begins to exceed the setpoint before the control system can respond to close the valve. The pressure peaks and begins to fall due to demand loading. When the pressure falls below 60 psi, the cycle repeats itself.

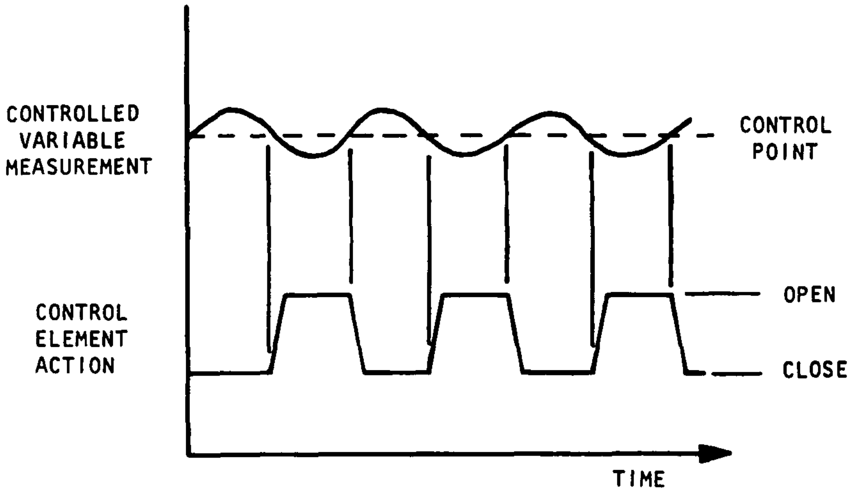


Figure 2-6. On-off control.

On-off control causes the controlled variable to oscillate about the setpoint with an amplitude and frequency that is dependent on the capacity and time response of the process. The amplitude and frequency will remain the same as long as the load on the process does not change. If the components of the pressure control system were idealized so that the valve could be made to open or close instantaneously in response to infinitesimal errors, the tank pressure error would approach zero but the frequency of control valve cycling would approach infinity.

In general, on-off control provides satisfactory regulation only when the process has a high capacity in relation to the load demand. A large process capacity also acts to buffer the input variations resulting from a control action that drives the final control element from one extreme to the other.

A familiar example of an application of on-off control is a thermostatically controlled heater. On-off control is not satisfactory in the pressure control example because the control action causes excessive valve wear and the controlled variable (tank pressure) may not be well regulated depending on the amount of load in relation to the capacity of the tank.

A variation of on-off control called differential-gap control is often used to reduce the wear on the final control element. A system response curve for this type of control is indicated in Figure 2-7. A band is defined about the setpoint value such that when the controlled variable drops below the lower limit, the valve is opened. The valve remains open until the upper limit of the band is exceeded. The valve then remains closed until the controlled variable again drops below the lower limit. Differential-gap control is commonly used in noncritical level control applications where the only requirement is to prevent a tank from overflowing or running dry.

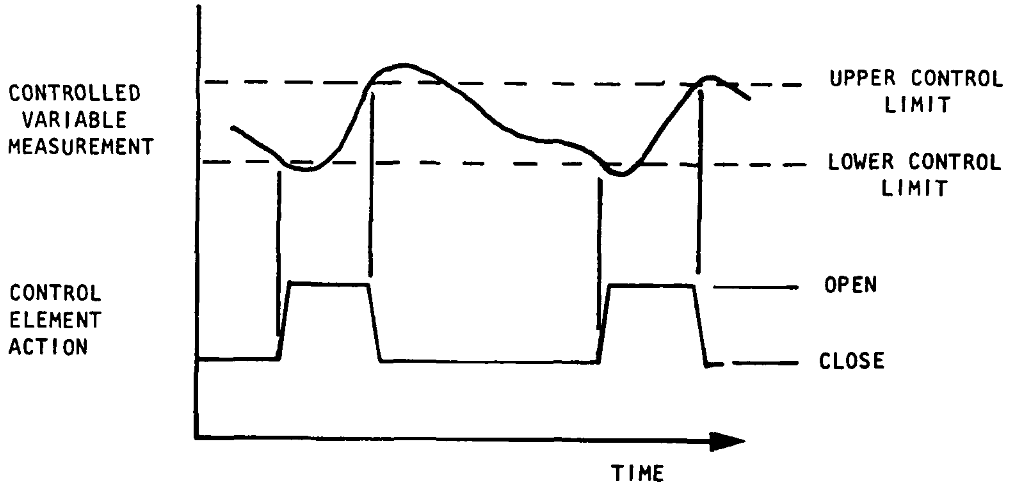


Figure 2-7. Differential gap on-off control.

On-off control is the simplest and least expensive form of automatic feedback control, but it is often unable to provide the regulation required or is impractical due to the characteristics of the process or control system. Methods of control which direct a final control element to intermediate points within its range (referred to as throttling control) were developed to resolve these problems. The remainder of this section on automatic controllers will describe methods of generating throttling control action.

Proportional Control

In proportional control, the controller positions the final control element based on the amount of deviation of the controlled variable from the setpoint. A fixed linear relationship is then established between the controlled variable measurement and the controller output as indicated by the input-output line in Figure 2-8. The line represents all of the possible operating points of the system. The slope of the line represents the amount of proportional action provided by the controller, referred to as the proportional gain. This gain is the ratio of the change in controller output to the change in the input.

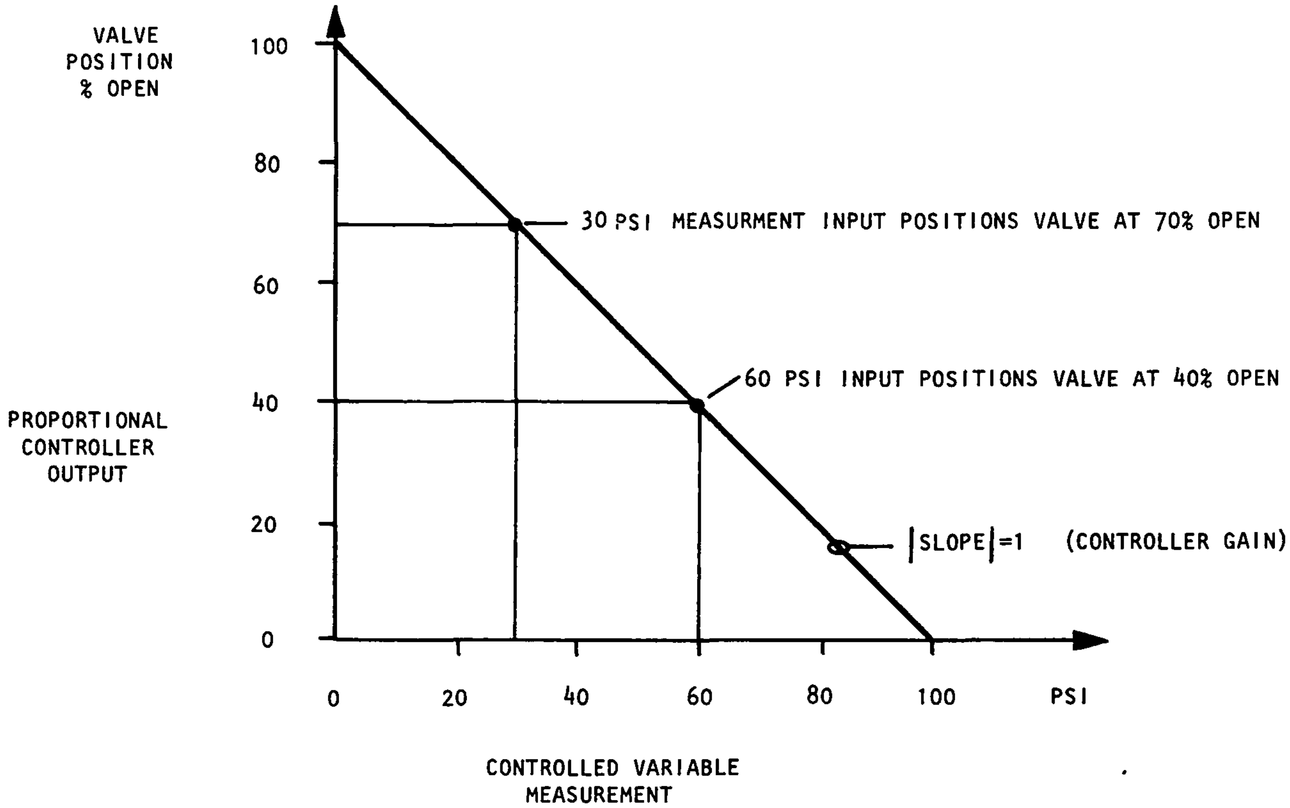


Figure 2-8. Proportional control input-output relationship, gain = 1. (Pressure control example)

$$\text{Proportional Gain} = \frac{\Delta\ \text{Output}}{\Delta\,(\text{setpoint - measurement})}$$

Many controllers have this gain adjustment expressed as proportional band which is the percent change of the controlled variable measurement that will cause the controller output to swing from 0 to 100%. Proportional band is related to proportional gain as follows:

$$\text{Proportional Gain} = \frac{100}{\%\ \text{Proportional Band}}$$

If the measurement range in our example is 0 to 100 psi, a valve position correction of 1% for a deviation of 1 psi represents a gain of 1 or a proportional band of 100%. A gain of 1 was arbitrarily chosen to be represented in Figure 2-8. Figure 2-9 shows the effect of varying the gain setting on the input-output relationship. At a gain of zero, changes in the controlled variable measurement do not affect the valve position so there is no control. If the controller could be adjusted for infinite gain, on-off control action would result because infintesimally small deviations from the setpoint would drive the valve fully open or closed.

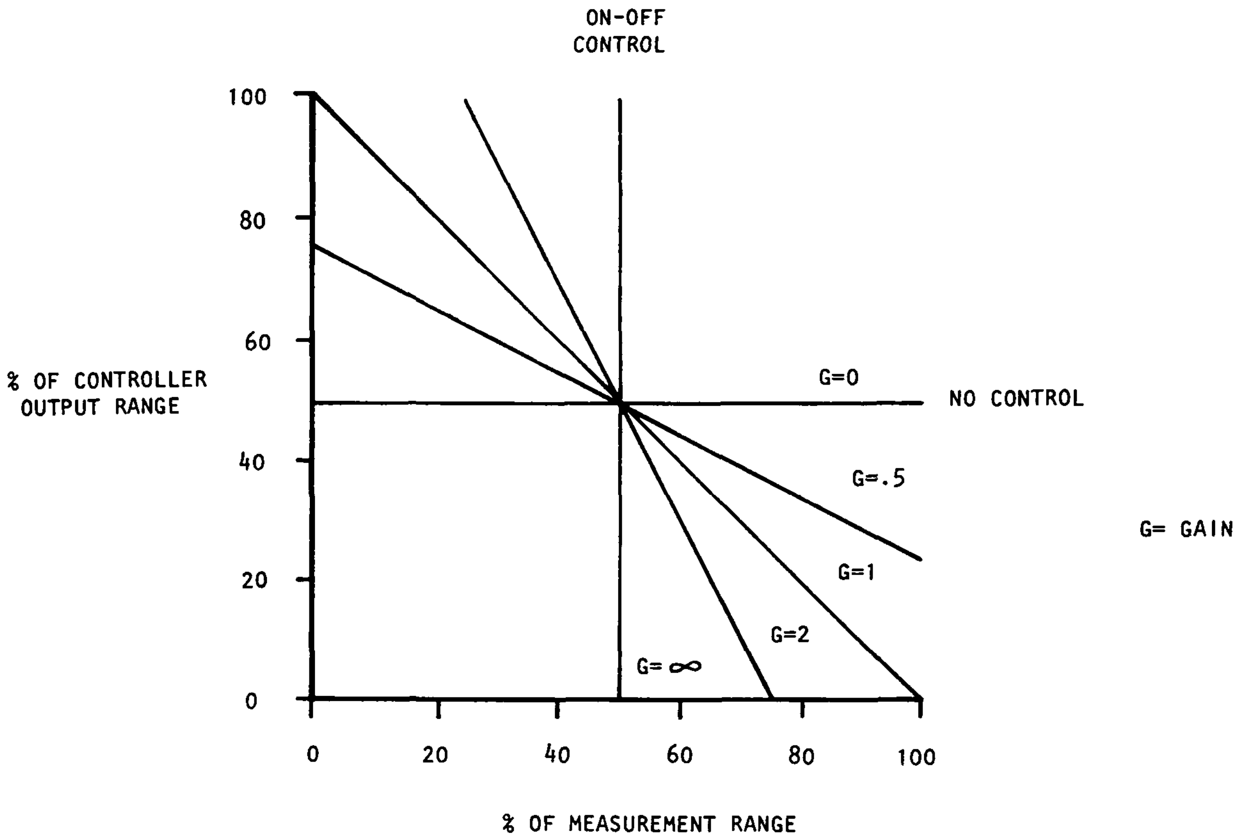


Figure 2-9. Effect of gain adjustment on input-output relationship.

For consistency, all of the proportional control input-output characteristics illustrated in this section are shown as having negative slopes indicating that the output decreases as the measurement value increases. These controllers are sometimes classified as "reverse acting." Controller characteristics having a positive slope are representative of "direct acting controllers."

An important characteristic of proportional control is that it can never return the controlled variable back to the setpoint after a load change. This is difficult to understand until one recalls that proportional control produces corrections proportional to deviations. No correction will be produced unless there is some deviation. It is obvious that any load change will require some control element movement to correct for it. Therefore, after any load change there must always be some deviation remaining, otherwise there would be no proportional action to provide correction. The residual steady state error that is inherent in proportional control is called offset. The occurrence of offset can be demonstrated in our pressure control system example by referring to Figure 2-10 in the following discussion. Assume that the process load conditions are such that the controlled variable is at the setpoint and the valve is positioned at 40% open (point A on the input-output line). Let us now disconnect the controller output from the valve so that it remains at 40% open. A load change occurs that causes the tank pressure to drift to 20 psi and remain at this point. If the controller is now reconnected to the valve, we see that the input-output relationship of the controller dictates that the valve position will be driven to 80% open for a tank pressure measurement of 20 psi (point B). When the valve position increases to the 80% open position, the tank pressure increases from 20 psi. This reduces the tank pressure deviation so that the controller no longer calls for the valve to remain at 80% open. The operating point begins to move down along the line toward point A. As the tank pressure continues to increase, the pressure deviation is reduced further which in turn reduces the controller's corrective action. Finally, a new equilibrium point is reached (point C) where there is just enough proportional action due to the remaining deviation to balance the effect of the load disturbance. The tank pressure and the offset will remain constant for as long as the current load condition continues to exist.

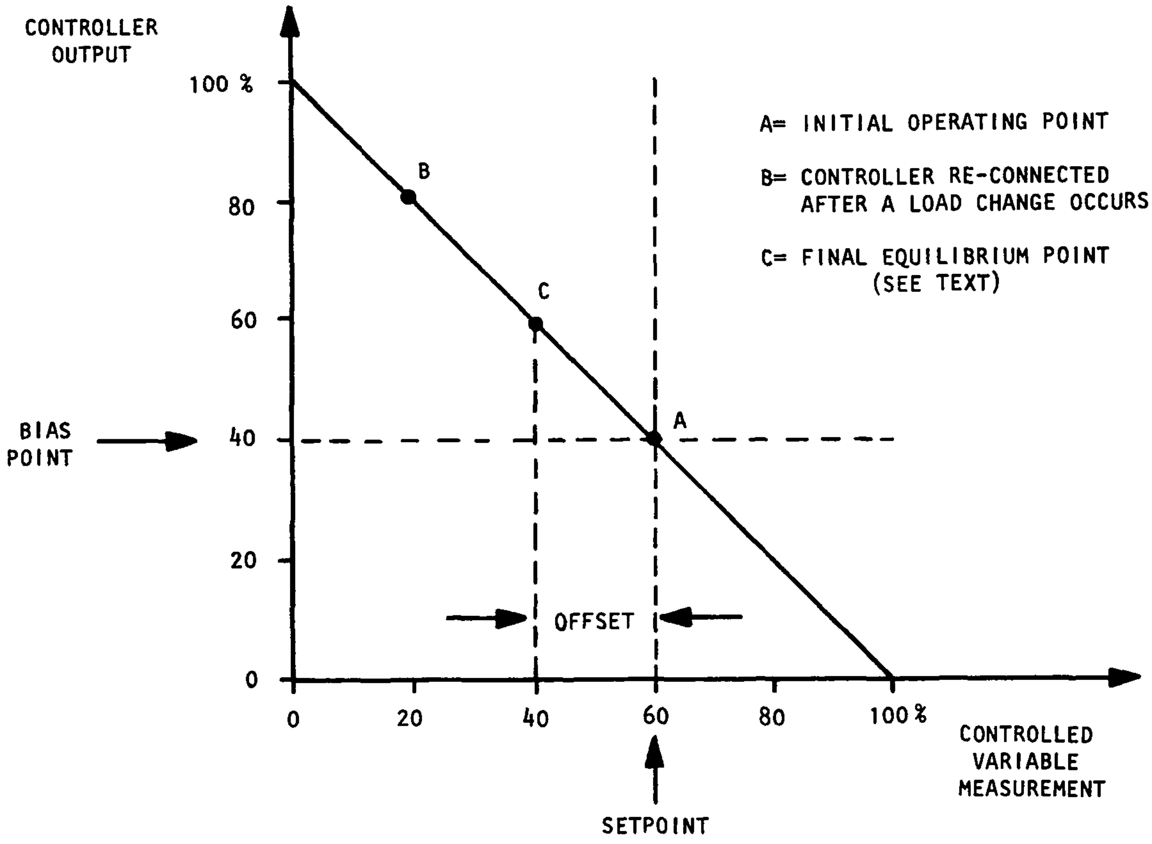


Figure 2-10. Proportional control offset (pressure control example).

Where operating conditions are such that the maximum offset that occurs is within the permissible variations of the controlled variable, a proportional controller will provide satisfactory control. In an attempt to reduce offset, it seems logical that all we need do is require the controller to provide more correction for the same amount of error. This represents an increase in the proportional gain. This will certainly be effective in reducing the offset, but it has the effect of making the system far too sensitive to disturbances. At high gain settings, the controller tends to overcorrect severely when a disturbance occurs and results in a system that oscillates in an unstable manner. Figure 2-11 Indicates the response of the pressure control system to a large load disturbance when three different gain settings are used. Note that the high gain setting results in the least amount of offset but also wider and more prolonged cycling of pressure before stable control is achieved.

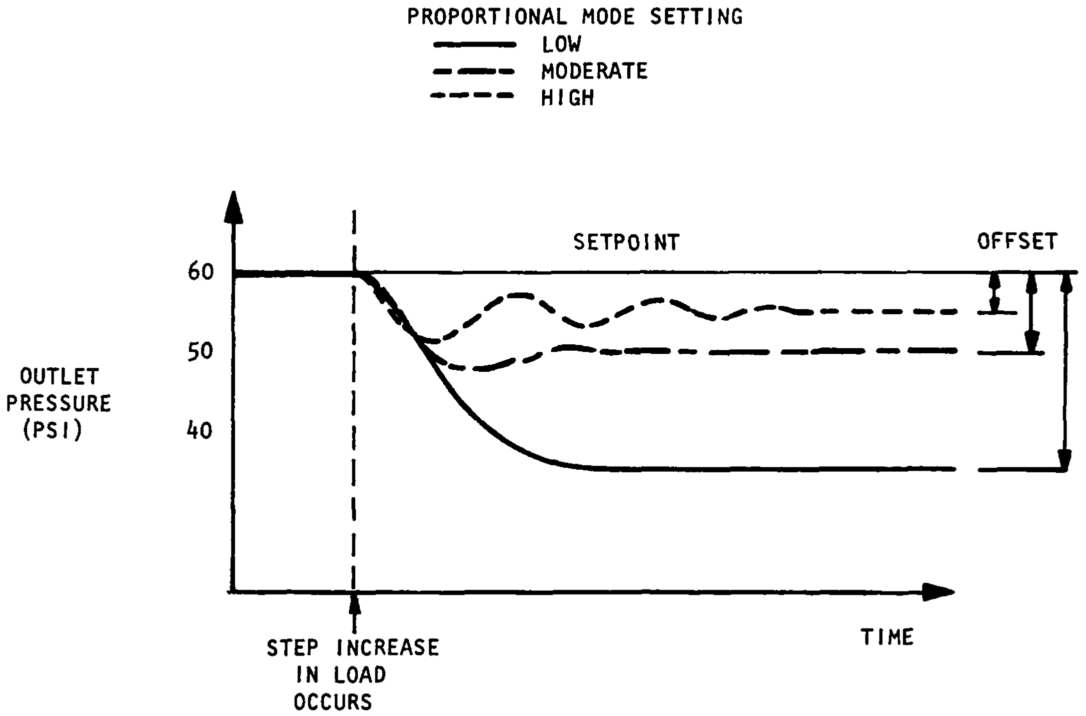


Figure 2-11. Proportional mode control response.
(Pressure control example)

Proportional controllers are usually provided with an adjustment to allow the output to be set at approximately 50% whenever the controlled variable equals the setpoint. As the controlled variable measurement deviates from the setpoint, the output will vary from this reference level (or bias) by a proportional amount. The output of the controller is expressed by the following equation:

Output = Proportional Gain (Setpoint - Measurement) + Bias

This adjustment can be used to eliminate offset. An operator could adjust the controller output bias to move the final control element as much as needed to return the controlled variable to the setpoint value. A bias adjustment or manual reset is represented in Figure 2-12 by an upward shift of the input-output line without changing its slope. In this way, the same value of the controlled variable measurement can be made to produce a different controller output than when the line was fixed.

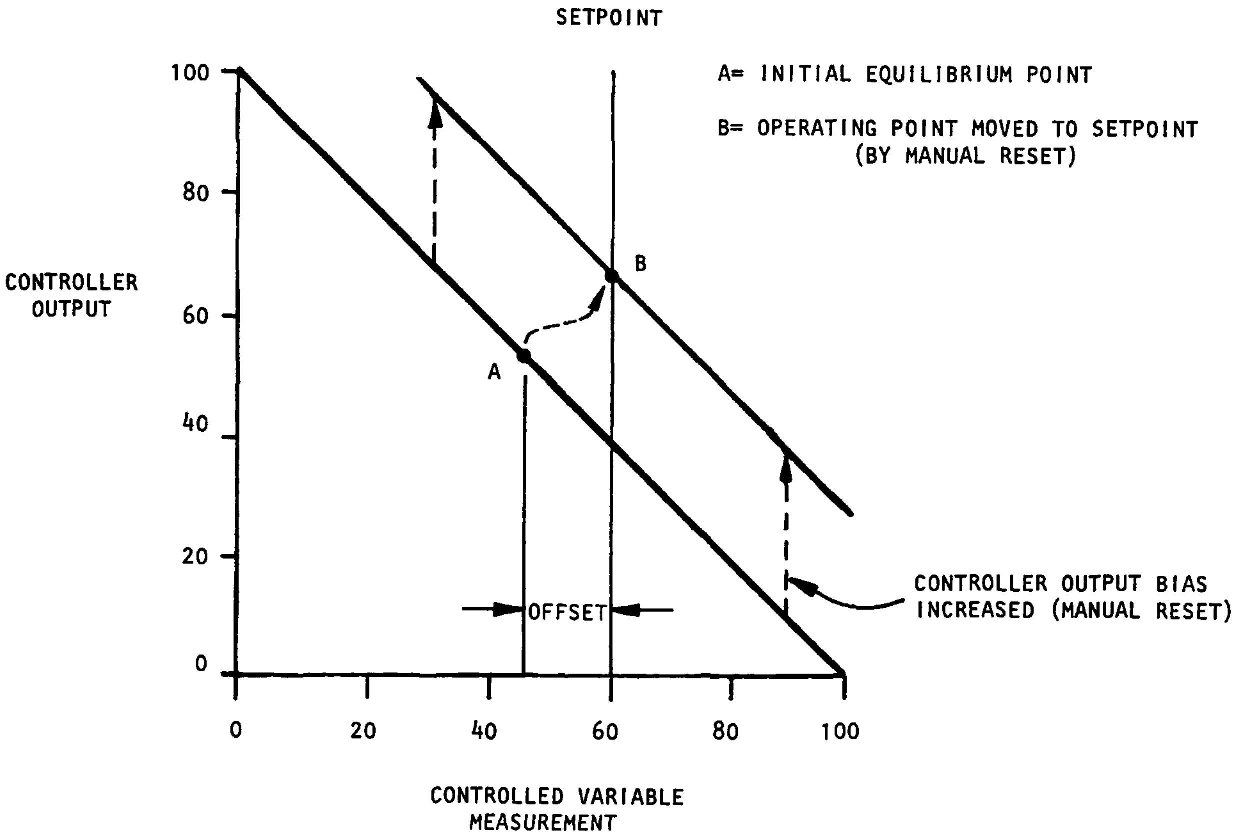


Figure 2-12. Elimination of offset by manual reset.

Integral Control

If offset cannot be tolerated, the use of a high proportional gain to reduce offset may be unacceptable because it can cause the system to become unstable. The other alternative, manual reset, can be used but is almost always impractical because the operator must readjust the controller every time a significant disturbance occurs. An additional control mode referred to as integral mode or automatic reset is required to automatically perform the reset function. The output of a controller due to integral action is the time integral of the error so that the output becomes a function of both the magnitude and duration of the error rather than a function of the magnitude only as in proportional control. Because error is integrated, the controller output will continue to change as long as a difference exists between the controlled variable input and the setpoint. The smallest error will cause the controller output to ramp up or down, driving the control element as much as is needed to eliminate the error.

Figure 2-13 demonstrates how an integral mode controller responds to a step change in the controlled variable input. It is important to note that only the response of the controller itself is indicated. The controller output has been disconnected from the process (i.e. the control loop has been opened) so that the controller input remains unaffected by the output.

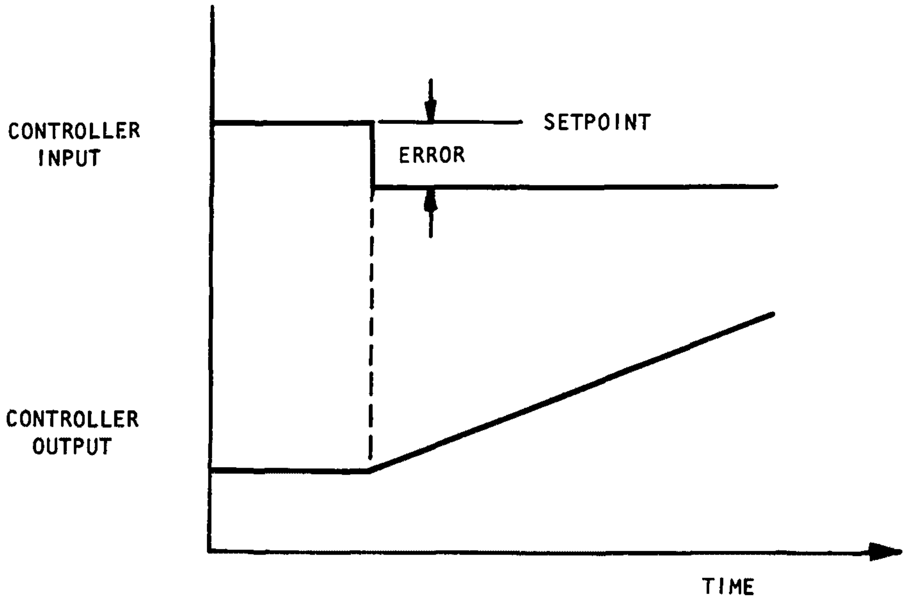


Figure 2-13. Integral mode controller action.

Integral action is very rarely used by itself because it is slow to act. It is most often combined with proportional action so that the two modes act simultaneously. Figure 2-14 indicates the output of a proportional plus integral controller in an open-loop response to a step change in the input. The integral time indicated in the Figure is the amount of time required for integral action to duplicate the amount of output change due to proportional action alone. The controller adjustment for integral mode is often calibrated in repeats per minute which is the number of times per minute the amount of change caused by proportional action is repeated by integral action.

Let us now apply proportional plus integral mode control to our pressure control example. Assume that the proportional gain has been adjusted to a moderate value that regulates the pressure in a nonoscillatory manner when a load disturbance occurs. Figure 2-15 indicates the response of the system associated with three different values of integral mode action that are added to the proportional controller. Note that in each case, offset is completely eliminated but the higher values of integral action cause the system to respond with less stability. Too much integral action causes the controller's output to change faster than the rate at which the process can respond and cycling results.

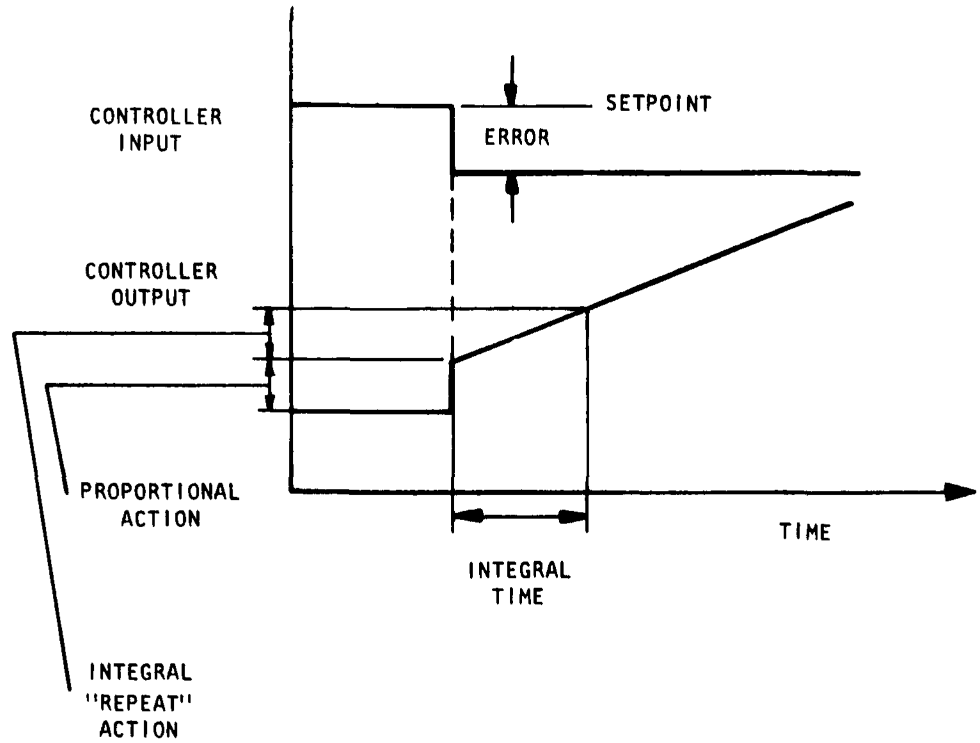


Figure 2-14. Integral plus proportional mode controller action.

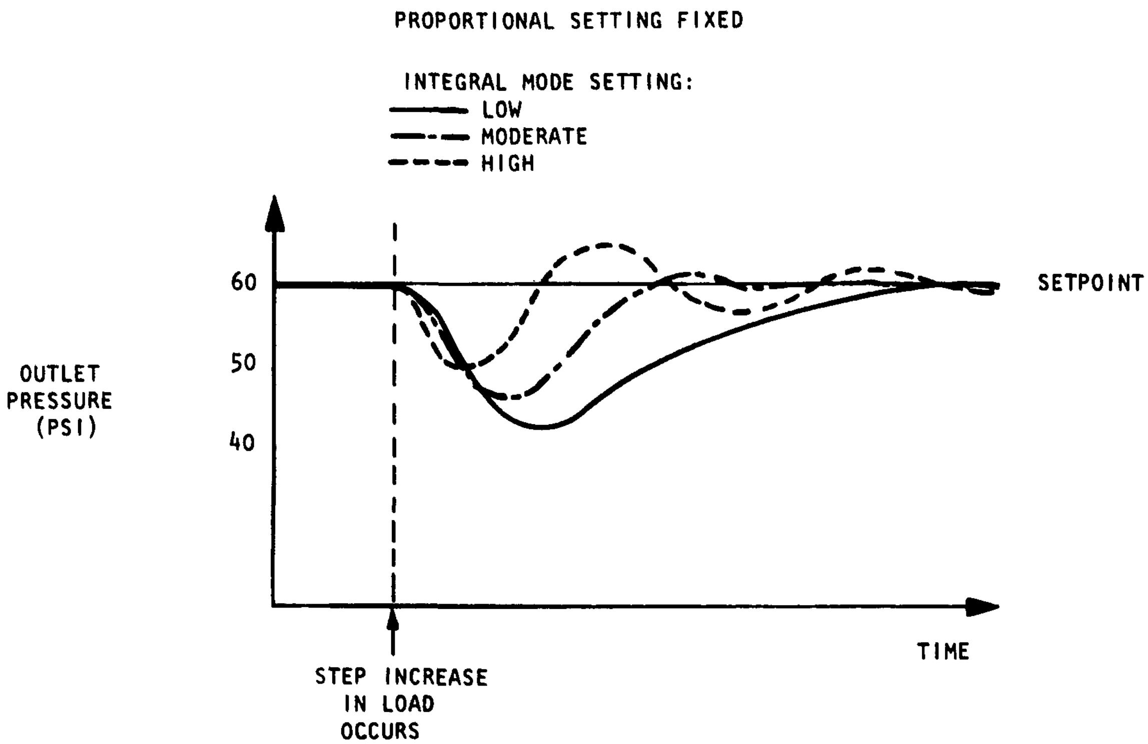


Figure 2-15. Proportional plus integral mode control response. (Pressure control example)

Integral mode action has a disadvantage that becomes a serious problem in some situations. For example, during startup of a process, the controlled variable is often far from the setpoint. The controller's integral mode function interprets this deviation as a large offset error and rapidly drives the final control element to compensate. By the time the controlled variable reaches the setpoint, the integral action may have built up the output to the limit of the controller so that it continues to apply maximum correction to the control device. The result is that the controlled variable drastically overshoots the setpoint value and cycles about it for a prolonged period of time. This problem is referred to as reset windup. To avoid this problem, it may be necessary to start the process with the integral mode turned off until the proportional action brings the controlled variable into equilibrium. Automatic means of accomplishing this are sometimes available as an option on automatic controllers.

Derivative Control

The addition of a third mode of control called derivative or rate is sometimes desirable in the control of some processes to overcome system inertia. Basically, derivative action provides an immediate output when a deviation begins to occur, so that the correction supplied to the final control element is initiallly greater than would normally be provided by either proportional or integral mode action. More exactly, the output of the controller due to derivative mode action is proportional to the rate at which the controlled variable deviates from the setpoint.

Derivative mode action will occur only when the controlled variable changes so that under steady state conditions, it makes no contribution to the controller's output. For this reason, derivative mode is used only in combination with proportional or proportional plus integral control. Figure 2-16 indicates the output response of a proportional plus derivative mode controller when a steadily increasing input is applied. Again, note that this is an open-loop response because the controller output has been disconnected from the control device. The rate time indicated in the figure is the time interval by which derivative action advances the effect of proportional action upon the final control element. Derivative control is often described as having an "anticipatory" effect because of the way it advances the action of the controller.

The example pressure control system responds to proportional plus integral plus derivative control as indicated in Figure 2-17. It is assumed that the proportional and integral mode adjustments have been set at levels that are judged to be optimum for this system. With these settings, three different values of derivative mode action are added to the controller and in each case, the response to a step load change is indicated. The addition of the proper amount of derivative action has the effect of stabilizing the system in a shorter period of time. As we have seen in the cases of proportional and integral mode control, excessive derivative action also degrades the stability of the system.

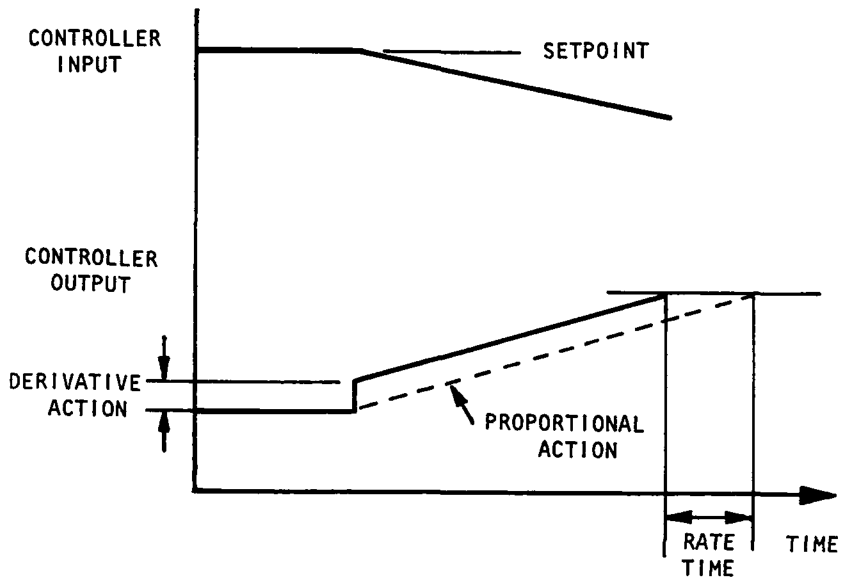


Figure 2-16. Proportional plus derivative mode controller action.

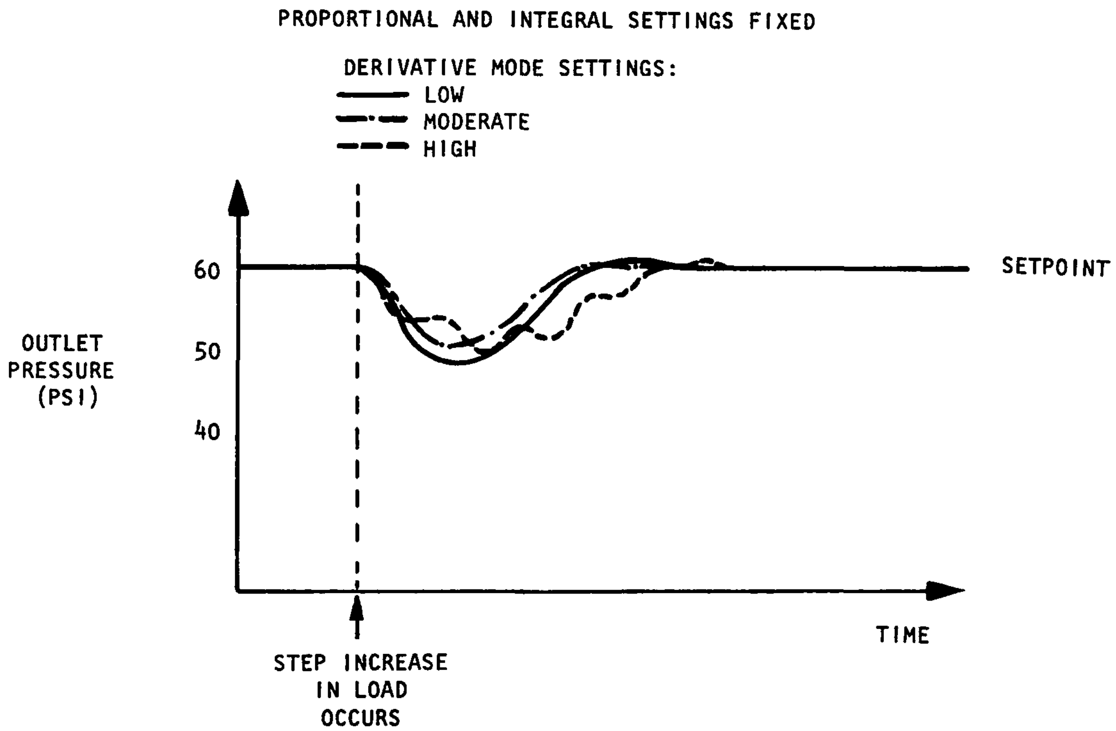


Figure 2-17. Proportional plus integral plus derivative control response. (Pressure control example)

Controller Tuning

Adjustment of the controller modes to obtain good system response is referred to as tuning the controller. There is a problem in defining what constitutes "good" system response because the criteria will vary for different types of processes. For example, offset can be tolerated in some processes but not in others. It may be desirable in some cases to have the system respond without overshoot and we are not too concerned with the length of time it may take for the controlled variable to reach the setpoint. In other cases, we may require strict regulation that quickly returns the system to the setpoint and we are willing to tolerate some overshoot of the controlled variable in order to achieve the faster response. The control modes are selected and adjusted to match the characteristics of the control loop. Numerous procedures for controller tuning have been published that are based on math matical and trial-and-error methods (1)(2).

Automatic Controller Summary

Table 2-1 summarizes the information presented on proportional, integral and derivative mode control.

ADVANCED CONTROL CONCEPTS

Cascade Control

For some applications, improved control can be obtained through the use of two conventional feedback controllers connected in series. In this way, two complete feedback loops are formed, one within the other.

To illustrate the need for and the application of cascade control, consider the dissolved oxygen (DO) control system shown in Figure 2-18 where the sensed variation in DO is used to manipulate the position of the air valve. Due to the large process capacity, disturbances in the air flow or the influent's demand for oxygen are not immediately sensed by the DO analyzer. Once the DO measurement begins to change appreciably, the control system can begin to act to modify the air flow to the aeration basin. There may be so much time lag in the process due to capacity, however, that the control is ineffective or unacceptable. For example, by the time the effect of a disturbance in the air supply pressure is sensed by a change in DO, the pressure disturbance may have subsided or the pressure may have changed to a third value. At this time, the correction signal from the controller based on DO becomes inappropriate for compensation of the current air supply conditions.

Two sources of disturbances that influence air supply pressure may be present. In a typical multiple tank system where all of the tanks utilize a common air supply, the changing demands of each tank can disturb the air supply pressure (only one aeration tank is shown in Figure 2-18 for simplicity). Also, where multiple blowers are used to match the demands of the process, the starting and stopping of blowers introduces additional pressure disturbances.

TABLE 2-1. SUMMARY OF CONTROL FUNCTIONS

Mode	Function	Operation	Notes
Proportional Action	Restores process equilibrium by counteracting disturbance effects.	Repositions the final control element in proportion to the magnitude of deviation from setpoint.	- Adjustment calibration is % proportional band or gain. - Action approaches on-off control at highest gain setting. - Action reduces, but cannot eliminate, deviations resulting from load changes. - Used in noncritical control applications only.
Integral Action (Automatic Reset)	Eliminates steady-state deviation from setpoint.	Repositions the final control element according to magnitude and duration of deviation from setpoint.	- Adjustment calibration is repeats per minute. - Action stops only when process is at setpoint. - Sustained deviation from setpoint will create a "wind-up" i.e. control device reaches an extreme. - Reset time should not be set faster than the process deadtime.
Derivative Action (Rate)	Reduces time required for controlled variable to stabilize.	Repositions the final control element according to the rate of deviation from setpoint.	- Adjustment calibration is rate time. - Acts only when the control variable is moving. - Aids in overcoming system inertia due to capacity. - Not used in control loops with prominent deadtimes. - Not used in control loops that have a high noise content.

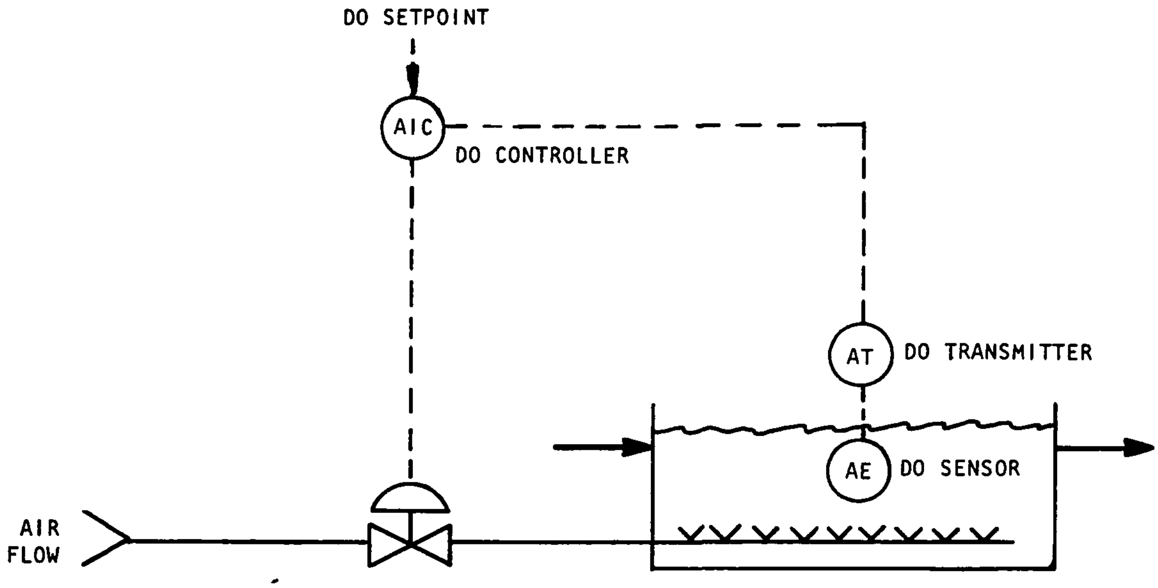


Figure 2-18. Direct control of dissolved oxygen.

Figure 2-19 illustrates the addition of a control loop for air flow with its setpoint derived from the DO controller. The DO controller is said to be "cascaded" into the air flow controller. The DO control loop is referred to as the primary, outer or master loop. The air flow control loop is the secondary, inner or slave loop. With this arrangement, disturbances in the air supply pressure that would affect the flow are now corrected by the inner flow control loop. Corrective action is now initiated without having to wait for the DO to change as was the case under single loop control. If a disturbance in the influent demand for oxygen occurs, it appears that the response of the cascade control system will be much as before except the corrective action must pass through two controllers. It can be shown, however, that the addition of an inner feedback loop around the control valve has the effect of increasing the speed of response and thus contributes some improvement in the speed of response of the overall system.

In general, selection of the inner and outer cascade control loops for proper operation and improved control requires that the inner loop have a faster response time than the outer loop, and that the inner loop be chosen as the one affected by the major disturbances in the system. The controllers are tuned in the same way as single loop controllers. The inner loop should always be tuned first.

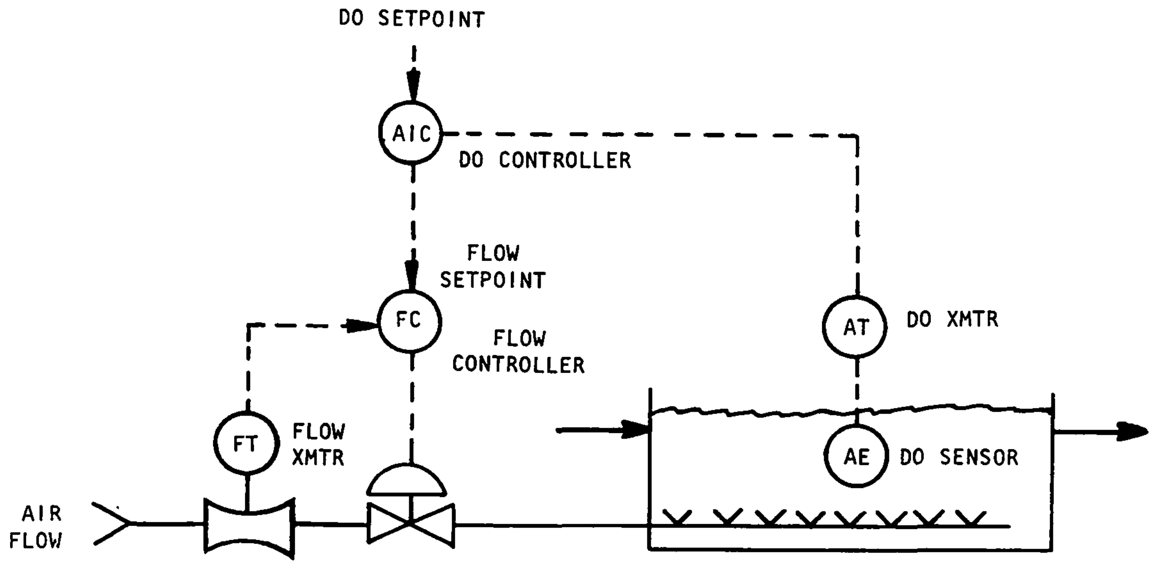


Figure 2-19. Cascade control of dissolved oxygen.

Feedforward Control

Nearly all of the preceeding material has been devoted to conventional feedback control which is control based on the comparison of the controlled variable measurement with its desired value and the use of any deviation to direct the manipulation of an input to a process to reduce or eliminate the deviation. Feedback control may not be satisfactory in some processes due to two disadvantages inherent in the concept. The most obvious disadvantage is that the control system does not act until after a disturbance has caused an error in the controlled variable to exist. Less obvious is the fact that the effect of the corrective action of the control system is not felt until after the changing process conditions have propagated around the entire control loop. These disadvantages are not significant in most common process control applications such as flow control, but they severely limit the effectiveness of feedback control of processes with significant deadtime.

A method known as feedforward control can be used as an alternative to feedback control. Feedforward control involves the measurement of one or more inputs to a process that are prone to disturbances and any deviations in their values are compensated by manipulation of process inputs before the disturbance affects the controlled variable (see Figure 2-20). In theory, if the exact amount of corrective action required can be predicted and correctly applied, no deviation of the controlled variable will ever occur. In practice, this is difficult to achieve because all of the possible sources of disturbances must be accounted for and the effect of the manipulated variables on the controlled variable must be thoroughly understood. Feedforward control is a form of open-loop control because the controlled variable measurement is not used by the automatic controls in the regulation of the process. In other words, the "input" to the process is measured and used for control rather than the "output" product, and there is no propagation of changing conditions around a loop as in closed-loop control.

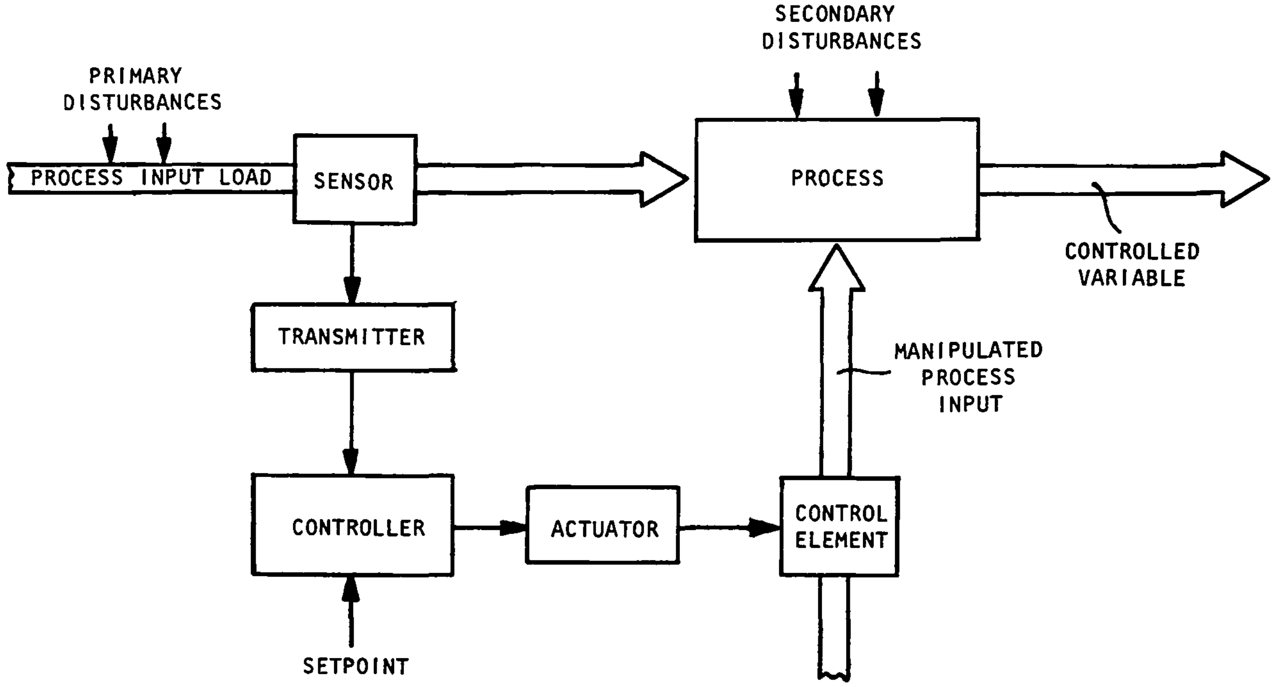


Figure 2-20. Feedforward control.

As an example of an application for feedforward control, consider the chlorination control problem discussed earlier as an example of a process having a large deadtime. Recall that the measurement of chlorine residual in the chamber effluent was not an adequate basis for control of chlorine feed due to the deadtime or transport delay between the process input and the controlled variable measurement. The primary disturbance to which this system is subjected can be described as a change in the demand for chlorine. Using a feedforward approach, the rate of chlorine application could be based on a proportional relationship with a measurement of the chamber inflow as shown in Figure 2-21. Provided that the characteristics of the influent do not vary, and there are no other disturbances that affect the chlorine demand, this strategy would provide good control of the chlorine residual. The fact that the system has no way of correcting for disturbances other than hydraulic load changes could represent a serious limitation.

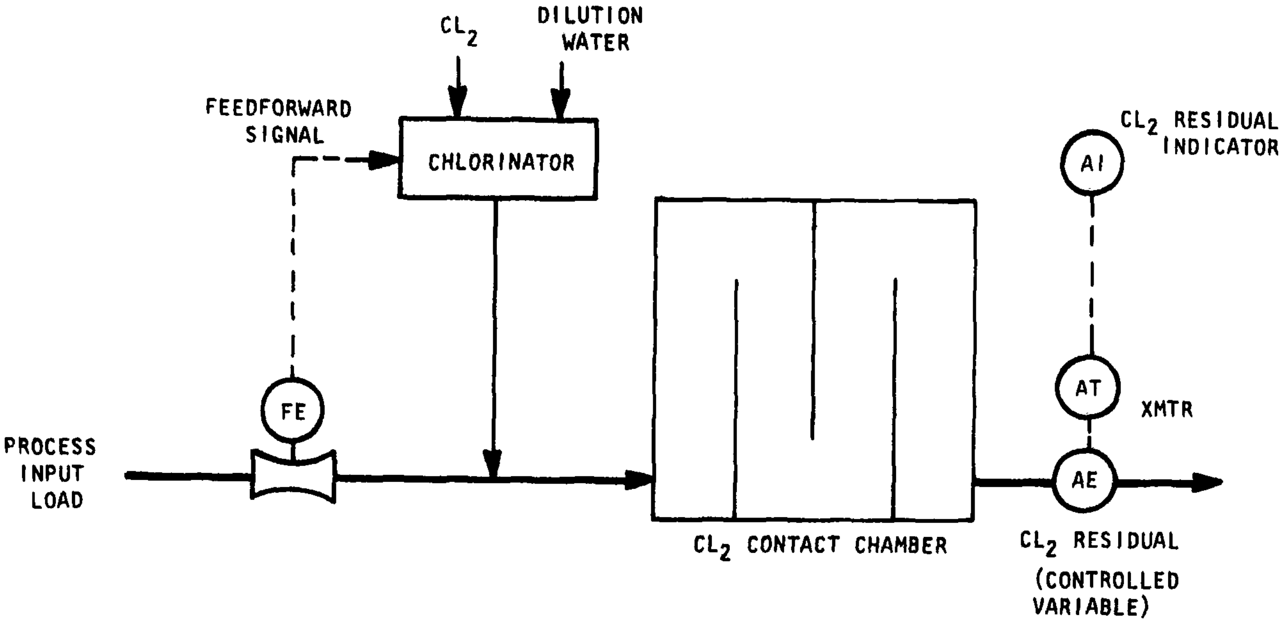


Figure 2-21. Feedforward (ratio) control of chlorination.

This control strategy is actually a special case of feedforward control referred to as ratio control and is very commonly used in processes involving chemical feed. Ratio control is often used in these processes because there is no practical way to measure the actual controlled variable in order to apply feedback control.

In general, pure feedforward control alone is not sufficient if strict regulation is required. In these cases it is necessary to add feedback to obtain the advantages of both types of control; feedforward providing advance compensation for major disturbances sensed in the process inputs, and feedback providing a trimming effect to correct for minor disturbances sensed as variations in the output of the process.

SECTION 2
REFERENCES

1. Murrill, Paul W., Automatic Control of Processes. International Textbook Co., Scranton, PA, 1967. pp. 345-365.

2. Soule, L. M., Tuning Process Controllers, Chemical Engineering. December 1, 1969, pp. 101-104.

SECTION 2
BIBLIOGRAPHY

Considine, Douglas M., Process Instruments and Controls Handbook, Second Edition. McGraw-Hill, New York, 1974, pp. 18-6 - 18-50.

Johnson, Ernest F., Automatic Process Control. McGraw-Hill Book Co., New York, 1967.

Lloyd, Sheldon G., and Gerald D. Anderson, Industrial Process Control. Fisher Controls Company, Marshalltown, Iowa, 1971.

Principles of Process Control. Study guide issued by Instrument Society of America, Pittsburgh, Pennsylvania, ISBN 87664-108-7.

Shinsky, F. M., Process-Control Systems. McGraw-Hill, New York, 1967.

SECTION 3

CONTROL STRATEGIES

TECHNICAL APPROACH

Objective

In keeping with the purpose of the Design Handbook, this section of the report deals with evaluation and documentation of actual process control strategies which are being utilized in the field. The purpose here is not to recommend control strategies, but rather to document strategies that have been found to be satisfactory. All process control strategies presented are based on working systems and document field visits and field observations. The descriptions given are purposely brief and to the point. The control strategies are not described in long complex technological terms, but rather in a manner that encourages the reader to examine the processes studied and to select the particular process areas of interest.

It was found to be difficult to define if use of a control strategy insured good performance of the process because, in most instances, the objective of the "overall" control loop is to maximize the efficiency of a system of processes. In addition, in many instances a measurement of the actual controlled variable is not available. For these reasons, it is seldom possible to provide documentation proving that a process control strategy is successful.

During each plant interview data was requested to illustrate the performance of a control strategy. Publication of such data is beyond the scope of this report. It can be said, however, that data collected in a timely manner, enabling a meaningful determination of performance, is only rarely available.

The strategies are not related to specific plants because the actual physical makeup of equipment at the various plants differs. The reader is cautioned to look at the technical approach documented and interpret this approach in light of the various configurations of equipment found in the field.

Processes to be Studied

The processes chosen to be evaluated and documented were indicated by EPA to be of specific importance because of the present and/or future expected frequency of their use. There are some processes which were not addressed because it was felt that the extent of their use is relatively low. The processes studied include all of those utilized in a typical activated sludge treatment plant. Therefore, both liquid treatment control strategies and solids treatment control strategies are included.

The specific processes studied and documented in this report are as follows:

	Liquid Train	Solids Train	Page
Interceptor Storage	X		36
Flow Equalization	X		40
Plant Lift Stations	X		44
Bar Screening	X		47
Grit Removal	X		50
Primary Clarification and Sludge Pumping		X	54
Hydraulic Flow Control	X		59
Dissolved Oxygen & Blower Control	X		64
Cryogenic Oxygen Generation	X		68
Return Activated Sludge	X		74
Waste Activated Sludge	X		83
Chemical Feed	X		89
Post-Chlorination	X		94
Ozonation	X		103
Gravity Thickening		X	110
Flotation Thickening		X	115
Anaerobic Digestion		X	120
Vacuum Filtration		X	128
Centrifugation		X	134
Roll Press Dewatering		X	139
Plate Press Dewatering		X	145
Incineration		X	151
Return Liquors		X	161

Again, these unit processes represent either frequently found unit processes in the wastewater industry or processes which are believed to be increasing in use. There are processes that possibly should be added to this list and the list of unit processes is growing every day. The point is that this report is not intended to be exhaustive. The intent is to document workable control strategies that exist today. Hopefully with future research and future studies additional processes can be documented for other equipment which is not addressed here.

Method of Data Collection and Process Control Evaluation

The many waste treatment organizations in the country were canvassed for organizations that had multiple facilities and multiple sizes of plants in addition to a full range of the unit processes under study. These organizations were further evaluated in terms of their application of process control to their particular plants and field visits were arranged. An interview form was developed which ensured consistency in the plant interviews. The purpose of the interview was to gather information relating to how the control strategy was implemented and how it performed. The interviews were in-depth analyses. At least one day was spent at each facility. The day was spent discussing control strategies with process control engineers and operators. The interviews concentrated on use of instrumentation, use of observations, use of laboratory data and specifically what an operator or process control engineer does to keep the process under control.

Table 3-1 is a matrix showing the wastewater treatment organizations which were visited to gather data for this section and details the unit processes utilized by these organizations. Most of the organizations visited have multiple facilities. These are listed with the wastewater treatment organization. The Chicago Sanitary District, as an example, has seven treatment facilities listed, all of which contributed data to the evaluation.

Plant visits began with a tour of the facility. After the tour of the physical facility, the interview took place using the interview form. Typically a process control engineer and the shift operator were interviewed. In-depth questions were asked regarding their technical approach to maintaining process control on a unit process basis. Performance data was requested. Remembering that process control strategies, especially in the wastewater industry, are not just execution of a specific task, but include many observations, the interview was directed at what observations the process control engineer or operator associated with his evaluation of a workable control strategy.

In summary, the method of evaluation of a specific control strategy for a unit process included in-depth discussion with technically competent engineers and operators, a plant visit to verify and validate the equipment utilized, and a technical discussion of operator observations which validate and verify the viability of any control strategy.

Method of Documentation

The method of documentation developed is intended to explain in a concise fashion the technical approach to each process control strategy. The most important criterion established for the documentation of the strategies was clarity. Each strategy is described in a consistent manner with a level of technical detail encouraging a consulting engineer or government official to make reference to this section for guidance in selection of a control strategy. Because of the varying differences in physical configuration, it was not possible to document the actual equipment at each plant but rather the technical approach of the control strategy. In this report, each control strategy is broken down into eight sections. Those sections and a brief explanation of the purpose of each section are as follows:

TABLE 3-1. UNIT PROCESS OR CONTROL STRATEGY UTILIZATION

ORGANIZATION	TREATMENT FACILITY	Interceptor Storage	Flow Equalization	Plant Lift Stations	Bar Screening	Grit Removal	Pri. Sludge Pumping	Flow Control	DO/Blower Control	Cryo. Oxygen Generation	Return Act. Sludge	Waste Act. Sludge	Chemical Feed	Post-Chlorination	Ozonation	Gravity Thickening	Flotation Thickening	Anaerobic Digestion	Vacuum Filtration	Centrifugation	Roll Press Dewatering	Plate Press Dewatering	Incineration	Return Liquors Processing
Minneapolis St. Paul (MWCC)	Metro	X			X	X	X	X	X		X	X	X	X		X	X		X	X	X	X	X	X
	Seneca				X	X	X				X	X	X	X			X		X				X	
	Blue Lake				X	X	X		X		X	X		X										
	Hastings				X	X	X		X		X	X		X				X						
	Chaska				X	X				X	X	X		X										
Chicago, MSD	West-Southwest	X		X	X	X	X		X		X	X	X	X				X	X					X
	Calumet	X		X	X	X	X		X		X	X		X		X		X						
	North Side	X		X	X	X	X		X		X	X		X		X								
	O'Hare			X	X	X	X		X		X	X	X	X										
	Eagan		X	X	X	X	X	X	X		X	X	X	X		X	X	X		X				
	Hanover		X		X	X	X		X		X	X	X	X		X		X						
	Streamwood				X	X			X		X		X	X				X						
	Lemont				X	X			X		X		X	X				X						
Metro Denver	District No. 1				X	X	X	X		X	X	X	X	X			X		X					
Unified Sewerage Agency	Durham		X	X	X	X	X	X	X	X	X	X	X	X			X			X			X	
	Rock Creek			X	X	X	X			X	X	X	X	X		X	X					X		
	Forest Grove				X	X	X				X	X	X	X				X						
Cincinnati MSD	Mill Creek			X	X	X	X		X	X	X	X	X	X		X		X	X	X				X
	Muddy Creek			X	X	X	X	X	X		X	X	X	X		X			X				X	
	Little Miami				X	X	X	X	X		X	X	X	X		X	X		X				X	
City of	Springfield, MO			X	X	X	X	X		X	X	X	X	X	X	X	X	X	X				X	
County of	Contra Costa			X	X	X	X	X	X		X	X	X	X		X				X			X	
City of	San Jose			X	X	X	X	X	X		X	X		X		X	X	X	X	X			X	
Ocean County Sewerage Authority	North			X	X	X	X	X	X		X	X	X	X		X		X						X
	South			X	X	X	X		X		X	X		X				X		X				
	Central			X	X	X	X		X		X	X		X				X		X				

1. Introduction - In this section a brief description of the unit process being studied is included. This is intended to give the reader a feeling for the general circumstances and variability of equipment configurations which are found in the field for this particular unit process.

2. Objective - The purpose of this section is to identify the overall objective of a particular control strategy and to give some indication of how this particular control strategy might be dependent on some other working process. Also, some indication of the stability of the process (in terms of the objective of the control strategy) is included.

3. Factors Affecting Process Performance - Any process is composed of three identifiable components. The input or load on the process is the first component. The process itself is the second, and the output, or result of the treatment process is the third component. From the field observations this portion of control strategy documentation is intended to explain the dynamic nature of each control strategy to allow a better understanding of why process control of the particular unit process is necessary.

4. Control Strategy - This is the section which documents the specific workable control strategies. The objective of this section is to clearly show how the control strategy is intended to work. In addition, constraints of the control strategy in terms of its meeting the objective stated is also explained. A process and instrumentation diagram (P&ID) is included to document each control strategy as it would be executed. The documentation is brief and is not in complete technical detail but rather outlines the basics of the control loop and the control strategy.

5. Other Considerations - In the evaluation of any control strategy, there are observations, calculations and lab tests which operators and process control engineers utilize to verify whether a control strategy is performing. In addition, they utilize this data to alter control strategies. The intent of this section is to amplify the importance of operator observation, calculations and lab data and to point out how this information is utilized to either supplement or modify the control strategy being implemented.

6. Instrumentation Utilized - The keys to any process control strategy are the sensors, the controlling devices, and the annunciation of problems to an operator. The objective of addressing instrumentation separately is to illustrate the importance of the sensors and to show the reader where instrumentation is used now in the field and where it can be expected to perform with reasonable realiability.

7. Variation of Strategy With Plant Size - It was found that the process control strategy used varies with plant size. Control strategies are not typically utilized in very small plants. Instead, methods where an operator simply fixes the operating point of a control device (e.g. valve position, pump speed) are relied upon. At the large plants, where unit processes are configured in multiple banks of process equipment, the control strategies are dominated by operations that control the amount of equipment in use at a time. It was therefore important to discuss differences in control strategy with plant size. For some unit processes, significant variation with plant size was found. In other cases, there is no difference, because whenever the unit process is utilized, a control strategy similar to the one documented is executed. The objective of this section is to clearly indicate to the reader, with brief explanation, how the process control strategy might change as the plant size changes.

8. Expected Performance - This section outlines the performance which can be expected from correct execution of similar control strategies. In most cases, the expected performance is given in terms of conventional criteria of efficiency observed in the field. In some cases, statistics and specific numbers are referenced which can be used as a practical guide.

INTERCEPTOR STORAGE

OBJECTIVE

Interceptor storage is utilized to reduce plant flow variations within the limits of water level imposed by the interceptor collection system and the minimum velocity required to prevent sludge deposition within the interceptor. The objective is the stabilization of the treatment process through stabilization of the influent load.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

The load on the storage process is influenced greatly by storm water infiltration, diurnal flow variations (especially rate of change of flow) and ground water infiltration.

Process Characteristics

The process of flow equalization is constrained by the usable storage volume in the interceptor. This usable portion is frequently less than the volume available within the full cross section of the interceptor due to the fact that some collection system laterals may enter the interceptor below the top of the pipe.

The use of interceptor storage for flow equalization requires that the plant raw sewage pumping equipment have very high redundancy and availability so that interceptor level is always controllable. Field installations report that if the interceptor is being filled to even out a diurnal peak, a storm can cause the system to be surcharged quickly. High capacity pumping equipment must be available to prevent surcharge. Pump system control reliability and redundancy must be considered in the design of the system.

CONTROL STRATEGY

Implementation of the control strategy requires level sensors, a variable speed pumping system, and pump sequence program controls (see Figure 3-1). An operator selects a plant flow rate setpoint to be maintained by the pumping system based on interceptor level, observed level rate of change, time of day, weather and any other information that may influence

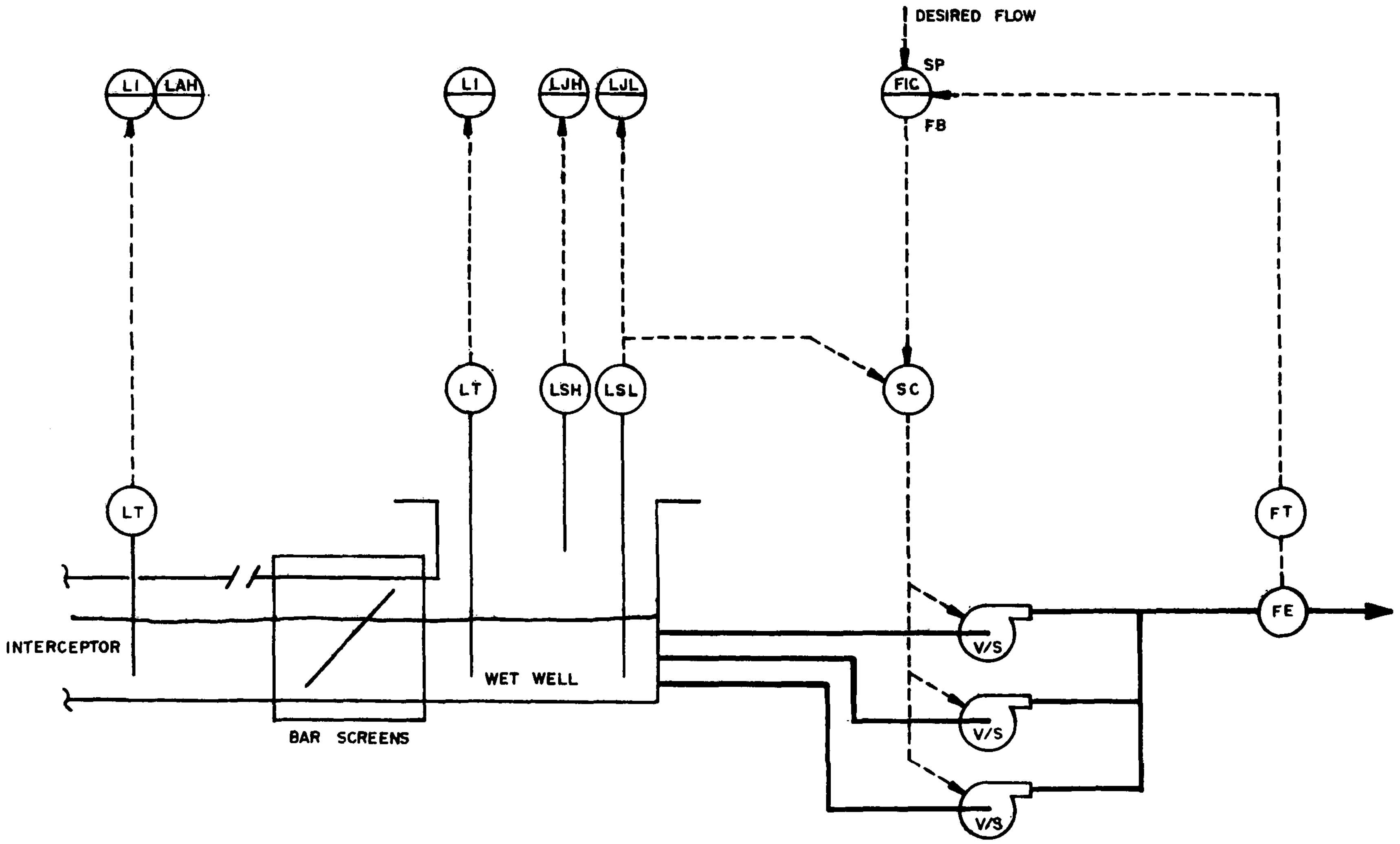


Figure 3-1. Lift station control for interceptor storage.

plant loading. The operator's judgement in selecting and changing the setpoint is critical. Field observations indicate that the selection of a correct setpoint (to balance the system) is an intuitive action. Typically the operator does not have a nomograph or formula to use. Adequate experience is the key to success. The plant flow setpoint is changed frequently by small amounts in order to keep the interceptor level within some operating limits and yet dampen out daily flow variations.

Pumped flow is both a controlled and manipulated variable. Interceptor and wet well levels are additional measured variables.

INSTRUMENTATION UTILIZED

The instrumentation and control devices typically used for this process are as follows:

1. Interceptor level - bubbler level sensor, can be located in a manhole a short distance from the plant.

2. Wet well level - bubbler level sensor, backed up by high and low level alarm float switches.

3. Variable speed pumping system.

4. Plant flow meter.

VARIATIONS IN STRATEGY WITH PLANT SIZE

The use of interceptor storage for flow equalization cannot usually be applied in the smaller plants because the interceptors tend to have limited storage capacity and the diurnal flow variation is often too great. If the control strategy is implemented in a small plant which is loaded by a disproportionally large interceptor, good performance can be expected but sludge deposition in the interceptor could become a problem. This problem may possibly be solved by nightly or weekly drawdown of the interceptor level.

Large plants usually employ more sophisticated pump control logic for implementing this control strategy. If the pump control logic is executed by a control program in a digital control system, the flow control system can be programmed to adapt itself based on excessive rate of change of level and anticipation of level operating limit violation.

EXPECTED PERFORMANCE

The degree of modulation of flow variation which can be achieved is a function of a number of parameters including: the actual diurnal variation of flow, the volume of interceptor storage available, the degree of operator involvement and the use of adequate instrumentation. At the West-Southwest plant in Chicago, interceptor storage allows operation of the plant at a nearly constant rate of 1,200 mgd (52,800 dm^3/s). Without this technique, the daily peak would be 1,440 mgd (63,360 dm^3/s) and the daily minimum would be 800 mgd (35,200 dm^3/s). Similar results were obtained at the Calumet treatment plant, also in Chicago.

FLOW EQUALIZATION

INTRODUCTION

Flow to most municipal wastewater plants in operation today exhibits significant diurnal variation. One means of improving the process performance is the use of a specially designed equalization storage basin to dampen out diurnal flow variations. This discussion describes the implementation of side-line equalization for a low capacity gravity flow plant.

OBJECTIVE

The primary objective of flow equalization control is improvement of the performance of the wastewater treatment process through the reduction of diurnal flow variations.

Almost all processes within a plant are, to some degree, affected by changes in influent feed rate. Achievement of a nearly constant flow rate has its greatest benefit in the improvement of the performance of solids/liquid separation processes. Problems with operation due to short circuiting are made worse by hydraulic flow variations. Problems of this nature are widespread in currently operating wastewater treatment plants. Other conditions caused by uncontrolled and large flow variations include undesired overflows and biological washouts.

When provisions for the reduction of flow variations are made in the design of a plant, the quantity and size of the equipment may be reduced. Clarifiers and other facilities can be sized to handle average rather than peak loads. Simpler arrangements of weirs and gates can be used to control flow splitting with greater accuracy when the range of flow rates to be controlled is reduced.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

Diurnal flow patterns, which are used to determine the equalization basin capacity required, vary from day to day (especially weekend as compared to week day flow) as well as seasonally, and are affected by storm inflow and infiltration.

Process Characteristics

The process is characterized by its capacity to store wastewater. If the size of the equalization basin is large enough, the variation of any dry weather flow can be reduced to provide a constant plant flow rate.

Flow equalization requires the capability to divert selected flows to the equalization basin when inflow is above average and to supplement normal plant flow with storage bleedback in the proper amount when plant inflow is below average. Sufficient rangeability is therefore required in the weirs, valves and pumps used in this process.

The instrumentation required for level and flow measurements used in conjunction with this process must be reliable and accurate in order for the system to function because these parameters are the basis for the entire control strategy.

CONTROL STRATEGY

The process discussed here as an example is a "side-line" diversion process as opposed to an "in-line" process where all wastewater flow is normally routed through the equalization basin.

The system requires a flow splitter with an adjustable weir, variable speed pumping system, flow metering for plant and return flow and a level sensor for basin level (see Figure 3-2). The adjustable weir is set to allow overflow to occur at a desired plant flow rate so that all flow in excess of selected rate will be diverted to the basin. The flow metering equipment and the variable speed pumps are used to return stored wastewater at the proper rate to achieve a constant plant flow.

Total plant flow is the controlled variable. Weir position and pumped return flow are the manipulated variables which are adjusted to achieve constant plant flow. Equalization basin level is used as an override to indicate when the control strategy should be abandoned.

The operator's positioning of the weir determines at what point flow is diverted to equalization. The decision to supplement plant flow with storage can be made by a switchpoint associated with the plant flow transmitter. The pumping rate is determined by the difference between interceptor flow and the constant plant flow setpoint chosen. The control strategy must, of course, be overridden if a basin level limit is reached. If a high level limit is reached, the weir must be repositioned to prevent continued diversion. If a low limit is reached, the pumps are turned off.

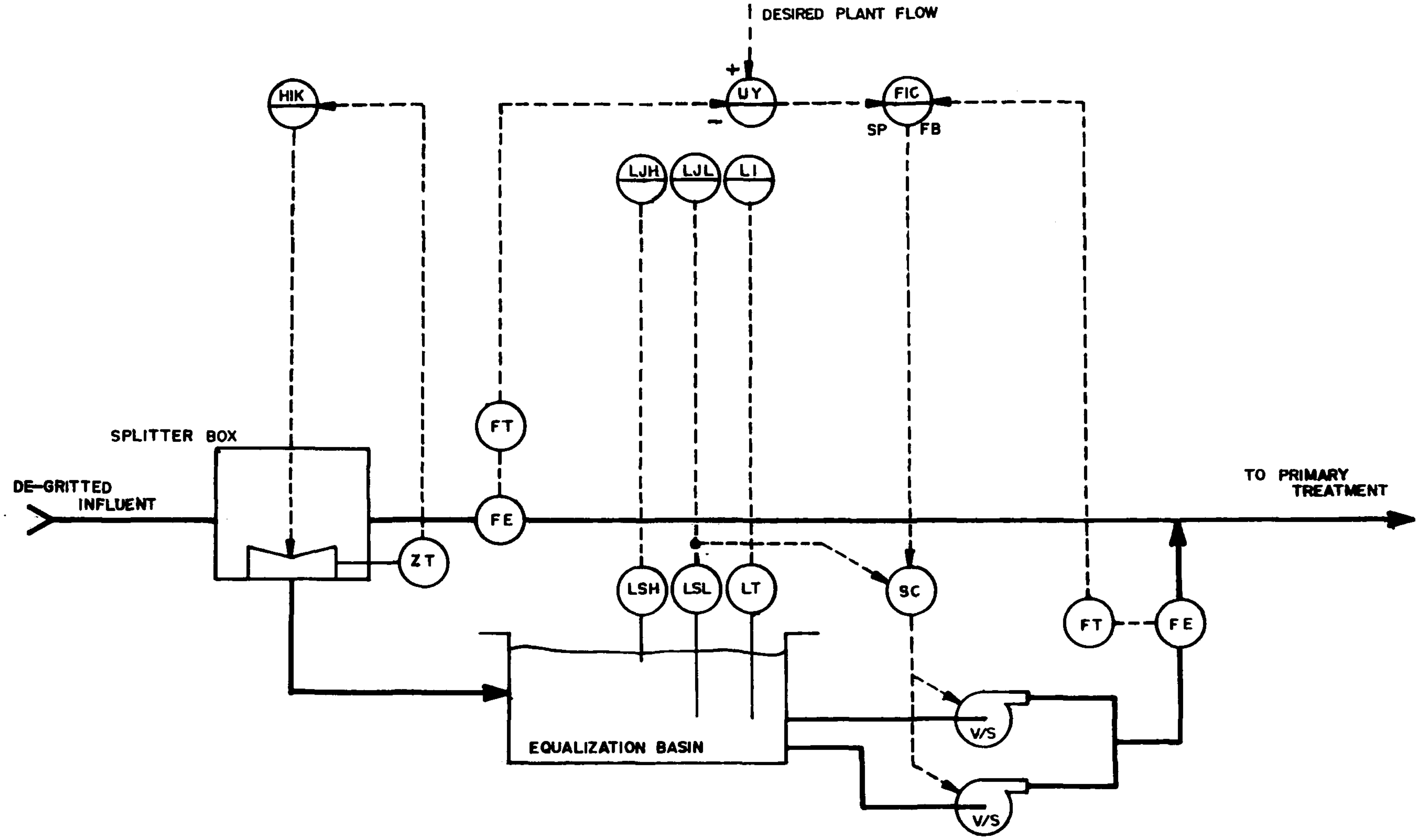


Figure 3-2. Flow equalization control.

INSTRUMENTATION UTILIZED

The following types of instrumentation and control devices have been used to implement the control strategy.

1. Basin level - bubbler level sensor.

2. Plant flow - parshall flume or mag meter.

3. Returned flow - mag meter.

4. Weir position - manual loading station.

5. Variable speed pump controls - eddy current coupling or SCR drive with sequence program logic.

6. Return flow controller - PID mode type.

VARIATIONS IN STRATEGY WITH PLANT SIZE

The example discussed applies to gravity flow plants of low capacity. Larger plants requiring a raw sewage pump station may use a portion of the pumped flow for diversion to an equalization basin, and later return flow to the plant by gravity flow through modulating valves.

The economics of the construction of an adequately sized equalization basin generally limits the application of this strategy. The largest plant where side-line flow equalization was observed was 30 mgd (1320 dm^3/s) capacity.

EXPECTED PERFORMANCE

Field experience has shown that the objective of dry weather flow equalization can be achieved provided the basin has been adequately sized, the operator is able to make the required adjustments for varying diurnal patterns, and the process instrumentation and control devices are reliable. In general, plant flow and performance are influenced greatly by frequency and amplitude of diurnal variations.

PLANT LIFT STATIONS

INTRODUCTION

Lift station level control is essential for plant operation, especially in instances where there is limited capacity to store wastewater for flow equalization. In most cases the actual level is not critical as long as it is maintained within acceptable limits. A lift station control system using variable speed pumps is examined in this discussion.

OBJECTIVE

Where limited storage capacity is available, a level control approach must be taken to approximately match the pumping rate with the influent flow. Within the constraints of level control, it is desirable to minimize abrupt changes in the pumped flow rate since the disturbances will propagate through the plant treatment processes. Frequent pump starts and stops also represent wasteful energy usage.

FACTORS AFFECTING PERFORMANCE

Load Characteristics

The system must respond to amplitude and rate of change of the diurnal flow pattern. Storm water inflow and ground water infiltration represent large additional loads on the system.

Process Characteristics

The dominant characteristic of the system is capacity. There is a trade-off between the use of a low capacity wet well to reduce construction costs, and the use of a large wet well for flow equalization. Field observations indicate the wet well storage capacity time should be a minimum of ten minutes at maximum pumping rate. This will allow some response time should problems develop with equipment in the field.

The range of individual pump control available and the length of time required to bring a pump on or off line may be constraints limiting the achievement of the stated control system objectives.

CONTROL STRATEGY

Variable speed pump control is most often based on proportional mode control only. Although rarely used, a small amount of integral mode action may be added to drive the wet well level toward a setpoint. This additional use of integral mode would provide some energy savings at low flow if the setpoint is in the middle to upper range of the wet well. Derivative mode action is not used because the capacity of the system and small fluctuations in the level would lead to instability in the control system.

The control system P&ID is shown in Figure 3-3. Wet well level is the controlled variable. Pump speed is the manipulated variable. Pumped flow may be an additional measured variable.

There are many possible variations observed in the field for the combination of speed control and pump sequencing used with multipump installations. The design of the control equipment will depend on the hydraulics of the system.

OTHER CONSIDERATIONS

Variable speed drive reliability is an important consideration since loss of a drive may require manual operation of pumps at constant speed.

INSTRUMENTATION UTILIZED

The following equipment is commonly used in the systems:

1. Wet well level - bubbler sensor backed up by high and low level alarm float switches.

2. Variable speed pump controls - eddy current coupling, SCR drive, wound rotor motor drive, or variable frequency drive. The latter must be carefully designed for the particular application.

VARIATIONS IN STRATEGY WITH PLANT SIZE

The objective of maintaining wet well level within acceptable limits remains the same regardless of plant size but the execution of control will vary. Plants of less than 1 mgd (44 dm^3/s) capacity typically use on/off level switches and constant speed pumps. A pump is started at a high level and stopped at a low level switch. Plants having capacity in the range of 10 to 50 mgd (440 to 2200 dm^3/s) commonly use variable speed control of two to four pumps of equal size. Larger plants (100 to 300 mgd - 4400 to 13000 dm^3/s) may have multiple pumps of varying size to handle wide load variations smoothly. The sequence control logic becomes far more complicated when many pumps of different capacity are used.

EXPECTED PERFORMANCE

Field observations show that most lift station level control systems provide satisfactory operation since precise level control is rarely required.

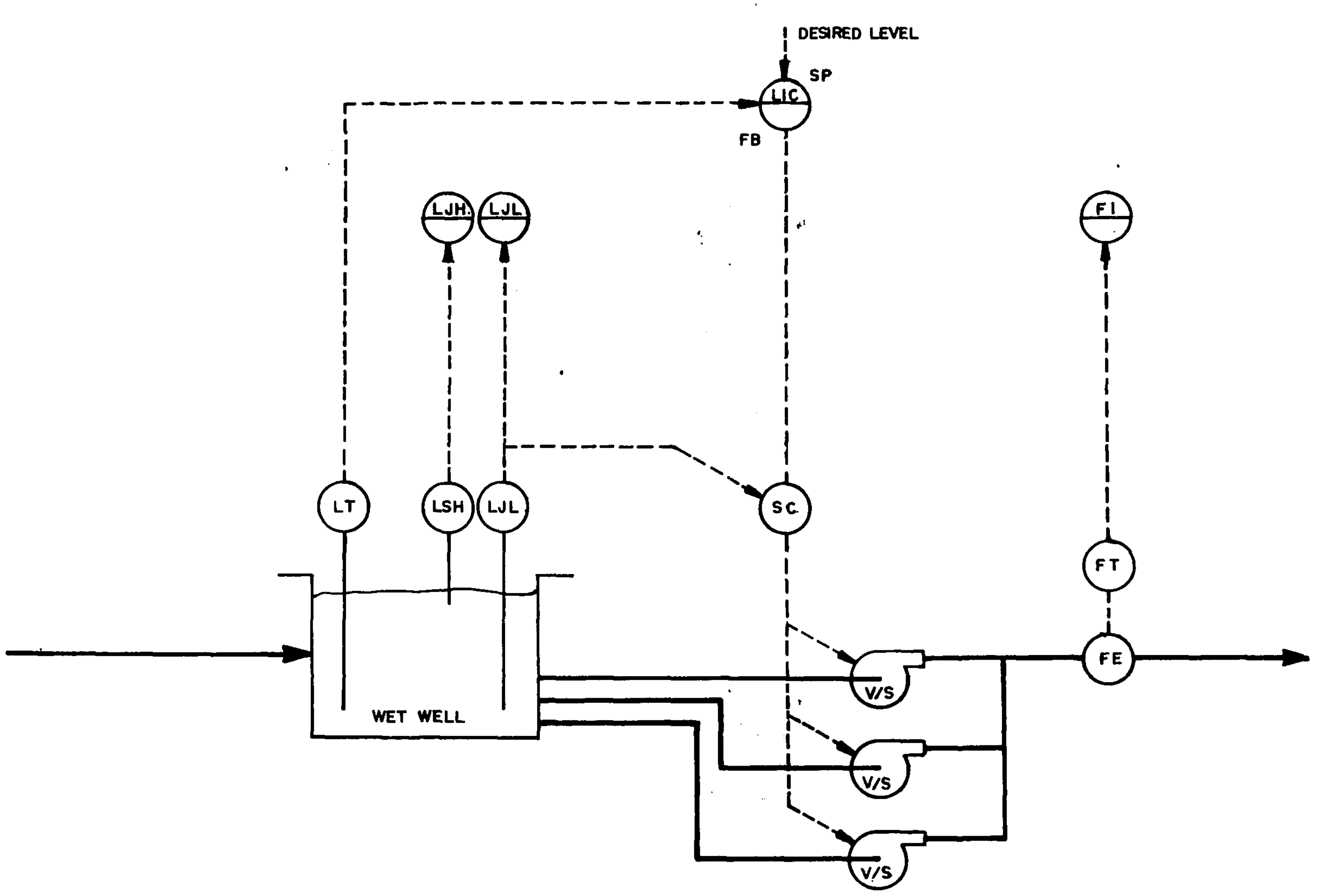


Figure 3-3. Lift station wet well level control.

BAR SCREENING

OBJECTIVE

Screening is performed to protect plant equipment from damage by removing large floating objects and any other debris that may be carried along by the influent stream. Screening may be fine or coarse, depending on the situation.

FACTORS AFFECTING PERFORMANCE

Load Characteristics

The nature of the interceptor system, i.e. the amount of debris present, often determines the success of any bar screen control strategy applied. If large amounts of sticks, rocks and trash are present, frequent breakdowns due to overloading of the cleaning mechanisms may be observed. Large objects which block the flow path are the primary load on the process.

Process Characteristics

The screens have very little influence on downstream processes efficiency but do prevent catastrophic mechanical failure. The reliability of the cleaning mechanism is the most important aspect of the screening system.

CONTROL STRATEGY

Field observations show that bar screen cleaning can be accomplished by any of the following control methods:

1. Periodic manual operation (requires operator attention periodically during each shift).
2. Continuous operation (wastes energy and wears out equipment).
3. Individual time clock operation.
4. Operate when a high differential level occurs.
5. Combination of 3 and 4.

Normally, strategy 4 is used. The accumulation of materials on the screens causes a differential level on the order of a few inches to occur across the screen (see Figure 3-4). Differential level is used because the absolute level will vary widely. Once a cleaning cycle is initiated by the differential level switch, the control circuitry should be interlocked to require the cleaning mechanism to make a complete cycle before turning off. This prevents the mechanism from blocking the flow stream if the high differential level condition is cleared midway through a cycle. Multiple screens should be cleaned consecutively when a high differential level is sensed.

INSTRUMENTATION UTILIZED

The following instrumentation and control devices are typically used:

1. Differential level - two bubbler tubes and a differential pressure cell.

2. Bar screen controls - timing and sequence logic.

3. Alarms - rake drive torque overload.

VARIATIONS IN STRATEGY WITH PLANT SIZE

Small plants generally do not have mechanically cleaned bar screens. Cleaning is manual followed by comminution of the collected solids. Frequent cleaning is often not required because the interceptors tend to be relatively free of harmful debris. The moderate size plants typically employ three or four locally automated screen units. Frequent maintenance is again generally not required. Large plants must often operate their cleaning equipment continuously due to the great amount of material that is often found in large interceptors.

EXPECTED PERFORMANCE

Within the constraint of the nature of the materials present in the interceptor, both differential level and time clock operation have been proven as effective means of control.

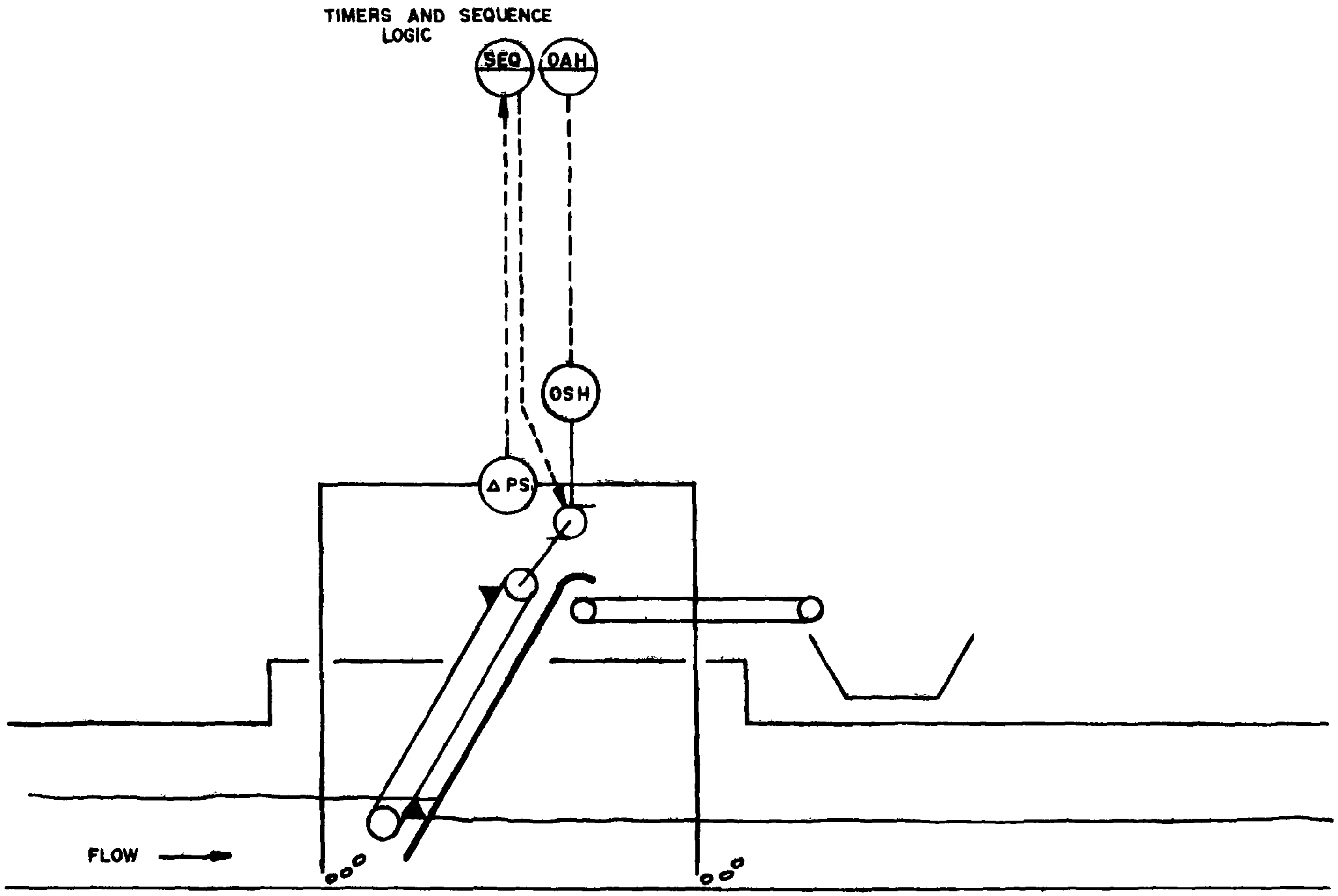


Figure 3-4. Bar screen control.

GRIT REMOVAL

INTRODUCTION

There are three basic types of grit removal facilities, velocity controlled, cyclone degritter, aerated grit chamber. This discussion is applicable to the monitoring and control of aerated grit chambers, because of their advantages over the other two types, and their frequency of use in new plants.

OBJECTIVE

Grit, consisting of sand, gravel and other inert materials, is removed to avoid physical damage to downstream plant equipment. Grit damages pump impellers, collection mechanisms, etc., and settles out in undesirable areas such as settling tanks and digesters. Equipment damage can lead to equipment failure and subsequent loss of process control.

FACTORS AFFECTING PERFORMANCE

Load Characteristics

Gritty substances are present in almost all wastewaters, especially storm water. Influent from combined sewer systems presents difficulties due to the large variations in the quantity of grit that must be removed. The grit load varies with the time of day, the flow rate to the plant and the amount of storm flow.

Process Characteristics

In an aerated grit chamber, a spiral roll velocity is imparted to the flow, the roll velocity being controlled by the chamber dimensions and the air flow rate supplied to the chamber. The roll velocity in an aerated grit chamber can be held nearly constant regardless of the influent flow rate by adjusting the air flow. The purpose of the roll is to resuspend organic solids which have settled with the grit. With proper adjustment of air flow, consistent removals can be achieved.

Removal of grit from the chamber often poses more of a problem than the original separation from the wastewater. Mechanical equipment such as screw or belt conveyors typically require much maintenance. The odor and other environmental conditions associated with the process often lead to lack of maintenance.

CONTROL STRATEGY

Since aerated grit chambers are designed to nearly eliminate variations in performance due to hydraulic load changes, the instrument and control requirements are minimal (see Figure 3-5). In the field, air flow is fixed at a specific rate and is only adjusted seasonally to compensate for variations in air density with temperature. Aeration blowers at the larger plants often have inlet butterfly valves to adjust air flow. Blower current monitoring is sometimes used to indicate air flow output. Although more frequent adjustment of air flow is desired, in practice it is only rarely observed.

Mechanical grit removal equipment can be operated continuously, but since it may take some time for grit to accumulate, time clock controls most often are used to start the screw conveyor and, after a time delay, start a bucket and chain grit conveyor to load a grit storage hopper. The storage hopper may be equipped with a high level alarm sensor which is interlocked to shut off the collection system.

The controlled variable, grit removal efficiency, is entirely qualitative and thus cannot be directly measured. Air flow and timer adjustments are the manipulated variables. Blower current (related to air flow) is a measured variable.

OTHER CONSIDERATIONS

The controlled variable being unmeasurable, the operator must rely on observation of environmental conditions to judge the success of the grit removal process. For example, reports of grit volumes removed or observation of grit in primary sludge will influence the control strategy.

INSTRUMENTATION UTILIZED

Sensors

Typically, no sensors are used other than perhaps a motor current transmitter and a storage hopper level switch. Occasionally air flow to grit will be measured.

Controlling Devices

1. Manual loading stations - may be employed for setting inlet valve positions on blowers larger than 100 HP.

2. Timers and sequence controls - mechanical grit removal.

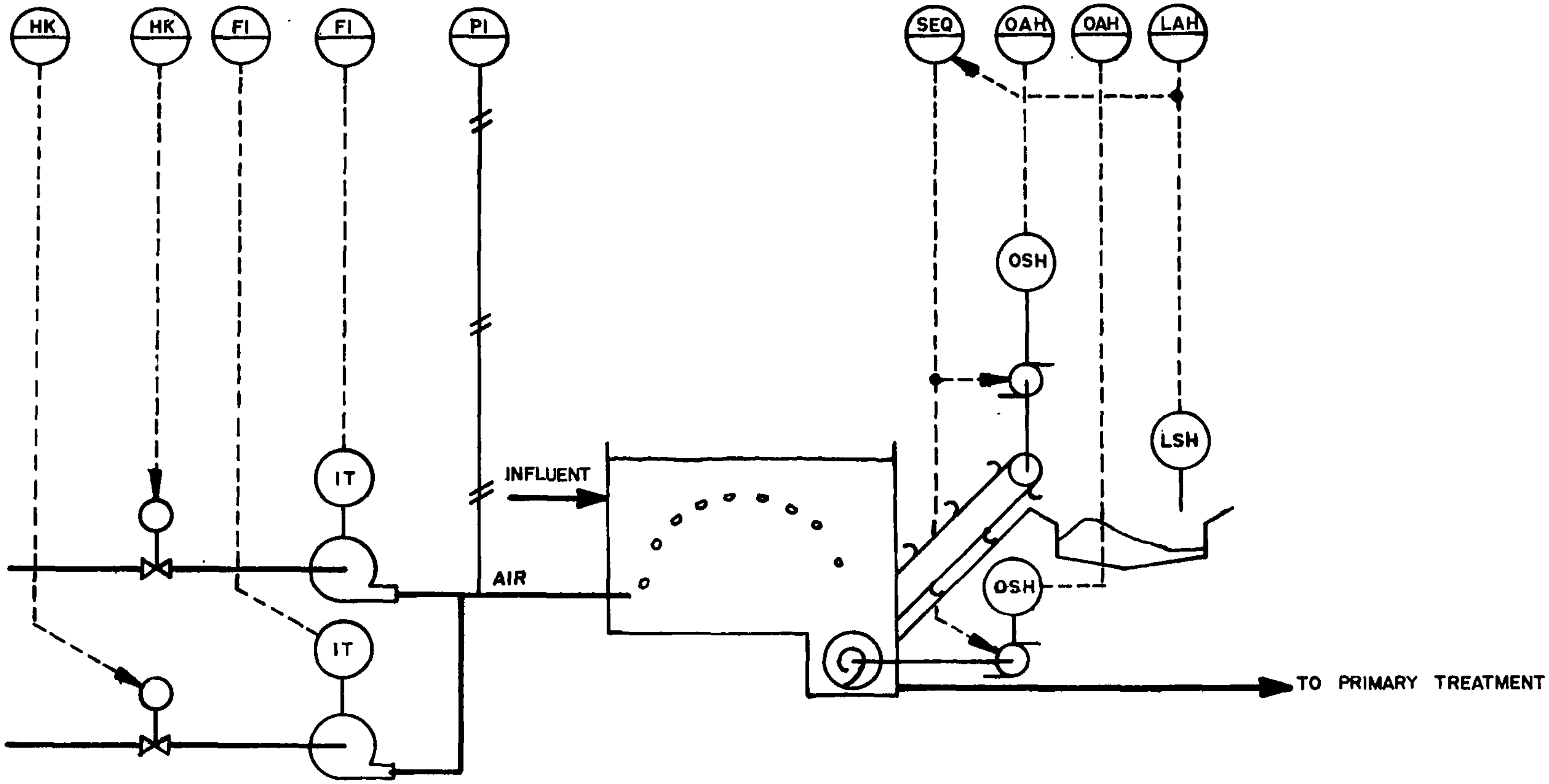


Figure 3-5. Aerated grit chamber control.

Annunciator Alarm Points

1. Grit conveyor drive overload.

2. Storage - high level.

3. Blower surge.

VARIATIONS IN STRATEGY WITH PLANT SIZE

When aerated grit removal is used, the control strategy is similar regardless of the size of the facility. The small plants seldom use aerated grit removal but apply velocity type. Intermediate size plants may use positive displacement aeration blowers if air flow requirements are low. Large plants often have centrifugal blowers with individual inlet valves for balancing air flow contributions from the multiple operating units.

EXPECTED PERFORMANCE

Grit removal efficiency data is not readily available. The operators interviewed assumed that the process operated efficiently and commented mostly about maintenance. Most plants using aerated grit chambers report satisfactory performance. On the other hand, larger plants using horizontal flow (velocity controlled) grit removal reported poor performance due to the frequent need to bring chambers in and out of service to maintain proper chamber velocities. Velocity control with sutro weirs or parabolic cross sections were observed only rarely and appeared to operate satisfactorily.

PRIMARY CLARIFICATION AND SLUDGE PUMPING

INTRODUCTION

Primary clarifiers are tanks used to remove or reduce suspended solids and organic loading from the wastewater before it goes to secondary treatment units.

Suspended solids removal is a function of flow and tank dimensions, thus process control is limited to flow equalization, flow proportioning to all units and avoidance of short circuiting. The control strategy discussed here concentrates on the removal of the sludge which accumulates in the tank.

Clarifiers may be rectangular, square, or circular in shape. In rectangular tanks, the wastewater flows from one end to the other and the settled sludge is moved to a hopper, usually at the inlet end, either by flights set on parallel chains, or by a single bottom scraper set on a traveling bridge. Floating materials such as grease and oil are collected by a surface skimmer and then removed from the tank.

In circular tanks, the wastewater usually enters in the middle and flows toward the outside edge. Settled sludge is pushed to a hopper that is in the middle of the tank bottom, and floating material is removed by a surface skimmer connected to the sludge collector.

The sludge pumping system typically includes some method of detecting clarifier sludge level (optical probes, air lifts for operator determination, or light transmitting devices), clarifier sludge removal rakes, isolation valves from the clarifiers, variable speed sludge pumping system, sludge density sensors and sludge flow meters (see Figure 3-6).

OBJECTIVE

The principal objectives of primary clarification are removal of settleable solids and removal of floatable solids.

Field observations indicate that the primary clarification process is controlled via the sludge pumping operation. The objectives most often found for primary sludge pumping are as follows:

1. Maintain as consistent a pumping rate as possible in order to minimize operational labor intensity.

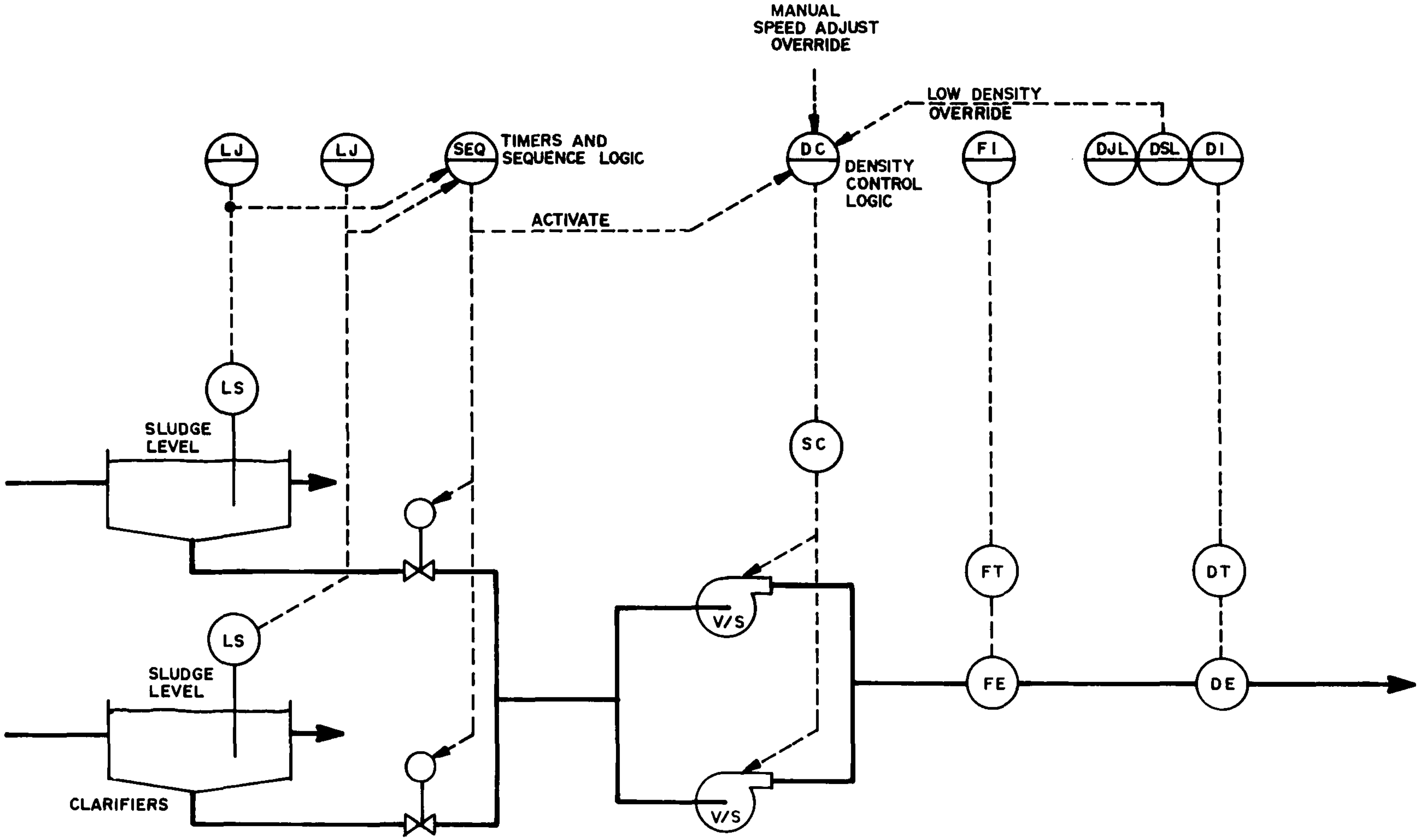


Figure 3-6. Primary clarification and sludge pumping.

2. Try to pump at a rate which will maintain a consistent primary sludge composition (density).

3. Observe, minimize and control any buildup of primary sludge in the clarifiers.

4. Be aware of downstream processes and minimize any disturbances on these.

FACTORS AFFECTING PROCESS PERFORMANCE

A number of factors affect the performance of sedimentation tanks, including the following:

1. The hydraulic overflow rate expressed in flow per unit time per unit top area of the tank. This is a velocity term and is equal to the sedimentation velocity of particles which will be completely removed from the wastewater.

2. Detention time which provides the opportunity for coagulation of small particles to larger, faster settling ones.

3. Wastewater characteristic (wastewater strength, freshness, and temperature; types and amount of industrial waste; and the density, shapes and sizes of particles).

4. Pretreatment operations (carryover of grit and screenings).

5. Nature and amount of any in-plant wastes recycled to the plant ahead of the primary clarifier.

Load Characteristics

The load continuously varies hydraulically and in composition. Changing waste characteristics and poor hydraulic distribution cause problems. Recycled in-plant waste also causes shock loads.

Process Characteristics

Clarifiers are usually quite long or large in diameter which can cause a problem in sludge collection and removal. The sludge should be removed at a rate comparable to the rate at which it is deposited. The problem arises in moving the sludge from where it is deposited to where it is removed. This is done by use of a mechanical sludge rake which typically moves very slowly, raking the sludge to a collection well at the center or end of the clarifier.

Grease and oil content make measurement "in situ" extremely difficult. If the sludge level is too high, the clarifier efficiency drops off due to smaller working volume. If the sludge level is too low, the clarifier sludge removal system is operating at less than optimum conditions. Proper sludge pumping requires reliable sludge level metering and a reliable method of metering sludge composition to maintain consistency for downstream processes.

CONTROL STRATEGY

The underlying control philosophy is to achieve a consistent total solids concentration in the sludge (underflow) and to remove all the sludge from the clarifiers. The system consists of a bank of clarifiers from which the sludge is sequentially pumped (usually on a timed basis). When a clarifier's sludge is to be pumped either in its sequential turn or due to a high sludge level, the clarifier's isolation valve is opened and the sludge is pumped out. The valve is closed at the end of the timed period, when the sludge level falls to its low level or when the composition (solids content) is below a preset cutoff concentration.

The variable speed pumps are fed from a common line into which the isolation valves empty. The speed of the pumps is determined by the sludge quality sensors or set after operator observation of lab data. When the pumps are speeded up, more water is drawn into the system, reducing the sludge solids concentration. Similarly, when the solids concentration level is too low, the pumps are slowed down so less water and more sludge is pumped. Field observations indicate that because of sludge collection time constants, response to changes in pump speed is sometimes slow.

The controlled variable is usually the flow and the suspended solids concentration or sludge blanket level in the sludge. The manipulated variable is the sludge flow while the measured variables (lab or on-line) include sludge level in the clarifiers, sludge flow, sludge suspended solids concentration and suspended solids concentration in the clarifier liquid overflow.

The constraints are that the instrumentation requires much maintenance and, therefore, is typically not reliable enough to use for on-line measurements. For this reason, lab tests must be conducted. Also, the makeup of the loads and the diurnal flow pattern greatly affect the load.

OTHER CONSIDERATIONS

At least once every shift the suspended solids in the liquid is observed. At the same time, any evidence of the sludge going septic should be noted. The pumped sludge itself should be occasionally observed to be sure that it isn't becoming too weak or septic. Lab tests are periodically conducted on both the suspended solids concentration of the clarifier overflow and sludge in order to determine the clarifier efficiency.

INSTRUMENTATION UTILIZED

The types of instrumentation and control devices found to be used for the process are as follows:

1. Sludge level - optical probes or ultrasonic detectors.

2. Sludge flow - usually heated tube mag meter with ultrasonic cleaning.

3. Sludge suspended solids concentration - optical or nuclear density.

4. Variable speed pumps - preferably not diaphragm pumps, but if used, stroke adjustable rather than speed controllable types are preferred.

5. Isolation valves - one per clarifier.

6. Variable speed pump control - eddy current coupling or SCR drive with sequence program logic.

7. Annunciators - for pump failure, clarifier level low and incorrect density.

VARIATIONS IN STRATEGY WITH PLANT SIZE

The configuration discussed here is typical for medium sized plants. For plants that are on the large end of the scale, there is more likelihood of individual pumping from clarifiers. For small packaged plants, typically less than 1 mgd (44 dm^3/s), a primary clarifier for removal of suspended solids typically is not provided.

EXPECTED PERFORMANCE

Field experience has shown that the objective of minimizing the inventory buildup in the clarifiers while controlling pumping rate and sludge composition (density) is difficult to accomplish. Automation of the sludge pumping process helps achieve the objectives but lack of maintenance on sensors limits success. Most operators usually revert to flow control to minimize the inventory buildup and let composition vary as it will.

HYDRAULIC FLOW CONTROL

INTRODUCTION

Control of volumetric flows to multiple units within a particular unit process was the most requested improvement from plant operators during our field visits. Most plants visited used splitter boxes or weirs. The problem observed in the field is that splitter boxes and weirs are fixed and the flow splitting process is dynamic. Splitter boxes work acceptably between two tanks with small design flows. As the design flows increase or the number of tanks increase, these methods lead to widely varying hydraulic distribution and very poor solids distribution.

Controlled flow distribution allows the flow and solids to be dispersed equally among all on-line units and allows the operator the latitude to adjust the distribution based on feedback from plant performance.

OBJECTIVE

The primary objective of flow control is to split process influent flow among multiple trains in a controlled manner. Field observations indicate that this can be achieved by two different methods. The first is used when the total incoming flow is measurable. The desired flow per train is then simply total flow divided by number of trains in service. The second strategy, referred to hereafter as "most open valve" (MOV), is used when the total incoming flow is unknown. This is a more complex method which is not as desirable as the first because the inherent instability of the control system leads to periodic oscillations in the flows controlled.

When provisions are made for flow splitting among multiple process trains, the chances of undesired washouts and overflows are greatly reduced so that more consistent results are achieved.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

The process load is characterized by the plant influent diurnal flow pattern, which will vary from day to day (especially week day flow as compared to weekend flow) as well as due to storm inputs. Peak diurnal variations were observed as great as 3 to 1.

Process Characteristics

The hydraulic control application is characterized by the need to adjust resistance to flow to equally split the total flow into more than one train. This ability is dependent on the hydraulics of the piping configuration or splitter box and the load changes which take place.

The instrumentation used for flow measurement and control in this process must be highly reliable because feedback control is applied which depends on a continuous signal of feedback flow.

CONTROL STRATEGY

Two strategies are discussed here. The first one is used when the total flow to be split is measurable (see Figure 3-7). Total flow is metered and divided by the total number of trains in service to determine the desired flow per train. A multiplier/divider sends a common setpoint signal to the train flow controllers. Each individual train flow meter compares the actual flow with the desired flow for adjustment of the valve. Total flow and individual flow per train are the measured variables, valve positions are the manipulated variables, and the individual train flows are the controlled variables.

The second flow control strategy, MOV, can be utilized when a measurement of the influent flow is not available (see Figure 3-8). This strategy requires the initial valve positions to be manually set for equal flow when the system is initially made operable. This also establishes an initial value of the "most open valve" for the master valve controller. Once this is accomplished, the control system is activated with the flow setpoints at the set conditions. The individual train flow meters supply feedback to the flow controllers to keep the flow rates constant. Variations in total flow cause the valve controllers to move all valves to maintain flow, producing a position other than the operator entered MOV position. Through the MOV high level select module, the "most open valve" is selected. This valve's position is passed on to the MVC which compares it to the operator entered MOV setting initially entered. A corrected setpoint (percent change) is then passed to the valve controllers. This feedback loop is repeated until the MOV position agrees with the operator entered MOV setting. The strategy accomplishes flow control with the valves as wide open as possible to assure that the total load is handled and energy loss through the valves in minimized.

OTHER CONSIDERATIONS

For proper flow control the operator should, at least once per shift, observe the individual train to check that flow is being split equally. When the MOV strategy is used, the operator must also enter the desired MOV setting and the initial valve positions. This need only be done on initialization of the control loop and after large flow changes (storm flows).

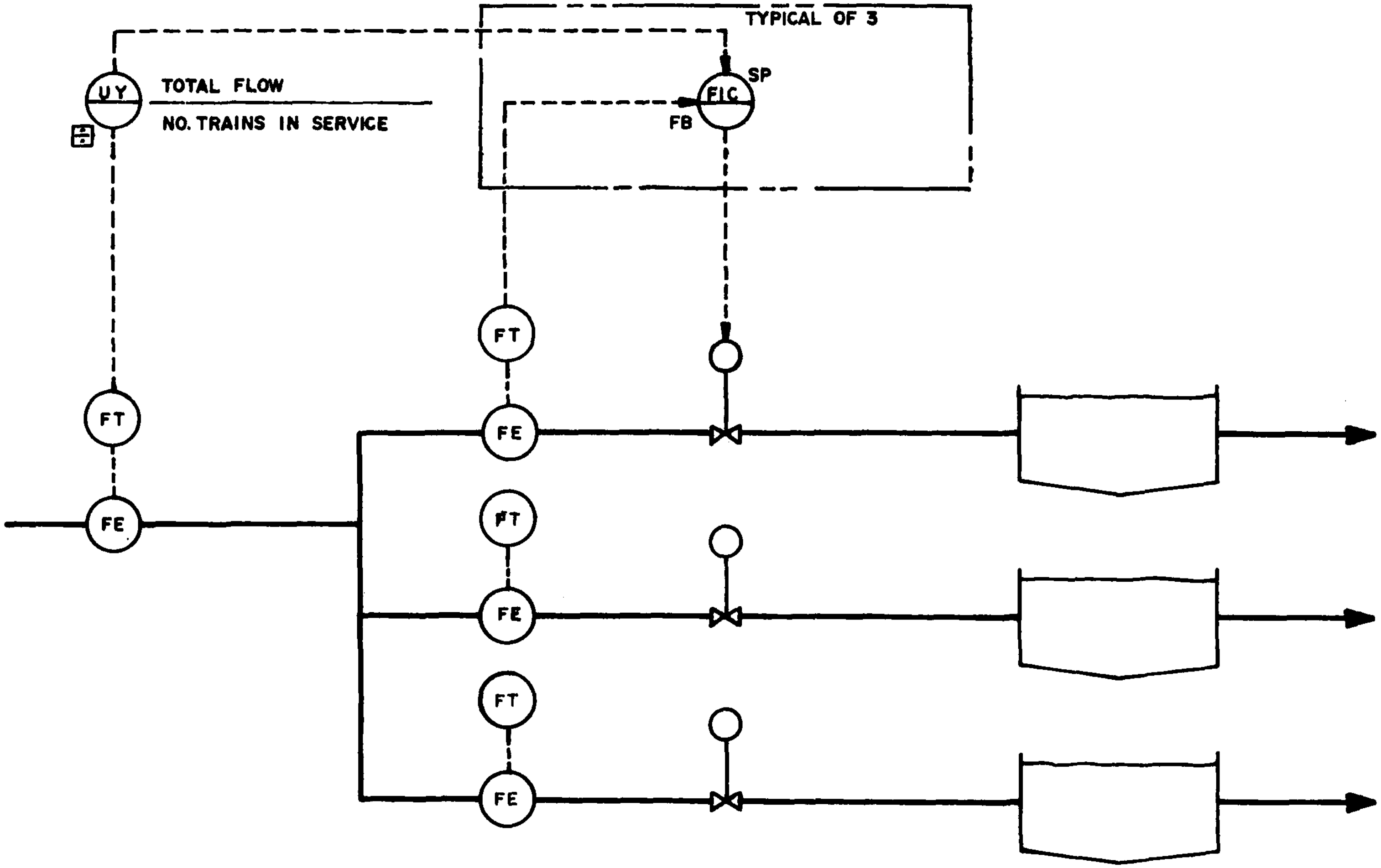


Figure 3-7. Flow control.

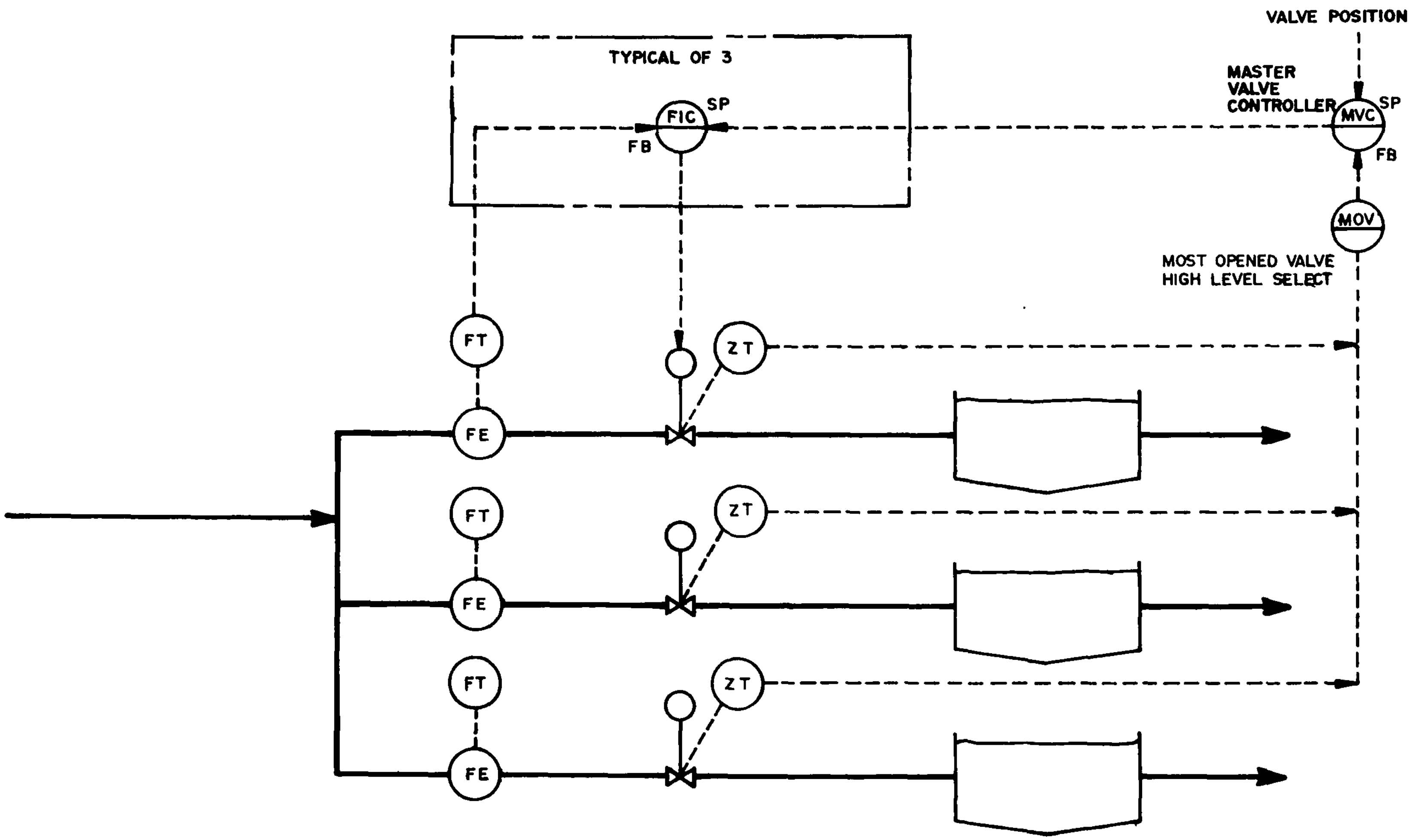


Figure 3-8. Flow control, MOV method.

In some instances it may be desirable to have unequal flows going through the different trains. This can be accomplished by the use of ratio stations having weighting ratios determined by the operator to correspond with the desired loading.

INSTRUMENTATION UTILIZED

The following types of instrumentation and control devices are typically used for the first method:

1. Flow meters - mag meters.

2. Flow controller - PID type.

3. Multiplier/divider logic module.

Instrumentation and control devices typically used to implement MOV control are as follows:

1. Flow meters - mag meters.

2. Flow controller - PID type.

3. MOV high level select module.

4. MVC (master valve controller) module.

VARIATIONS IN STRATEGY WITH PLANT SIZE

Use of the first strategy is preferrable but is limited by the need to measure total flow. Flow splitting for processes within the larger capacity plants must often rely on an alternate strategy such as the MOV method because it is not economically feasible to meter large flows.

EXPECTED PERFORMANCE

When using the first method, there should be little deviation from equal flow splitting. The accuracy of control of the individual flows can be expected to be within the accuracy of the flow meters.

The MOV method has a flow control cycle period (natural period of oscillation) of about two hours. The diurnal flow pattern changes cause an inherent amplitude inaccuracy. Large load changes like those caused by storm flows can cause the MOV control system to go unstable.

DISSOLVED OXYGEN & BLOWER CONTROL

INTRODUCTION

The subject of aerator DO control has received extensive coverage in EPA publication "Design Procedures for DO Control of Activated Sludge Processes," EPA-600/2-77-032, June 1977. This discussion will highlight briefly the control strategy used in a typical process configuration including centrifugal blowers with diffused aeration.

OBJECTIVE

The activated sludge process, where used, is a main component in a secondary wastewater treatment plant. Control of oxygen level in the activated sludge reactor is an important factor in maintaining the stability of the process. If poor control results in DO levels that are too low, aerobic bacterial activity may be reduced and/or poorly flocculating organisms can predominate. Both will result in poor effluent quality. Excessive DO levels are produced by excess levels of air flow. Not only is this a waste of energy, but it may cause the mixed liquor to become dispersed or fragmented, thereby reducing solids capture in the final clarifier.

FACTORS AFFECTING PERFORMANCE

Load Characteristics

Aeration requirements are affected by the mass of organic material resident in the aeration chamber. This in turn is the result of the volume and composition of returned sludge, and the volume and composition of the raw wastewater influent. Industrial waste contributions may affect the biodegradeability of the wastewater. If stormwater influent is a large component of the influent load, the objectives of DO control may be almost impossible to achieve due to the accompanying wide variations in hydraulic and organic loading.

Process Characteristics

Field observations indicate that control of the DO level in aeration tanks is difficult because the dominant characteristic of the process is the large volumetric capacity of the aeration tank. Direct blower air flow manipulation cannot be effectively used to control the level of DO in aeration because the time lag between a change in air flow and the resultant change in the DO level often leads to instability. Manipulation of blower air flow is also constrained by the need to sustain adequate mixing in the aeration tank and the turn-down limits of the blowers (these are frequently oversized).

Measurement of DO presents difficulties in mounting instruments to obtain representative readings, and in the accuracy and reliability of the instrument. Responsive instruments providing reasonable accuracy with acceptable maintenance requirements are currently available.

CONTROL STRATEGY

Automatic closed-loop control of aeration air flow as discussed here has been demonstrated, but is not typically implemented. The control philosophy typically involves control of blower discharge pressure and oxygen dissolution as separate loops to decouple the demands of each process, thus reducing the degree of interaction between the two (see Figure 3-9).

The object of the blower control subsystem is to maintain constant discharge header air pressure to ensure stable operation of the individual DO control loops. A cascade control system, having pressure as the primary controlled variable and air flow as the secondary, is used to provide pressure regulation. Blower speed, inlet guide vanes, or suction throttling valve positions are manipulated to control the output of the individual blowers. Sequence control logic is required for starting and stopping blowers to meet varying system demand and to alternate the operation of blowers for equalization of wear.

A separate cascade control, having aeration basin DO as the primary controlled variable and air flow as the secondary, is used to obtain good system response and stability in maintaining the desired DO level. A slow acting controller uses measured dissolved oxygen as the feedback. This controller uses the comparison of measured dissolved oxygen versus the desired dissolved oxygen to call for more air flow or less air flow. The air flow is usually maintained by a conventional flow controller whose setpoint is adjusted periodically by the slow acting dissolved oxygen controller.

OTHER CONSIDERATIONS

The operator must periodically observe the color and odor of the mixed liquor as a check on the DO setpoint employed. The results of half-hour settling tests and lab DO measurements may indicate that modification of system setpoints is required. Other lab tests to be performed include measurements of MLVSS and SVI.

INSTRUMENTATION UTILIZED

Instrumentation and control devices found in use are as follows:

Sensors

1. DO probes - galvanic or polarographic.

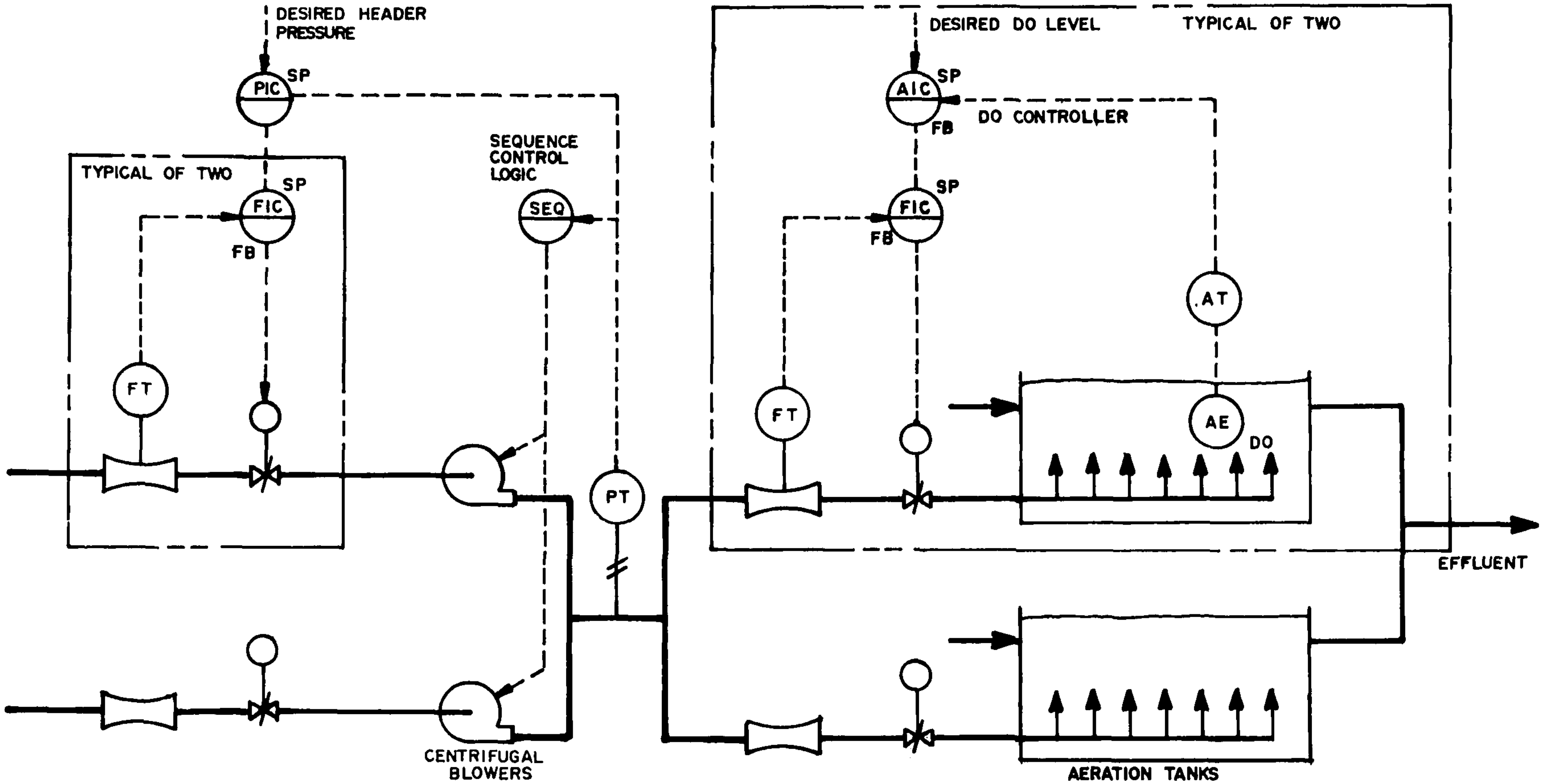


Figure 3-9. Dissolved oxygen and blower control.

2. Aeration air flow - orifice plates, venturi tubes or annubars (the latter provides a measurement that is not as stable as the others).

3. Header pressure - diaphragm force balance.

4. Blower flow - venturi.

5. Header air temperature - sometimes used to compute volumetric air flow at standard conditions.

Modulating Control Devices

1. Butterfly valves - these typically have good response and rangeability. Air flow rangeability, however, is limited by the working pressure not the valve.

Controlling Devices

1. PID mode controllers for DO, air flow and pressure.

2. Sequence control logic is sometimes used for automatic control of blower startup and shutdown.

Annunciator Alarms

1. Blower alarms - bearing and winding temperature, high vibration, current sensing for impending surge condition.

2. DO level alarms - useful for sensor failure as well as process degradation alarm.

VARIATION IN STRATEGY WITH PLANT SIZE

Small capacity plants (less than 1 mgd - 44 dm^3/s) may have a single oxidation tank equipped with a positive displacement blower and manual DO controls. A control strategy similar to that discussed is typically used in plants ranging from 5 to 50 mgd (220 to 2200 dm^3/s). The larger plants (100 to 300 mgd - 4400 to 13000 dm^3/s) may follow a similar control strategy but startup and shutdown of blowers is not often under automatic control due to the increased complexity of the procedures and the consequences of possible misoperation of devices associated with the large blowers.

EXPECTED PERFORMANCE

Automatic closed loop control of dissolved oxygen can offer significant advantages in adaptation to variations in loading and in energy savings. At the present time, however, most DO control is manually implemented. Automatic DO control has been successfully implemented at the John Eagan plant in the Chicago Sanitary District, consistently maintaining the DO level at a desired setpoint on a long-term basis.

CRYOGENIC OXYGEN GENERATION

INTRODUCTION

Cryogenic generation of high purity oxygen (95 to 98%) from air has recently begun to be used in wastewater treatment. This process provides oxygen which is used as an alternative to air in biological treatment processes and as a feed stream to ozone production. It produces oxygen by distillation of partially liquified air. Ambient air is first compressed by a multistage compressor. The air is then cooled and a portion condensed by a combination of heat exchanges with product and waste streams and expansion in a turbine. The expansion turbine provides the majority of refrigeration in a standard plant while miniplants obtain refrigeration from purchased liquid oxygen. Two distillation columns finally separate the air into high purity oxygen and nitrogen. Several suppliers furnish complete cryogenic plants which use compressors, expansion turbines, heat exchangers and distillation columns to separate oxygen from air. Cryogenic plants are complex but steady state operation is often fully automatic.

OBJECTIVE

The objective of cryogenic plant operation is to produce the pure oxygen required for use in treatment plant operation. A guiding principle of cryogenic plant operation is minimization of energy use.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

The oxygen demand is determined by the oxygenation and ozonation processes. These processes are affected by diurnal and seasonal fluctuations in hydraulic and organic loadings.

The oxygen supply is air which is of constant quality (about 21% oxygen). Changes in ambient temperature have little effect on distillation column operation since the compressed air is cooled to a constant temperature with a cold water heat exchanger and the cryogenic plant components are well insulated.

Process Characteristics

The response of a cryogenic plant to load changes must be slow in order to avoid severe column upsets. Upsets could result in column flooding or physical damage to the columns.

Product purity is limited by column design and is variable only over a small range. Usually setpoints for product and waste nitrogen purities are not changed once the plant is on line.

Energy is conserved in many areas, but those of particular importance are:

1. Maintaining a low cold end temperature differential to limit heat losses via the waste nitrogen stream.

2. Inhibiting vaporization of stored liquid product since making liquid requires four times as much energy as producing gas.

3. Eliminating overproduction of oxygen.

This last consideration is constrained by the turndown capacity of the cryogenic plant which is usually 60% of full capacity. Slow control responses inevitably result in venting to the atmosphere of some product. An important factor improving the process energy balance is that the cryogenic plant is heavily instrumented to achieve complete automatic control.

CONTROL STRATEGY

The cryogenic process is very complex as can be appreciated from the simplified P&ID provided (Figure 3-10). In order to minimize column upsets, several parameters are controlled such that the ratio of their value to the cold end flow is kept constant. The compressor capacity which determines plant production is controlled by a mass flow controller using product output as feedback. This arrangement speeds up responses over configurations with feedback closer to the compressor discharge.

The primary controlled variable is usually product oxygen flow. In situations where the cryogenic plant is too slow in response or is shut down, oxygen is obtained from vaporization of liquid oxygen stored during times of overproduction. Product pressure becomes the rate controlling variable regulating vaporization. The manipulated variable is ultimately compressor discharge flow. Measured variables are: cold end flow, product purity, product pressure and product flow.

The cryogenic plant is limited in achieving the objective by the constraints of slow response and limited turndown capability.

During startups and shutdowns plant operation is manual until automatic control loops are activated. Table 3-2 describes the relationships of the major control loops during steady state operation.

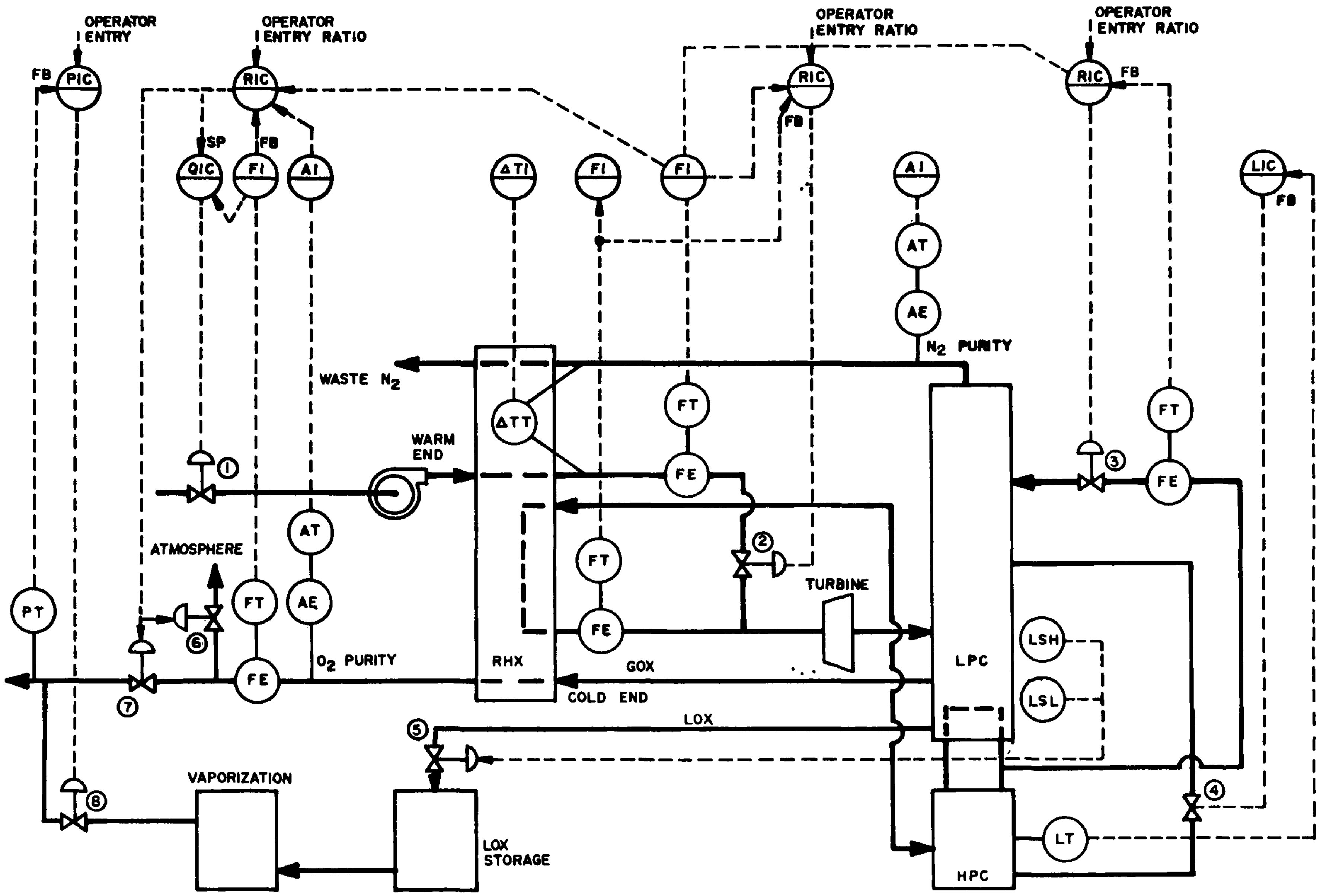


Figure 3-10. Cryogenic oxygen generation.

TABLE 3-2. STEADY STATE MODULATION

Device Name	Device Number*	Feedback	Controlling Device
Compressor Guidevanes	1	GOX flow	QIC, mass flow controller
Cold End Turbine Feed Valve	2	Unbalance air flow	RIC, ratioed to CE flow
LPC Reflux Valve	3	Reflux flow	RIC, ratioed to CE flow
HPC Level Control Valve	4	HAC liquid level	LIC, level indicating controller
LOX Transfer Valve	5	High and low levels	On/off controller
GOX Vent Valve	6	GOX flow	RIC, GOX make valve (7) controller only when make valve is full open
GOX Make Valve	7	GOX flow	RIC, ratioed to CE flow based on product purity
LOX Vaporization Valve	8	Pressure	PIC, pressure indicating controller

*Device number indicated on Figure 3-10

Abbreviations:

CE - Cold end
GOX - Gaseous oxygen
HPC - High pressure column
LOX - Liquid oxygen
LPC - Low pressure column

OTHER CONSIDERATIONS

A problem inherent with high purity oxygen is the potential for explosion and combustion. Many materials that are normally difficult to oxidize, burn or explode in an oxygen rich environment. To reduce the hazard two gel traps adsorb hydrocarbon impurities in the cold end air stream and the liquid oxygen. A hydrocarbon analyzer will automatically alarm at 25% LEL. In addition, the operator must periodically check the liquid produced for clarity (cloudiness is caused by carbon dioxide particles, hence other hydrocarbons may be present) and test for the presence of acetylene.

INSTRUMENTATION UTILIZED

The sensors and control devices listed below are typically used in the process and are normally reliable and accurate.

Sensors

1. Gas flow - orifice plate often with pressure and temperature correction.

2. Temperature.

3. Pressure.

4. Oxygen purity, Nitrogen purity - membrane covered polarographic electrode.

5. Level - differential pressure.

Modulating Control Devices

1. Centrifugal compressor - inlet guide vanes or butterfly throttling valve with butterfly valve on recycle for surge protection.

2. Gas flow control valves - butterfly valves.

3. Liquid flow control valves - gate valves.

On/Off Control Devices

1. Compressor.

2. Turbine expander.

Startup and shutdown of these are usually manual operations.

Controlling Devices

1. PIC - pressure indicating controller.
2. LIC - level indicating controller.
3. RIC's - controlled flows are ratioed to cold end air flow.
4. QIC - mass flow indicating controller.
5. Level switches - float pots.

Alarms

1. Hydrocarbon - LEL.
2. Liquid oxygen level in LPC, high and low.
3. Turbine discharge low temperature.
4. Compressor and turbine operating alarms, such as high oil temperature, low oil pressure, vibration and coolant high temperature.
5. LPC and HPC high pressure.

VARIATION IN STRATEGY WITH PLANT SIZE

Cryogenic plants larger than about 180 TPD have an energy recovery system linked to the expander turbine which can reduce energy requirements by about 2 to 3%. Plants less than about 40 TPD usually have positive displacement type, rather than centrifugal, compressors. Compressor discharge is then varied by step unloading or by recycle, which leads to inefficient energy utilization. Oxygen production rates are controlled in the same way as in larger plants. Mini-cryo plants (6 to 16 TPD) obtain required refrigeration from purchased liquid oxygen rather than from a turbine expander.

EXPECTED PERFORMANCE

Data showing the performance of cryogenic plants in regard to the stated objective are lacking due to limited operating experience. Operators have indicated that the plants operate very well with a minimum of attention or shutdowns. However, system constraints have caused oxygen losses. For example, the plant at Springfield, Missouri, is designed for 50 TPD but is only operating at about 30 TPD which is the minimum that can be produced. System requirements are often less than 30 TPD so excess production must be vented to the atmosphere. The other major constraint is sluggish response to load changes. On at least one occasion at the Denver plant, load changes were occurring too fast for the cryogenic plant to keep up or to stabilize. To maintain adequate oxygen, the cryogenic plant capacity was manually set (by controlling compressor discharge) at a fixed capacity. This open-loop control operation resulted in venting or underproduction of oxygen.

RETURN ACTIVATED SLUDGE

INTRODUCTION

The activated sludge process is utilized extensively in its original form as well as in the modified forms. There are five main versions of the process in common usage (Figure 3-11). Conventional plug flow and complete mix are the most common forms found in larger plants. Step aeration is gaining in popularity for use in large plants because of its greater flexibility. Contact stabilization is utilized in plants with flows of less than 10 mgd (440 dm^3/s). Extended aeration is usually used at flows of less than 0.5 mgd (22 dm^3/s). For purposes of this discussion, only control of sludge return and withdrawal from the clarifiers is considered. Control of wasting and of dissolved oxygen are discussed independently. The need for an integrated control strategy for the entire activated sludge process is discussed in the Recommended Future Activities, Section 8.

OBJECTIVE

The primary objective of return activated sludge (RAS) control is to maintain the stability of the activated sludge process. This is accomplished by returning an active mass of microorganisms in a sufficient quantity to remove the biodegradable organics from the influent wastewater.

The stability of the process is of key importance. Any perturbation of the process may affect the ability to separate solids in the clarifier and will degrade effluent quality. Changes in the clarifier removal efficiency affect the makeup and density of the returned sludge. This may result in a spiral decay of process performance. Any fluctuations in the process will affect bacterial growth rates which will affect the quantity of solids wasted to the thickener.

The microbial culture which dominates this process is subject to population shifts; because growth and species predominance are controlled by a variety of environmental parameters which are constantly changing. In addition, the actual effect of variations in environmental parameters on microorganism predomination is only poorly understood. Due to this very dynamic environment, the process is difficult to control. In order to consistently control the process, the strategy must compensate for process variations. This can be (partially) accomplished by careful control of return solids flow.

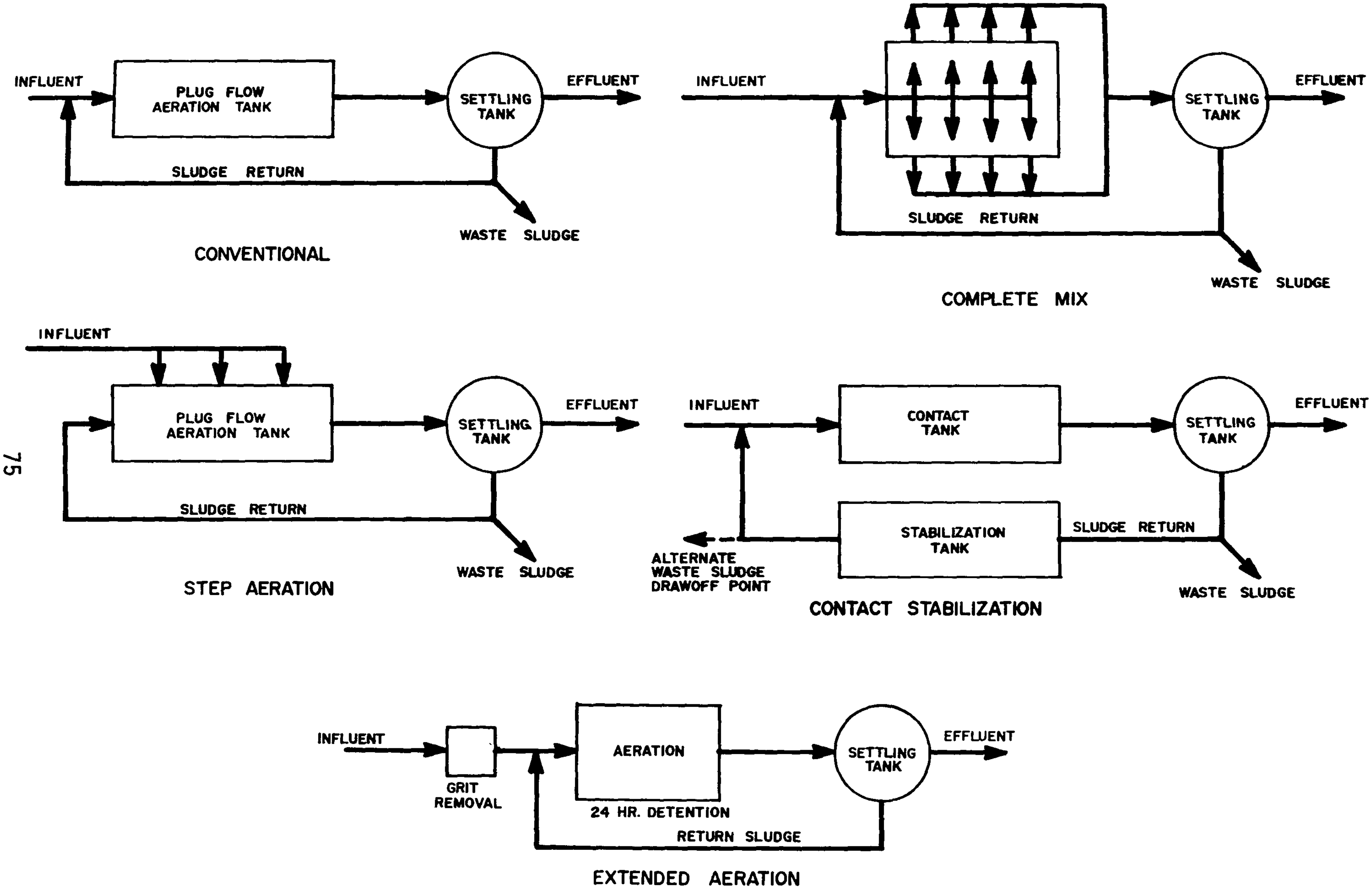


Figure 3-11. Activated sludge process flow diagrams.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

The activated sludge process is subjected to a variety of loads. Diurnal fluctuations in both hydraulic and organic loading are often of large magnitude and high frequency. The process is affected by changes in water temperature. Industrial discharges of concentrated organics or toxins may have dramatic effects on the process. The method of control used may even introduce additional process loads. The dynamic conditions of the process result in variations in the concentration and viability of the return sludge. Any load change on the process may have delayed repercussions due to resultant changes in return sludge characteristics.

Process Characteristics

Environmental conditions such as temperature and physical characteristics such as pH all affect the growth rates and kinetics of the microorganisms in the process. Physical conditions such as short circuiting, uneven mixing or problems due to design affect process performance. Distribution of both liquid and solids to multiple units is often out of control and results in large differences between supposed parallel units. The process is subject to constraints on the ability to transfer oxygen to the medium.

Two factors have a major affect on the process. One is the flow rate which is a short lag parameter. Excessive flow which can occur during the daily peak can result in a poor effluent irrespective of the condition of the biological culture. Here the effect is due to an excessive overflow rate in the secondary clarifier. The second factor is the effect of process or load changes on the biological culture. This has a long lag period. It may take several days to several weeks for the effect of a process condition change to be manifest in predomination in the biological culture. Control is further hindered by the difficulty in measuring process parameters. Reliable on-line instruments for some important parameters such as TOC, ATP and BOD are not yet available.

The most significant fact regarding the process is that the process itself generates the active biomass to sustain the process. If the process degrades, a degraded biomass is formed and when returned causes further process degradation. The bacteria returned to the process are very sensitive to process fluctuations.

CONTROL STRATEGY

Two types of control strategies are extensively utilized in the field to control RAS. One returns sludge at either a fixed flow rate or a rate paced to the flow rate of primary effluent. This can be considered a volumetric control strategy. The second is based on clarifier sludge inventory control. Typical instrumentation is illustrated in Figure 3-12.

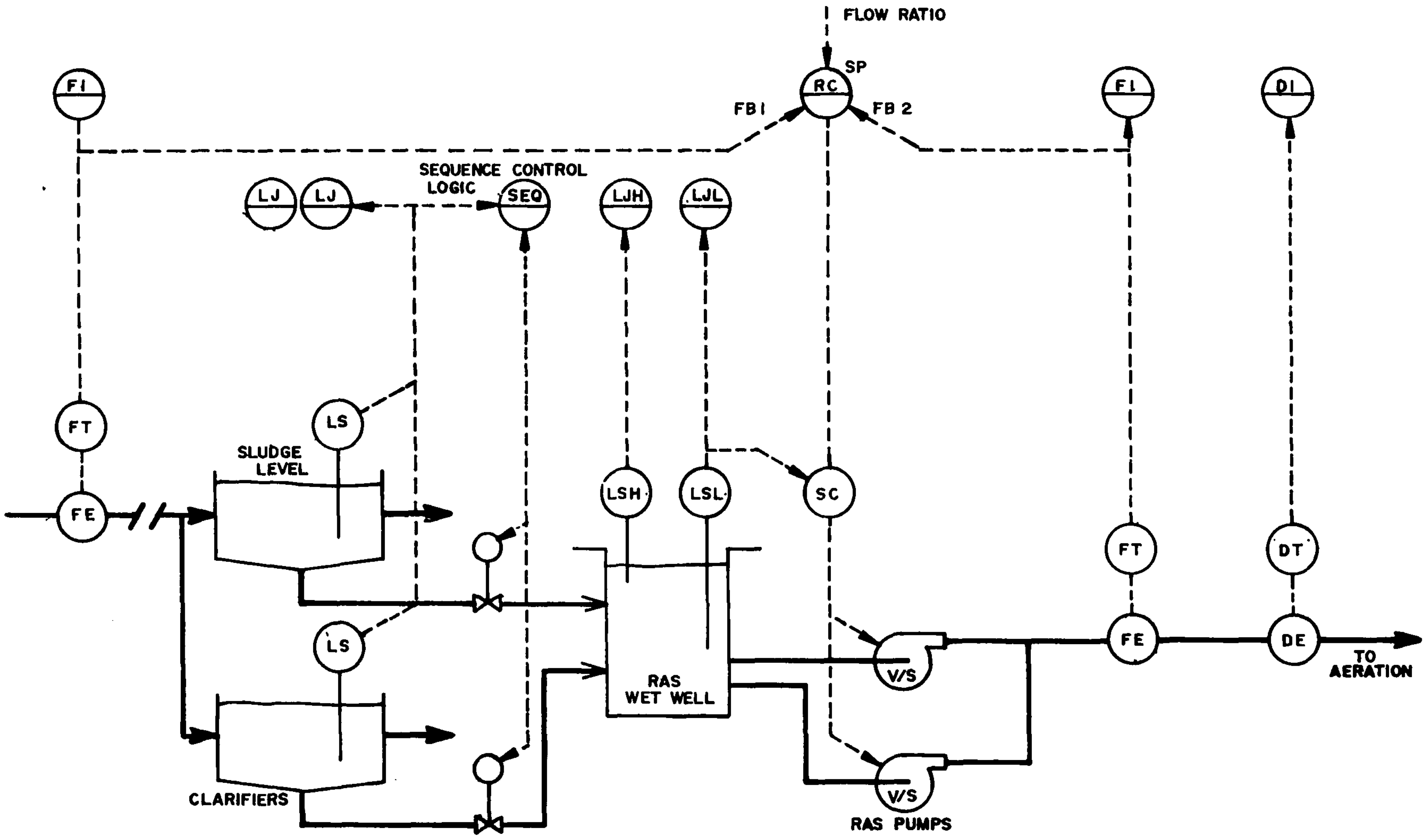


Figure 3-12. RAS control.

Volumetric RAS Control

Determination of the volumetric return rate is generally by operator experience based on the anticipated organic loading and present sedimentation characteristics of the sludge. One widely used method of determining the average volumetric rate of sludge return is based on a short time sedimentation test conducted in the field. A sample of mixed liquor is put in a one or two liter graduate and allowed to settle for one-half hour. The initial and final sludge volume is recorded. The ratio of final sludge volume to initial sludge volume is multiplied by the primary effluent flow to determine the rate of sludge return. When the rate of return is fixed (ratioed to average primary effluent flow), the MLSS in the reactor will vary inversely with the primary effluent flow. If the return rate is ratioed to instantaneous primary effluent flow, the MLSS remains constant but more severe flow transients are produced in the reactor and final clarifier.

Although volumetric control of return rate is widely practiced and generally seems effective, it suffers from significant drawbacks. The required sludge return should be a mass rate of flow rather than a volume rate of flow. As long as sludge concentration after clarification remains relatively constant, control on a volumetric basis is satisfactory. However, during upsets produced by microorganism shifts and during peak flow periods, the sludge concentration will change significantly. In addition, when high rates of return are used, the return sludge concentration can then vary considerably. For these situations, volumetric control of return rate is not satisfactory. Another constraint is that return rates are limited by the capacity of the sludge return pumps available in the plant and the availability of a reservoir of return sludge in the secondary clarifier.

Volumetric return sludge control is relatively easy to implement and is reasonably successful under conditions where sewage flow and characteristics do not change significantly. RAS rates are generally 20 to 50% of the primary effluent flow rate.

Clarifier Sludge Inventory Control

The objective of the withdrawal strategy is to maintain a desired sludge inventory (in the clarifier) within the constraints of RAS volumetric demand. Control is implemented by measuring or observing sludge blanket levels and adjusting return to maintain an an adequate sludge blanket.

Checking the depth of the sludge blanket in the clarifier is the most direct method for determining the inventory. The location of the sludge blanket may be found by several types of devices. Some are commercially available while others must be made by the operator. The following are some of the different types of detectors observed:

1. A series of air lift pumps mounted within the clarifier at various depths.

2. Gravity flow tubes located at various depths.

3. Electronic sludge level detector - a light source and photoelectric cell attached to a graduated handle or drop cord. The photoelectric cell actuates a meter, buzzer, light, etc.

4. Sight glass finder - a graduated pipe with a sight glass and light source attached at the lower end.

5. Some type of portable pumping unit with a graduated suction pipe or hose.

The blanket depth should be kept to less than one-fourth of the clarifier sidewall water depth. The operator checks the blanket depth on a routine basis, making adjustments in the RAS to control the blanket depth. If the depth of the sludge blanket is increasing, the increase may result from having too much activated sludge in the treatment system, and/or, because of a poorly settling sludge, or plugging of the sludge removal system. Long-term corrections must be made that will improve the settling characteristics of the sludge or remove the excess solids from the treatment system.

Measurements of the sludge blanket depth in the clarifier should be made at the same time each day, or continuously. The best time to make these measurements is during the period of maximum daily flow, because the clarifier is operating under the highest solids loading rate. The sludge blanket should be measured daily, and adjustments to the RAS rate could then be made. Adjustments in the RAS flow rate should only be needed occasionally if the activated sludge process is operating properly.

Availability of sludge is dependent on the performance of the clarifiers and the activated sludge process. Due to the instability of the aeration process loading to the clarifier, both flow and solids often fluctuate. Hydraulic splitting problems often lead to unbalanced clarifier loadings. One or two clarifiers may receive a disproportionately high load of solids even when flow is evenly split. Clarifier solids separation performance is dependent on solids loading and hydraulic loading as well as the settling characteristics of the sludge flocs.

The inability to accurately measure the sludge level and concentration hinders implementation of a control strategy. Sludge collection by vacuum or scrapers has historically been less than optimum. Since the quantity of sludge required to treat the wastes is the first priority, the consistency must suffer at high volumetric demands.

INSTRUMENTATION UTILIZED

Sensors

Sensors were observed to be in use in the field for measurement of the following parameters:

1. MLSS - suspended solids analyzer.

2. RAS flow - magmeter or ultrasonic.

3. RAS suspended solids - optical or nuclear.

4. Clarifier underflow - magmeter or ultrasonic.

5. Sludge level - optical, ultrasonic or airlift.

6. TOC - both influent and effluent (may be performed in lab).

7. RAS wet well level switch.

Modulating Control Devices

1. Variable speed pump drives.

2. Valves (plug).

Controlling Devices

1. Switching logic for pumps.

2. Flow controllers (PID).

3. Level controllers.

Annunciator Alarm Points

Annunciators should be provided for:

1. Low and high sludge levels in clarifier.

2. Wet well level.

3. Pump failure.

4. Sensor failures.

VARIATION IN STRATEGY WITH PLANT SIZE

Extended aeration is often used in small plants with flows of less than 0.5 mgd (22 dm3/s). Flow arrangement is similar to conventional treatment with the exception that primary treatment is omitted as shown in Figure 3-12. The goal in extended aeration is to completely oxidize the organic material in the waste. Aeration times are usually about 24 hours and require greater oxygen inputs. With this process configuration, all activated sludge generated is returned. No wasting is typically required.

Plants treating flows of less than 5 mgd (220 dm3/s) may utilize contact stabilization. Flow arrangement is as shown in Figure 3-12. Adjustment of return rate is controlled by adjusting air flow rates to air lift pumps. A longer lag time in response to return demand is present in the sludge aeration basin. Again with contact stabilization, all the sludge generated is returned to stabilization (and ultimately contact) and wasting is only necessary very infrequently (monthly).

In our plant surveys conventional, complete mix and step aeration were observed. Flow diagrams for these processes are shown in Figure 3-11. The strategy of control does not vary significantly among these forms of the activated sludge process, but implementation of the strategy will vary due to variations in process arrangement.

OTHER CONSIDERATIONS

As shown in the Minneapolis-St. Paul Metro and Denver #1 plants, laboratory tests and physical observations such as color and smell of return sludge all weigh heavily in an operator's decision to override the control strategy. Chemical, organic and settling tests are made each shift or more frequently and may indicate that significant changes in strategy are required. Other lab tests include MLVSS, influent BOD and effluent BOD. Each shift a F/M ratio and mass balances are calculated as a check on calibration of sensors and control devices. Any lab test or observation that indicates a need for an immediate change in control strategy is typically repeated before action is taken.

In the previous discussion no indication was given of the need to periodically waste excess activated sludge from this process. In fact, as detailed in the next section, controlled wasting of sludge must be conducted. Over the long run, sludge not wasted must be returned to the aerator and vice versa. Thus, on the average, sludge return and sludge wasting are linked, not independent parameters. In this section and the next one these parameters have, however, been treated as independently variable. This was done because accepted control strategies in the field treat them as independent. In addition, temporary storage of sludge will permit some degree of independent action. The degree of independence is a function of sewage and recycle flows, tankage configuration and mode of activated sludge operation. Conventional activated sludge provides little storage as only a portion of the clarifier capacity is available. Step aeration provides more as the front portion of the aerator is available when all sewage flows are routed to the downstream compartments. Contact stabilization systems provide the most storage since the whole of the sludge reaeration volume is available for short term storage. Although in the short term independent action is possible, it must be remembered that on a daily average basis return sludge and sludge wasting are linked and will limit the degree to which the other can be varied.

This will be taken up again in Section 8 under research needs for activated sludge control.

EXPECTED PERFORMANCE

A good deal of work has been done at the Denver Metro plant regarding instantaneous control of return sludge via TOC and other advanced control strategies. To date, this work has shown little advantage. The volumetric or sludge inventory methods utilized in the field have provided adequate process stability under most circumstances. Further work on control of this process is indicated.

WASTE ACTIVATED SLUDGE

INTRODUCTION

The activated sludge process (including all variations) will generate solids which inevitably must be wasted. Some process configurations produce more sludge to be wasted than others. Sludge can be wasted from the underflow of a single chosen clarifier, from the RAS pumping well, from a separate WAS pumping well or directly from one aeration reactor or all the reactors. Some process configurations allow both wasting from the clarifier underflow and from the aeration tank.

Field observations indicate that wasting of the activated sludge is normally done by removing a portion of the RAS flow. The waste activated sludge is either pumped to thickening facilities and then to a digester, or to the primary clarifiers where it is pumped to a digester with the raw sludge.

The alternate method for wasting sludge from the mixed liquor in the aeration tank was not frequently observed. There is much higher concentration of suspended matter in the RAS than there is in the mixed liquor. When wasting is done from the mixed liquor, larger sludge handling facilities are required. Many plants do not have the flexibility to waste from the mixed liquor nor is there sufficient sludge handling facilities to handle the more dilute sludge. For these reasons, this discussion will concentrate on control strategies for wasting sludge from the RAS pumping well. This configuration was most often observed in the field.

WAS pumping influences mainly the solids train processes in the short term. Rapid changes in wasting rates affect solids train performance but contribute only small hydraulic effects on the liquid train. Improper wasting rates maintained for prolonged periods will seriously affect the performance of the activated sludge process.

OBJECTIVE

The objective of sludge waste control is to control the level of solids in the activated sludge system. If the quantity of solids becomes too high or too low, the performance of the process will degrade. Excess solids in the system produce too high a solids loading on the clarifier. If the level of solids in the system is too low, sufficient organisms will not be present to remove the required organics from the wastewater. Predomination of poorly settling organisms has often been traced to too high or too low a solids level with respect to the organic loading.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

All load characteristics discussed in RAS also influence the control of WAS pumping rates. If the cell synthesis rate is disturbed by physical or environmental changes, the wasting rate must be altered if the system is to stay in balance.

The effect of the loads influencing control of WAS flow are not as dynamic as those affecting RAS flow control since solids residence time is of the order of days as compared to a liquid train residence time of hours. Overflow suspended solids should be considered as unintentional sludge wasting and should be accounted for in determining WAS requirements.

Process Characteristics

WAS flow is generally expressed in terms of mass of sludge to be wasted per day. The availability of a measure of mass flow is dependent on the ability to measure both sludge flow and density accurately. Measurement of these variables and qualities such as cell synthesis rate are difficult and in some cases, not possible. The typical rangeability designed in the WAS pumps may also create problems at peak demands if mass flow is to be maintained.

CONTROL STRATEGY

Wasting of the activated sludge can be done on a intermittent or continuous basis. The intermittent wasting of sludge means that wasting is conducted on a batch basis from day to day. Intermittent wasting of sludge has the advantage that less variation in the suspended matter concentration will occur during the wasting period, and the amount of sludge wasted will be more accurately known. The disadvantages of intermittent wasting are that the sludge handling facilities in the treatment plant may be loaded at a higher hydraulic loading rate and that the activated sludge process is out of balance for a period of time until the microorganisms regrow to replace those wasted over the shorter period of time.

The simplest and most commonly used approach in controlling the amount of sludge wasted is to waste enough to maintain a nearly constant MLVSS. This technique usually produces good quality effluent as long as the incoming wastewater characteristics are fairly constant with minimal variations in influent flow rates. The operator tries to maintain a constant MLVSS concentration in the aeration tank to treat the incoming wastewater organic load.

Field observations produced four control strategies commonly used to control the activated sludge wasting rate. Typical control and instrumentation is illustrated in Figure 3-13.

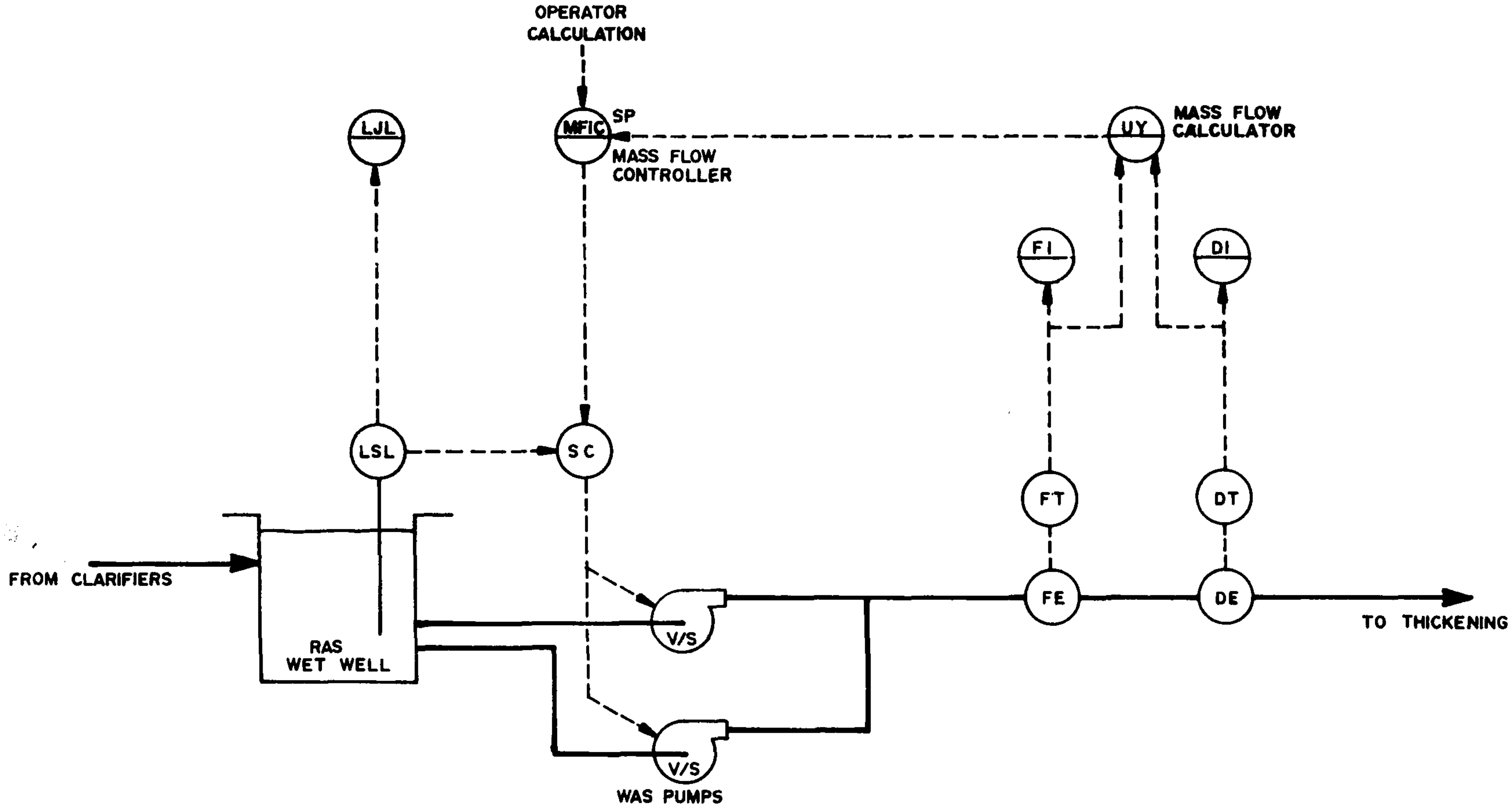


Figure 3-13. WAS control.

1. Controlled Solids Retention Time (SRT) - A quantity of WAS is calculated daily based on the system solids and the selected SRT value. The SRT value used is determined by experience at each plant. The optimum value shifts seasonally. The wasting rate is then set to maintain a desired SRT.

$$SRT = \frac{\text{Pounds of System Solids (aeration and clarification)}}{\text{Pounds Wasted Daily (intentional and unintentional)}}$$

2. Biosynthesis - A wasting rate in pounds per hour is calculated based on the rate of new cell synthesis. This system has been implemented at the Denver plant with very good results.

3. Setpoint based on mass flow - A setpoint is determined and varied on a daily basis. The setpoint is based on maintaining a desired range of F/M ratio in the aeration basin.

4. Setpoint by flow - A WAS flow setpoint is determined based on the target level of MLSS in the aerator.

In the WAS process, the volumetric flow is typically both the controlled and manipulated variable. Measured variables include MLSS, effluent suspended solids, primary effluent suspended solids and RAS solids concentration.

WAS flow control is limited by the rangeability of the WAS pumps. The use of WAS control calculations based on solids balance is limited by the ability to accurately measure all of the necessary parameters. The frequent unavailability of certain measurements due to the high maintenance requirements of the instruments also limits the use of WAS calculations in a control strategy.

OTHER CONSIDERATIONS

All operator and laboratory observations of the process pertaining to RAS also apply to the WAS flow. MLSS is observed and used as an override on the WAS calculation if the solids are too low or too high. Most plants surveyed used a daily solids balance to check the calibration of measurement devices. If the process has poorly settling sludge as indicated by a high SVI reading, the WAS flow may be either stopped or run at maximum depending on the assumed cause of the poor sludge compaction.

INSTRUMENTATION UTILIZED

Sensors

The following sensors were observed to be in use in the field:

1. WAS flow rate - magmeter or ultrasonic.

2. WAS suspended solids - optical or nuclear.

3. Blanket level - optical, ultrasonic or airlift.

4. MLSS - suspended solids analysis.

5. Effluent suspended solids - usually a lab test can be done with analyzer.

6. TOC - influent and effluent, can be a lab test.

Modulating Control Devices

1. Pump drives.

2. Valves, if applicable.

Controlling Devices

1. Pump speed controllers.

2. WAS flow calculator.

Annunciator Alarms

1. Pump failures.

2. Low flow in pump.

3. Low return suspended solids.

4. Low wet well level.

VARIATION IN STRATEGY WITH PLANT SIZE

`The wasting control strategy for the activated sludge processes utilized in the larger plants--conventional, complete mix and step aeration--do not significantly change with plant size. Process design is similar except in size of units and method of carrying out the strategy. In small plants the use of contact stabilization or extended aeration becomes advantageous. In a contact stabilization process, wasting is typically intermittent and infrequent. Wasting is usually to the aerobic digestors.

In a plant using the extended aeration process (usually less than 0.5 mgd, 22 dm^3/s), wasting is done very infrequently and only when needed. The goal in extended aeration is complete oxidation of all organic material. This strategy yields very little growth in cell mass. The non-degradable solids eventually build up and must be cleaned out, usually once or twice a year.

EXPECTED PERFORMANCE

Denver has shown improvement in process consistency since implementing a strategy of mass flow control based on a calculated biosynthesis or sludge growth. The key is not to maintain a flow, but a mass flow as solids concentration from the clarifiers does change radically. Most other plants visited waste based on MLSS set by a volumetric flow rate. Process consistency suffers but the monthly average performance is generally adequate with laboratory diligence.

CHEMICAL FEED

INTRODUCTION

Chemical addition has many applications in wastewater treatment, including polymer addition to aid suspended solids removal, sludge conditioning prior to the various dewatering techniques, lime addition for adjusting pH, and chlorine addition for disinfection. Chlorination is covered in a separate section. Three methods of chemical addition are discussed here; fixed rate, flow proportional and mass flow proportional. These approaches are discussed because they were observed in the field.

OBJECTIVE

Objectives in chemical feed control include the improvement in the operation of the unit process and minimization of chemical usage. In solids/liquid separation, chemical addition promotes removal of suspended solids by adding a flocculant. In a sludge dewatering process, chemicals are added to aid in the formation of sludge cake from which water can be readily removed. The particular chemicals that are used in dewatering will depend on the method of removal used. For example, lime may be added to control the pH after use of a coagulant aid in dewatering. Coagulation is pH sensitive.

The interactions of chemical feed are extreme. If the unit processes upstream are unstable, the chemical dose must be highly variable in order to compensate for the changes in feed character. If the unit processes downstream are sensitive (dewatering), the chemical feed control must be precise in order to maintain performance.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

The required chemical dosage is difficult to determine because of the number of variables which affect the required dose. Also, the relationships between the process goal and the chemical dose is often not well understood (e.g. how much polymer is needed to produce a solids capture of 90% in a flotation thickener). For this reason, empirical modeling is required to determine dosages and optimization is not attempted. If necessary, the strength of the stock chemical solution should be frequently monitored.

Process Characteristics

The metering pumps, typically positive displacement with SCR drive speed controls, provide good rangeability to control chemical addition. Flow feedback measurement is not generally required since the pump speed provides a fair estimate of feed flow.

CONTROL STRATEGY

Three strategies are described below; operator set speed, flow pacing, and mass flow pacing (see Figures 3-14 and 3-15). In all cases the controlled variable is chemical feed rate, pump speed is the manipulated variable, and measured variables are those that are associated with the load including process feed flow, influent suspended solids, and occasionally effluent suspended solids.

Two important constraints of the control system are the large process time constant and the lack of an on-line feedback signal.

Chemical feed rate control is typically based on process hydraulic flow or mass flow and the degree to which the desired results are achieved is used to further modify the chemical feed rate. Chemical feed pumping is typically alternated between primary and standby pumps. Pump control can be interlocked to shut off on day tank low level.

Operator Set Speed

Chemical feed control could consist of simply having the operator set the feed rate as determined by the process flow rate. However, this method requires very frequent operator attention, otherwise much chemical will be wasted. Adequate load following cannot be achieved with this method unless there is frequent operator attention.

Flow Pacing

This method requires an operator entered ratio of chemical feed flow to process flow. The process stream flow rate is used as input to the ratio controller to control the pump speed rate based on an operator ratio.

Mass Flow Pacing

This method is similar to above except a calculation of process feed mass flow rate is utilized as the input to the ratio controller. The controller then drives the chemical feeder based on an operator entered ratio setpoint around the load input (mass flow).

INSTRUMENTATION UTILIZED

The following instrumentation and control devices are typically used:

1. Flow meters - mag meters.

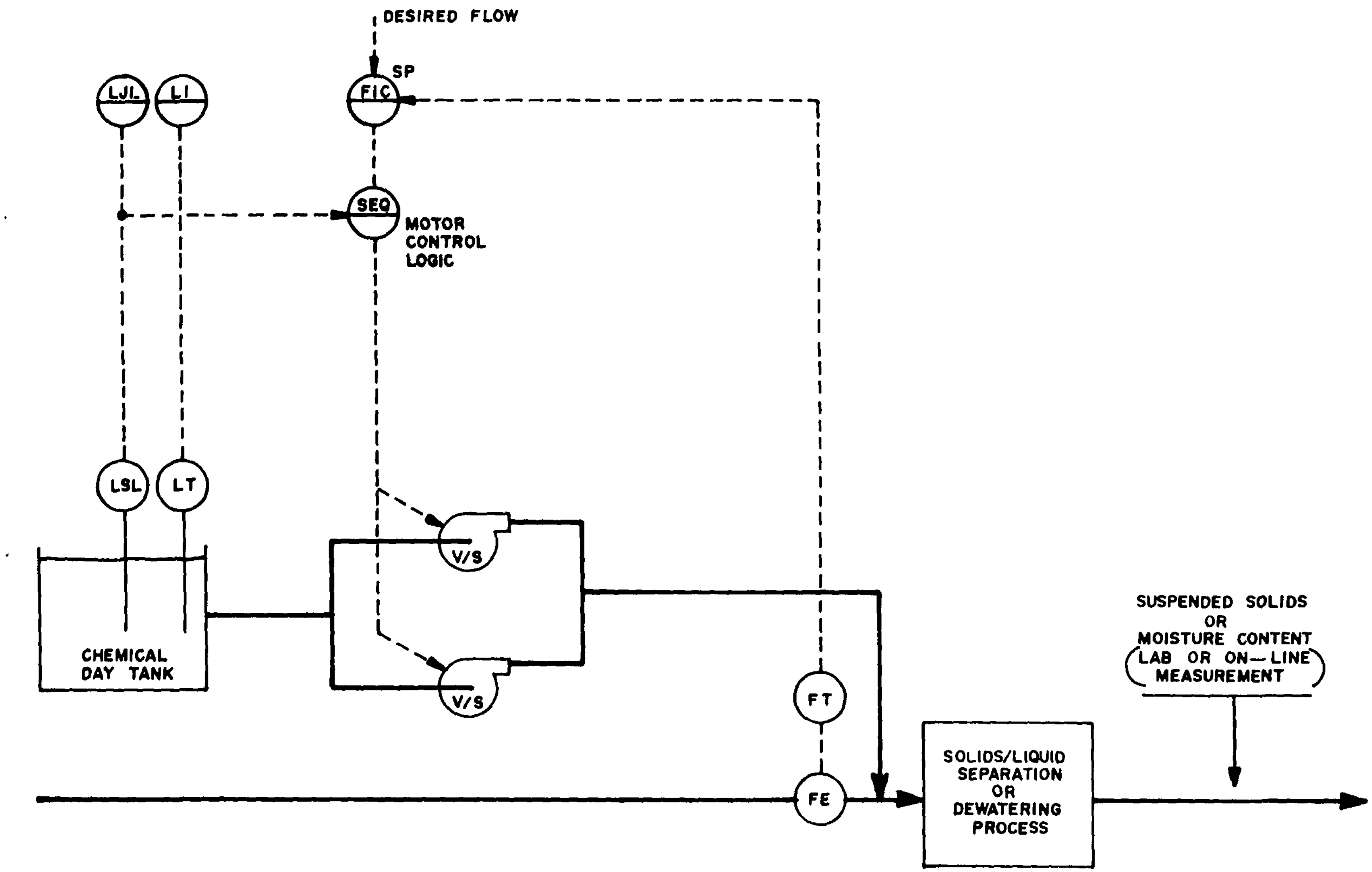


Figure 3-14. Chemical feed control - flow pacing.

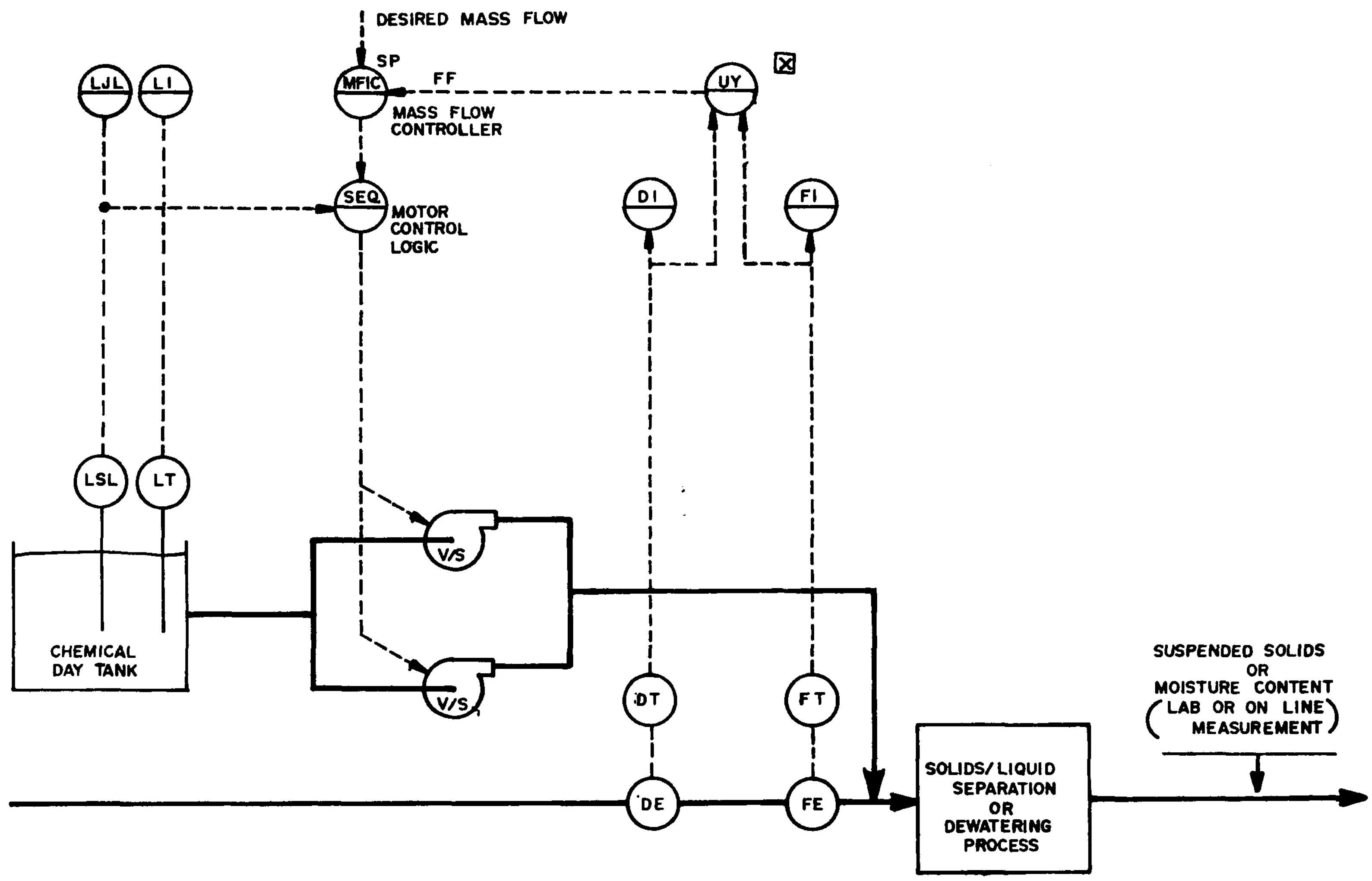


Figure 3-15. Chemical feed control - mass flow pacing.

2. Suspended solids analyzer (optional) - this is used to establish process mass flow.

3. Level switches in feed tank.

4. SCR metering pump drive.

5. FIC or MFIC flow or mass flow control - PID type.

6. Mass flow calculator.

VARIATIONS IN STRATEGY WITH PLANT SIZE

Small plants typically use fixed rate or intermittent addition of chemicals. The intermediate sized plants usually use the flow pacing method. Large plants will typically use flow pacing and start/stop sequence controls for a number of metering pumps. The larger plants sometimes incorporate suspended solids measurements in the control strategy. Mass flow ratioing was observed, but infrequently.

EXPECTED PERFORMANCE

The large time constants make measurements difficult and therefore the improvements gained through the use of chemical feed control are difficult to evaluate. Field results have shown that chemical feed control allows dewatering and separation processes to function properly, but the nature of the loads involved make it nearly impossible to predict the improvement that may be achieved by utilizing one mode versus another.

POST-CHLORINATION

INTRODUCTION

Chlorine has historically been used in this country for wastewater treatment plant effluent disinfection. Chlorine gas is the form in which this substance is most frequently used. The dangers of this gas are widely known. At smaller facilities a hypochlorite solution is preferred. It is more expensive, but safer. At very large facilities, hypochlorite is becoming prevalent again because of the safety aspect. Safety is also one of the reasons for the adoption of ozone for effluent disinfection at new plants.

Because post-chlorin tion overwhelmingly includes use of chlorine gas and because hypochlorite and ozone are discussed with other strategies, post-chlorination with chlorine gas will be discussed here.

OBJECTIVE

The specific goal of chlorination control is to maintain adequate chlorine residual to insure that disease producing organisms (pathogens) are destroyed. The more complex process control systems are better able to follow the load and maintain the desired chlorine residual, saving excess chlorination costs. However, the uncontrolled hydraulics and difficulty of measuring bacteria level affect the ability of the control system to consistently meet the process objectives.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

The load on the process is not the quantity of microorganisms, but rather substances which exert a chlorine demand. The load is organic, inorganic, hydraulic and solids and follows diurnal flow patterns. Also, there are industrial dumps which can produce peaks of highly oxidizable wastes in the plant influent. With the exception of flow, on-line real time measurement of other load parameters (TOC, SOC, ammonia, nitrate, sulfides) is difficult to achieve. Empirical relationships between these load parameters and chlorine demand are under development.

Process Characteristics

The most important process characteristic is that the final chlorine residual is not determined until long after (e.g. 15 minutes) chlorine has been added. This time is required to provide the contact time necessary to effect kill of the organisms. The final chlorine residual analysis is sometimes not even done on site, further delaying the measurement. Another typical process characteristic is the crude mixing achieved in flow over weirs in the chlorine contact basin.

Other difficulties arise in measuring chlorine gas flow rate. Control of the gas flow rate requires sensitive equipment to regulate a low flow under vacuum. Instrumentation to measure suspended solids level for feed-forward chlorine control is increasing in reliability as is instrumentation for TOC.

CONTROL STRATEGY

A chlorinator is a device which takes gaseous chlorine and prepares a stock solution of the chlorine in water and meters the stock solution into the flow to be treated. The vacuum regulating valve sets the flow of chlorine gas and thus controls the preparation of the stock solution. The orifice positioner meters the stock solution into the flow.

There are four different control strategies commonly used for chlorination control. They are, in order of usage; flow proportional, compound loop, double compound loop, and ratioed feedback.

For all methods described below, the controlled variable is chlorine residual (indirectly, the bacteria level). The manipulated variable is gas flow. Measured variables include plant flow, and chlorine residual. Suspended solids and TOC would be included as measured variables if they are used in conjunction with plant flow as feedforward control, although this is rarely observed in practice.

Flow Proportional

This method requires a process influent flow meter, chlorinator and a ratio station control. The vacuum regulator is manually set to meter chlorine for maximum plant flow. The operator enters the ratio setting, as determined from the lab analysis of the parameters of the load, to control the orifice positioner in relation to the process stream's measured flow rate. Only manual monitoring of chlorine residual level is done, so optimum residual level cannot be maintained.

Instrumentation and control devices typically used in conjunction with the chlorinator are as follows (see Figure 3-16):

1. Flow meter - mag meter (process flow).

2. Ratio station - orifice control.

3. Manual loading station - vacuum regulation.

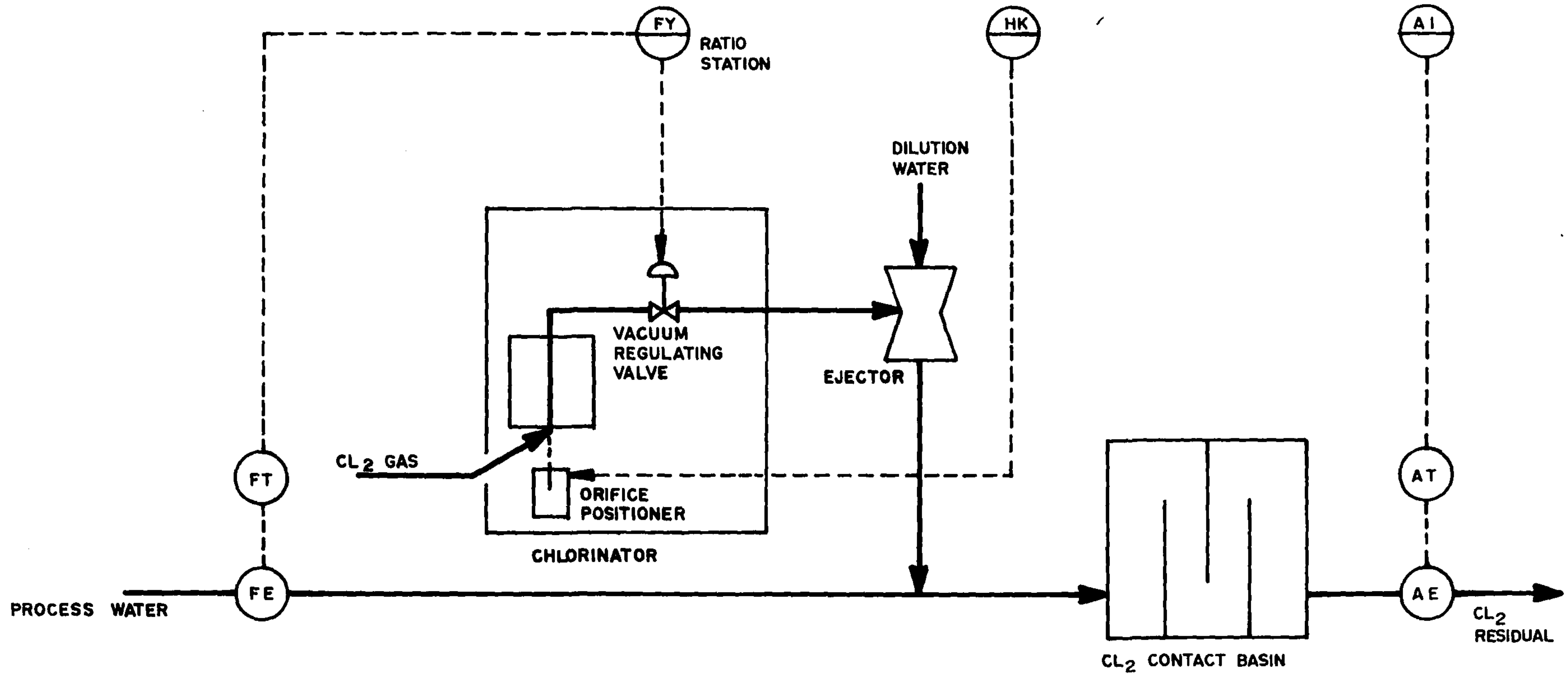


Figure 3-16. Chlorine feed control - flow proportional.

Compound Loop

The compound loop process is set up so as to modulate both vacuum regulation and orifice position. In this control strategy feedforward control based on process flow and feedback control based on chlorine residual are employed. The feedforward control is on the vacuum regulator while the feedback control is effected on the orifice positioner. This split must be used because of the inability to utilize analog control devices with simultaneous feedforward and feedback elements. A chlorine residual controller (CRC) is used in addition to the devices described under flow proportional control. Compound loop control uses a ratio station with process flow input and an operator entered ratio setting for vacuum regulation. Orifice position is set by the output of the CRC which uses an operator entered setpoint and feedback from the chlorine residual analyzer. This control strategy has the advantage of closely matching the chlorine dosage to the requirements of the process by controlling orifice position as well as vacuum regulation.

Instrumentation and control devices typically used in conjunction with the chlorinator are as follows (see Figure 3-17):

1. Flow meter - mag meter (process flow).

2. Chlorine residual analyzer.

3. Ratio station - vacuum regulation.

4. Chlorine residual controller - PID type.

Double Compound Loop

Double compound loop uses a cascade control system to control orifice position (gas flow). An additional chlorine residual analyzer is used in the contact basin to provide more rapid feedback control. The process flow through the chlorine contact basin takes approximately fifteen minutes in this example. To overcome the long delay in obtaining residual chlorine measurement when the analyzer is at the end of the basin, a second residual chlorine analyzer is placed to obtain a sample at a position five (flow) minutes into the basin. The latter provides feedback to the CRC in the secondary loop controlling orifice position. The secondary loop CRC setpoint is provided by the output of the primary loop CRC using an operator entered setpoint and the residual chlorine level at the exit of the chlorine contact basin as feedback. This method provides superior load following and can save a substantial amount of money through reduction in unnecessary chlorine use.

Instrumentation and control devices typically used in conjunction with the chlorinator are as follows (see Figure 3-18):

1. Flow meter - mag meter.

2. Ratio station - vacuum regulation.

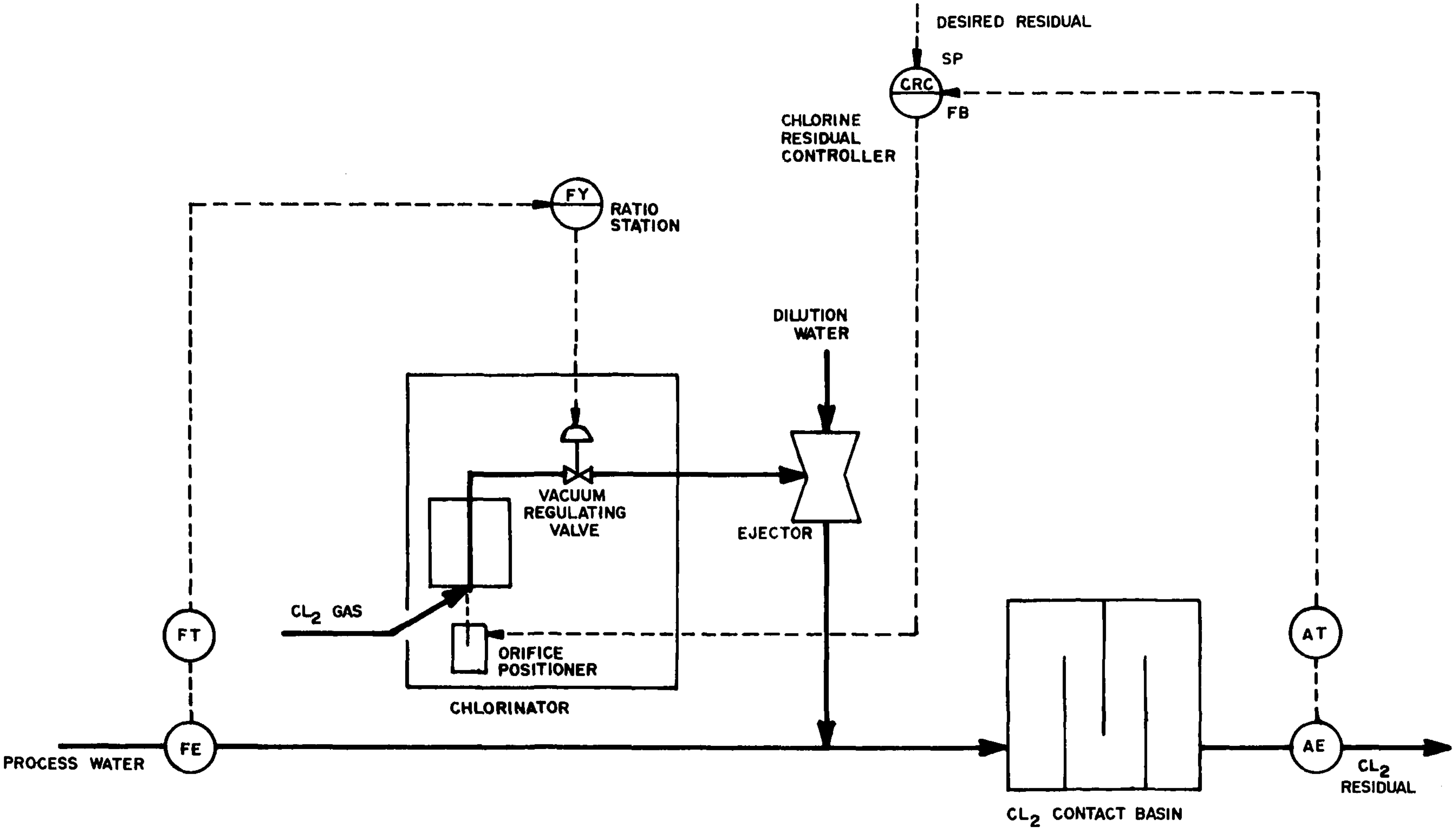


Figure 3-17. Chlorine feed control - compound loop.

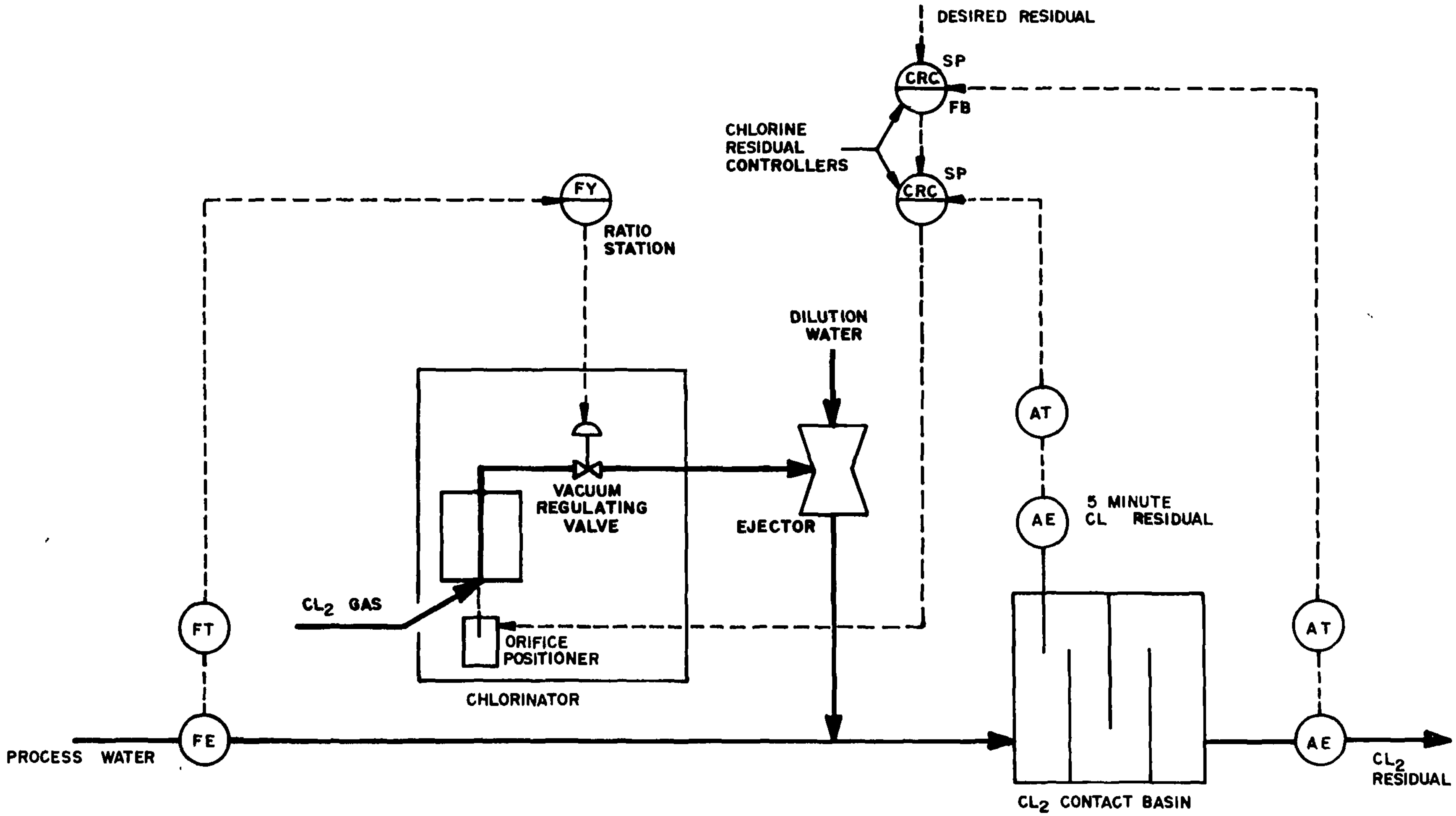


Figure 3-18. Chlorine feed control - double compound loop.

3. Two chlorine residual analyzers.

4. Two CRC's - PID type.

Ratioed Feedback

This method requires a flow meter, control valves, residual chlorine analyzer, chlorine residual controller (CRC), and ratio controller. The vacuum adjust is manually set to meter chlorine for maximum plant flow. The CRC compares the chlorine residual with an operator entered setpoint and the output varies the ratio controller's ratio setting. The process stream's flow measurement is wired to the ratio station as the driving signal. The feedforward flow times the variable ratio determines the output to the gas flow control orifice.

Instrumentation and control devices typically used in conjunction with the chlorinator are as follows (see Figure 3-19):

1. Flow meter - mag meter.

2. Chlorine residual analyzer - requires daily cleaning, but the primary benefit returned is good effluent residual control.

3. Ratio station - orifice control.

4. Chlorine residual controller.

5. Manual loading station - vacuum regulation.

This configuration was shown in the field to produce highly variable and unpredictable results because it attempts to combine feedforward and feedback control with a single control device.

VARIATIONS IN STRATEGY WITH PLANT SIZE

Different size plants typically use different control strategies. In the small plants (less than 5 mgd - 220 dm^3/s) flow proportional control is usually adequate or the chlorine feed rate is sometimes fixed. Midsized plants (5 to 50 mgd, 220 to 2200 dm^3/s) typically use compound loop control. Chlorine residual is often measured to determine the ratio settings for control. Larger plants (100 to 300 mgd, 4400 to 13000 dm^3/s) usually use flow proportional control, often sequencing the operation of multiple chlorinators (although problems arise due to system complexity and corrosion of relays by chlorine gas). Plants of this size may also automatically control the liquid chlorine evaporator delivering chlorine gas to the chlorinator.

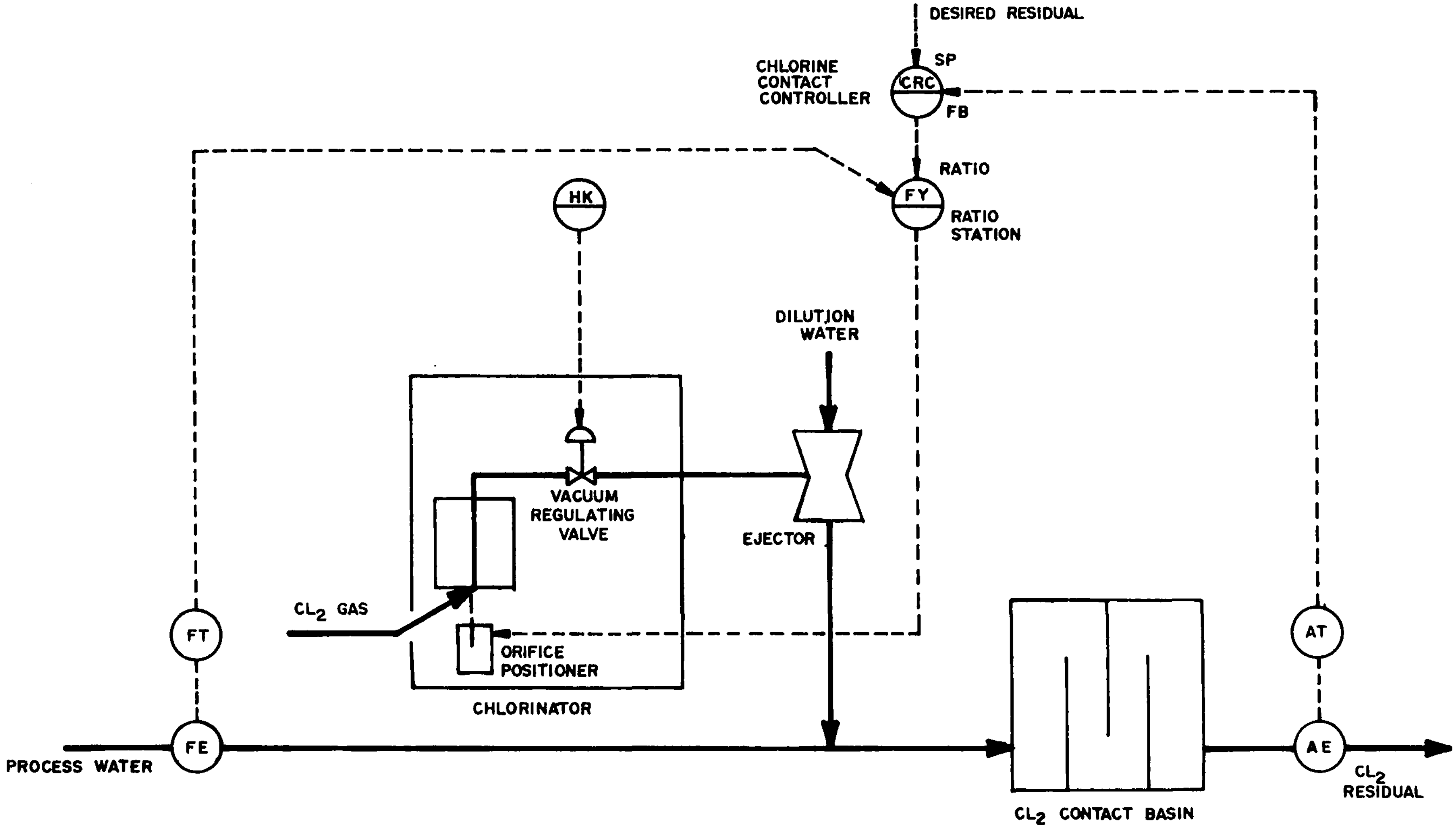


Figure 3-19. Chlorine feed control - ratioed feedback.

EXPECTED PERFORMANCE

Experience has shown that chlorine residual is difficult to control. There are often significant deviations from the setpoint, usually excess chlorination. Control system performance achieving a chlorine residual within 10% of setpoint will be a fortunate occurrence due to the dominance of the process time lag and the problems associated with residual analyzers. With use of flow proportional control only, it is possible to stay above the minimum desired level, but difficult to accurately adjust dosage for load variations.

OZONATION

INTRODUCTION

The use of ozone in wastewater treatment for disinfection and odor control has only recently begun to be implemented. Ozone is generated by high voltage, electric discharges in air or oxygen. In general, the amount of ozone generated is increased by increases in the oxygen bearing gas flow rate, oxygen concentration, applied voltage level and electrical discharge frequency.

Ozone generation can be an independent process utilizing air as the oxygen source. However, ozone generation becomes cost effective if high purity oxygen is available at the plant for other purposes since the energy required per unit mass of ozone is about half of that which is required if air is the feed gas. Ozone is considered to be a more potent disinfectant and oxidant than chlorine, and ozonation byproducts may not be harmful, in fact, one byproduct is oxygen which is beneficial to water quality.

For these reasons the major use of ozone in wastewater treatment in the future will be as a disinfectant in conjunction with a high purity oxygen source. The oxygen is usually generated for use in pure oxygen activated sludge systems. The oxygen source will generally be a cryogenic plant for flows of about 15 mgd (660 dm^3/s) and greater, or a pressure swing adsorption (PSA) unit for lower flows. Liquid oxygen can be purchased for revaporization for extremely small flows.

In this report the model studied uses ozone for disinfection generated from high purity oxygen supplied by a cryogenic plant, with ozonation off-gases reused in an activated sludge process.

OBJECTIVE

The objective of ozonation is disinfection of wastewater to meet federal or state standards. Disinfection is assumed to be accomplished with the destruction of all disease producing organisms (pathogens).

Disinfection is a high priority goal in wastewater treatment because of the potential health hazard of improperly treated sewage. Ozone demand is dependent on the quality and quantity of the liquid being treated and is not synchronous with oxygen demand or supply. This requires ozonation to be widely rangeable in order to provide adequate disinfection at a reasonable cost.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

The required ozone dose is affected by changes in wastewater flow and quality. Diurnal and seasonal fluctuations in hydraulic loading and refractory organic loading are often large in magnitude. Instabilities in plant operation lead to varying loadings of dissolved organics, dissolved inorganics and suspended solids. Industrial discharges may cause large changes in pH which can alter ozonation efficiency.

Process Characteristics

The ozonation process is controlled by mass transfer of ozone into the wastewater. Since ozone rapidly decomposes and has slow diffusion rates, it is important to intimately mix the ozone bearing gas with the wastewater. The contact basin should be designed for an average contact time of about fifteen minutes and should be compartmentalized to prevent short circuiting.

The controlled variable (disease producing organisms) is not a measured parameter in the automatic control system but tests are performed to indicate the possible presence of pathogens. Ozone residual, which would indicate ozone in excess of that required for disinfection, is difficult to measure because ozone rapidly decomposes. Furthermore, ozone analyzers are not ozone specific and require a great deal of maintenance. Thus, ozone production requirements (in an hour-to-hour sense) are largely determined from feedforward parameters.

CONTROL STRATEGY

The high purity oxygen feed gas is first pressurized by a boost compressor to overcome the liquid depth in the contact tank. The compressed gas is sent through the generators where ozone is produced by a corona discharge. The ozone bearing gas is next diffused into the wastewater in the contact basin. The off-gases are removed from the contact basin by a blower which sends the gas to the oxygen dissolution process. These gases are typically not recycled to the ozonator.

As stated earlier, the controlled variable (fecal coliform count) is not available as an automatic control parameter, nor is ozone residual. Thus ozonation is usually operated in an open-loop control mode which can lead to over or under disinfection.

Manipulated variables are corona discharge voltage or frequency (but not usually both) and oxygen flow. These variables are manipulated to increase or decrease the amount of ozone produced.

Measured variables can include the following:

1. Flow, pressure and temperature of the boost compressor discharge. These are used to determine mass flow rate.

2. Flow of boost compressor inlet.

3. Flow of off-gas blower inlet.

4. Flow of effluent to be disinfected.

5. Contact basin pressure.

6. Generator discharge ozone concentration.

7. Ozone residual (dissolved in water).

8. Ozone purity (gas phase).

There are several factors limiting the ozonation control system from meeting the disinfection objective. As indicated previously, the primary constraint is that the controlled variable is not readily measured thus requiring open-loop operation. Another constraint is that the oxygen supply varies with the oxygenation requirements of other sections of the plant. If these coincide with oxygen demand for the ozonation, system capacity could be overcome.

An ozone-oxygen system has been operating continuously for about five months at the Southwest Treatment Plant in Springfield, Missouri. The automatic controls used are indicated in Figure 3-20 and discussed below. The P&ID is a simplified representation; for example, there are actually thirteen generators although only two are shown.

Startup and shutdown of generators is performed manually; the number of generators operating at one time is based on the operator's experience in obtaining the required ozone for the least energy.

During steady-state operation the following automatic controls are active:

1. Plant flow controls oxygen feed flow.

2. Contact basin pressure controls off-gas flow rate.

3. Operator controls generator output based on feedforward from plant flow and feedback from generator discharge ozone generation.

OTHER CONSIDERATIONS

Ozone required for disinfection increases with increasing suspended solids (SS) levels, nitrite levels and total organic carbon (TOC or COD) levels of the effluent to be treated. The operator should adjust the ozone production to compensate for fluctuations in these. Filtration prior to ozonation reduces the variation in SS.

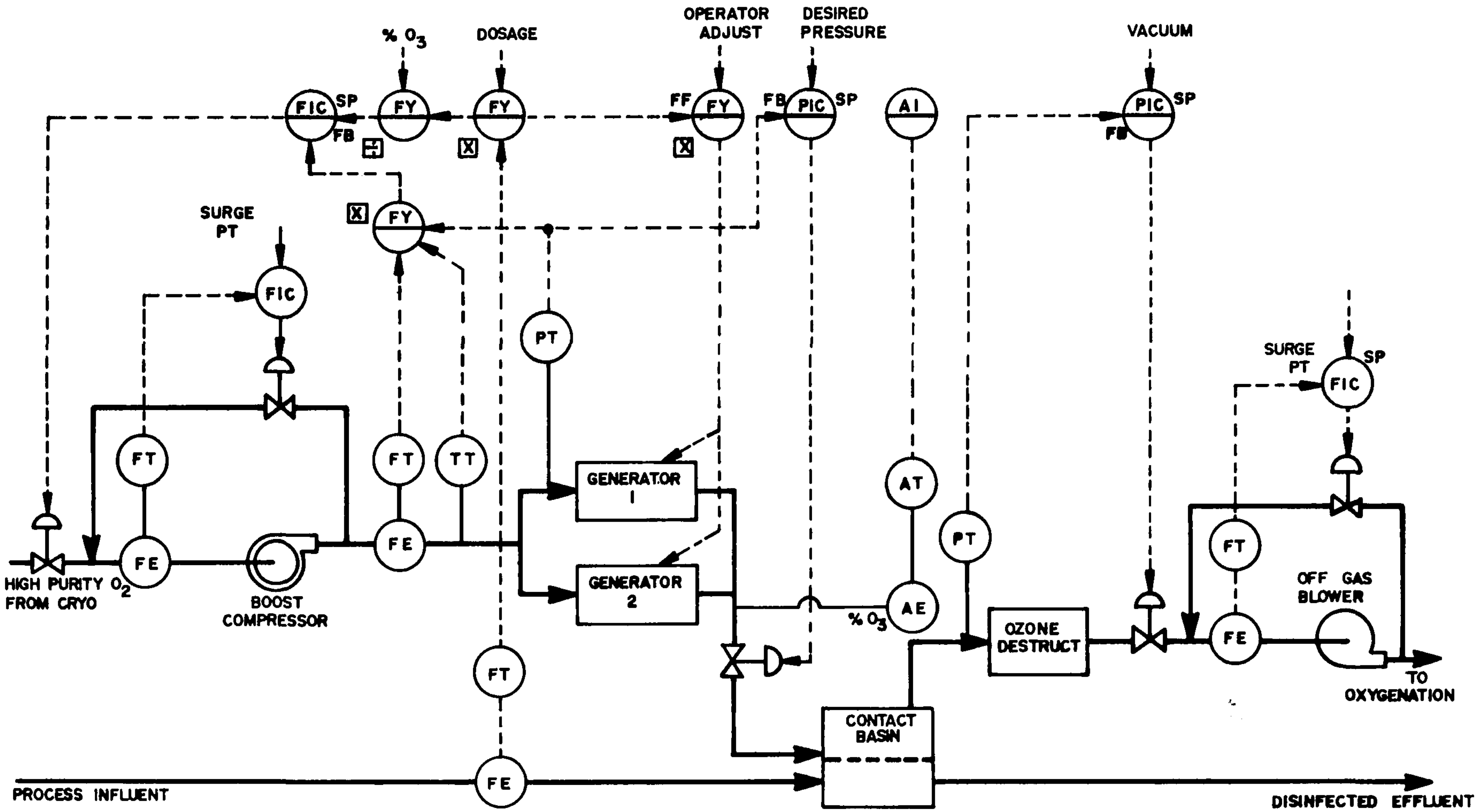


Figure 3-20. Ozonation control.

Fecal coliform counts and laboratory ozone residual tests show if over or under disinfection is occurring. The operator uses this information and experience to adjust ozone dosage accordingly, usually once per shift.

The operator must also periodically inspect the equipment performance.

INSTRUMENTATION UTILIZED

The following lists contain typical instrumentation for an ozonation system. Unless otherwise stated, the sensors and devices are capable of a high degree of accuracy and reliability.

Sensors

1. Gas flow meters - orifice plates with correction for temperature and pressure.
2. Plant flow - flume.
3. Temperature (generator gas discharge).
4. Pressure (generator gas discharge).
5. Ozone concentration - infra-red.
6. Ozone residual - electrode with ozone gas permeable membrane or other amperometric method. These instruments usually have high maintenance and poor accuracy, however improvements in both areas are being made.

Modulating Control Devices

1. Centrifugal compressors - inlet guide vanes or butterfly throttling valve control flow until surge point is reached. Bypass lines with butterfly valves control recycle to give net gas flows below surge conditions.
2. Generators - variable voltage transformer or discharge frequency oscillator.

On/Off Control Devices

1. Compressors.
2. Generators.
3. Purge blower.

Controlling Devices

1. PIC's.

2. FIC's.

3. Manual loading stations.

Annunciator Alarms

1. Compressor surge.

2. Compressor aftercooler gas temperature.

3. Compressor aftercooler coolant temperature and pressure.

4. Generator coolant temperature and pressure.

5. Ozone purity high and low.

6. Contact basin pressure.

7. 50% Lower explosive limit (LEL).

8. Supply gas dew point.

VARIATION OF STRATEGY WITH PLANT SIZE

For small plants (less than about 15 mgd - 660 dm^3/s), the oxygen source would probably not be a cryogenic plant, but rather pressure swing adsorption (PSA) or vaporization of purchased liquid oxygen. This may change the economic picture and was not observed in the field. The size cutoff is not exact because a high BOD influent would require more oxygen, hence a cryogenic plant might be justified at flows less than 15 mgd (660 dm^3/s).

In large plants the number of generators required can become very high because they are not currently manufactured with large capacities. For example, the Springfield, Missouri, plant has thirteen generators at a design flow of 35 mgd (1540 dm^3/s).

EXPECTED PERFORMANCE

Good control of the ozone generation process can be expected. Operators at the Springfield plant have not experienced any control problems related to generation. They report good disinfection reliability; however, there were periods when the disinfection objective was not met. This occurred during a period of system adjustment. Initially six generators were put on line; each one set to produce about 300 pounds of ozone per day. Total coliform inactivation was obtained so the number of operating generators was reduced until the ozonation objective was no longer achieved to determine the minimum required. For current plant flows, three or four generators are operated, depending on the effluent flow and suspended solids. In this operating mode, excess disinfection most often occurs.

Although this plant's ozonation system is operating well now, part of this success is due to operation at partial capacity. The c.'yo plant is designed to produce 50 tons per day of oxygen but is currently being operated at about 30 tons per day, which is the maximum turndown achievable so that excess oxygen must be vented. The excess production does, however, minimize cryo-ozone-oxygenation system interaction because the required ozone supply of oxygen is always available. Loads where oxygen generation energy conservation controls can be implemented will provide a more stringent test condition for the ozonation control system.

No operating data is available at this time to quantify the reliability in meeting the objective.

GRAVITY THICKENING

INTRODUCTION

Gravity thickening is generally utilized to concentrate primary or a mixture of primary and waste activated sludge. Thickening tanks are typically the center feed, vertical picket type. Polymer is sometimes used to improve thickener performance. Gravity thickening is usually followed by additional dewatering, or biological stabilization.

OBJECTIVE

The primary objective of gravity thickening is to concentrate the sludge as much as possible within the constraints of the process to maintain as consistent an underflow quantity and composition as can be achieved. Of secondary importance is operation of the process at maximum solids capture efficiency and minimization of chemical usage. Optimization of hydraulic loading with dilution water is also desired for improved performance.

The solids processes downstream of the thickeners are directly affected by the performance of the thickening process. Poor performance will greatly affect the volume of sludge withdrawn from the tank. The thickener overflow liquor is usually not treated separately but is returned to the head of the plant. Thus, overflow solids may represent a significant solids and organic load on the liquid train processes.

The process operates by gravity separation and is by nature stable. Stability is often affected by hydraulic control of multiple units. Typically the degree of flow control employed is less than adequate, often resulting in a flow or solids imbalance between units. Stability may also be affected by floating solids (and scum) from septic sludge if sludge is maintained in the system too long or dilution water flow is either insufficient or excessive.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

The loads on a gravity thickener are difficult to predict since quantity and composition of the feed is determined by how well the primary and secondary clarifiers perform as well as the wasting schedule adopted. If a combination of primary and waste activated sludge is fed, the hydraulic and solids loads are more unpredictable. Dilution water added as a ratio of primary flow represents a significant hydraulic load on the process. Dilution appears, however, to favor thickening perhaps by washing out fines which disrupt thickening.

Process Characteristics

Field observations indicate that the process is susceptible to short circuiting problems. Solids removal is also troublesome, resulting in the development of septic conditions and associated odors.

The measurement of underflow concentration and blanket level is difficult. Sensing equipment for these applications has improved so that capability exists for obtaining acceptable measurements. Often, however, the sludge blanket interface is very diffuse which leads to insensitive measurements.

CONTROL STRATEGY

The goal of the strategy is to maintain a consistent and maximum concentration of sludge in the underflow (see Figure 3-21). Thickeners are usually fed continuously, with flow split to all units in operation. Dilution water flow is controlled as a ratio of sludge flow. Sludge withdrawal is typically a batch operation, but if continuous pumping is employed, each unit is usually equipped with individual pumps.

Underflow concentration is the controlled variable in the strategy. The manipulated variables are the underflow pumping rate, influent rate, dilution water flow and, if applicable, polymer addition. Typical measured variables include total flow, individual unit flow, density of influent, sludge blanket level and underflow concentration.

OTHER CONSIDERATIONS

Lab analysis typically supplements the control system. Underflow and overflow solids should be analyzed each shift to check instrumentation and establish efficiency of solids capture. Sludge level and sludge color are also periodically checked. Process modifications may be made based on these observations. Sludge volume ratio (SVR, volume of thickener sludge blanket divided by the sludge volume pumped per day) is a good control calculation occasionally used to modify strategy seasonally. This parameter is analogous to SRT and gives a measure of sludge age in the thickener.

System Constraints

Field observations indicate that the following process characteristics can constrain the ability of a control system to meet stated objectives:

1. The ability to consistently control feed and equally split the flow is usually not provided.

2. Concentration of feed sludge is variable.

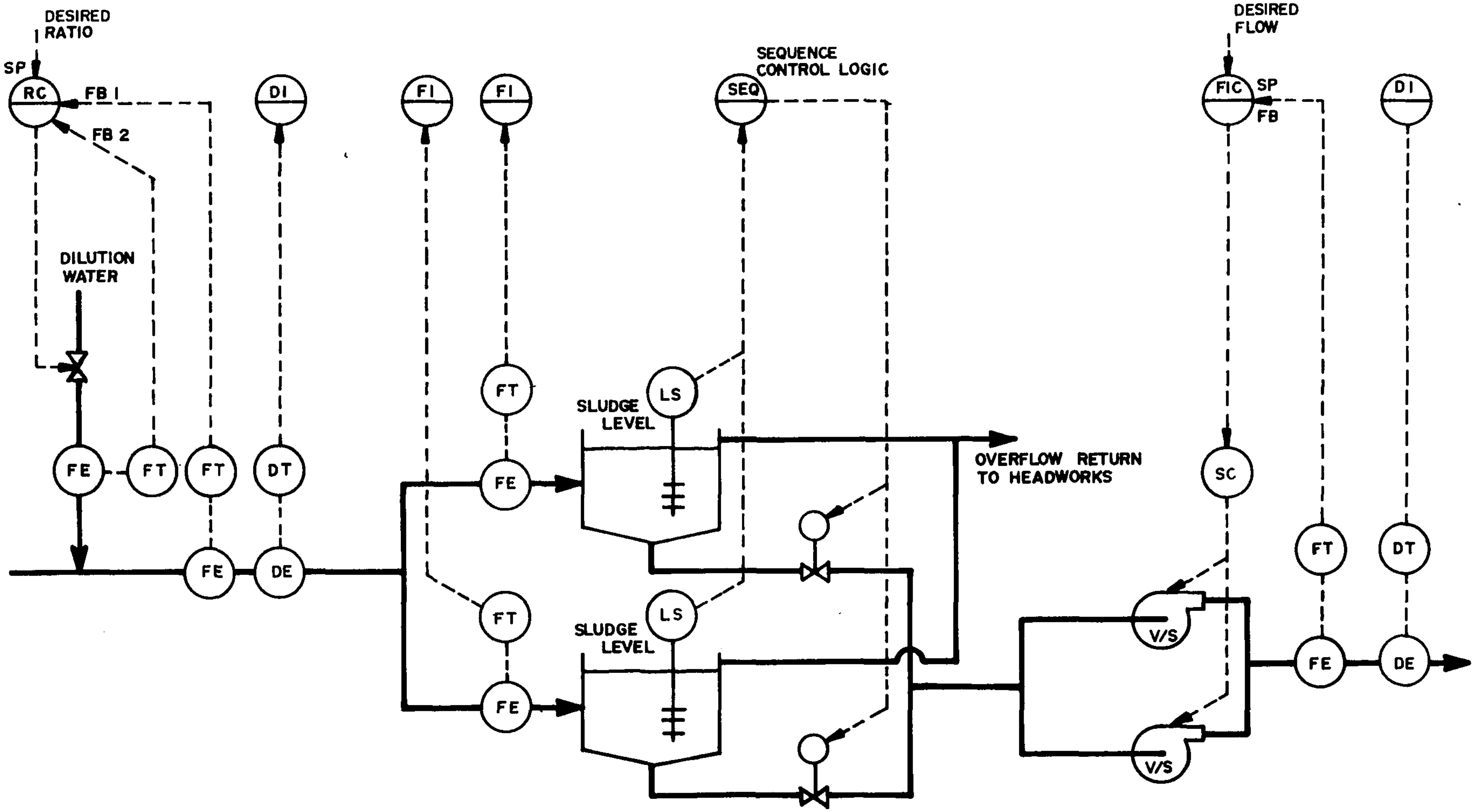


Figure 3-21. Gravity thickener control.

3. Collection and removal of concentrated sludge is difficult.

4. Response time of sensors is slow.

5. The use of positive displacement pumps results in flow surges that affect flow measurement.

INSTRUMENTATION UTILIZED

The following instruments and control devices are applicable and were observed in the field:

Sensors

1. Flow - typically magnetic flow meter (others observed include ultrasonic).

2. Density - a difficult measurement but can be accomplished with optical or nuclear devices.

3. Level - optical, ultrasonic or air lift with visual observation.

Modulating Devices

1. Plug valves on thickener feed and dilution water.

2. Polymer metering pumps.

3. Variable speed or stroke sludge pumps.

On/Off Device

1. Underflow isolation valves for common pumped systems.

Controlling Devices

1. Flow indicating controller - typically PI mode.

2. Sequence control logic for sludge withdrawal valves.

3. Ratio controllers (for dilution water and polymer).

4. Multipliers.

VARIATION IN STRATEGY WITH PLANT SIZE

In small plants (less than 1 mgd, 44 dm^3/s), use of gravity thickeners is usually not practical. Moderate size plants (5 to 50 mgd, 220 to 2200 dm^3/s) utilize the strategy previously described. Large plants (100 to 300 mgd, 4400 to 13000 dm^3/s) employ a similar strategy but each thickener is usually equipped with separate pumps to allow independent control of underflow pumping. The control equipment, and hence control strategy, becomes more complex.

EXPECTED PERFORMANCE

This strategy should be capable of producing a consistent underflow concentration, which is a function of sludge characteristics. Overflow solids should be checked as use of the control strategy does not guarantee improvement in capture efficiency. At the Ocean County, New Jersey plant, measurement of overflow solids is used to aid the operator in adjusting pumping rate.

FLOTATION THICKENING

INTRODUCTION

Flotation thickening is generally used for the concentration of waste activated sludges. Most older thickeners may be rectangular, but most new installations observed are circular. The flotation process feeds air into the sludge under pressure so that a large amount of air can be dissolved. When the air comes out of solution in the thickener, small bubbles attach themselves to sludge particles and float them. Chemical flotation aids (polymer) are used to help improve sludge concentration and capture efficiency.

The thickeners are in the middle of the solids process train and are highly interactive with both the activated sludge process and the solids disposal train. Thickeners are usually followed by either a holding or blending tank. Performance of the thickening process will affect the sludge processing train.

Field observations indicate that the process operates with inconsistent results because of varying loading and uncontrollable process characteristics. WAS loading, recycle requirements, bubble size, etc. are not directly controllable and make process control complex.

OBJECTIVE

The objective of flotation thickening control is to concentrate the feed sludge to as high a concentration as practical with the minimum of chemical feeds. In addition, maximum capture of solids is desirable to minimize the effect of returning solids to the head of the plant.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

The material being delivered to the flotation thickener units varies in composition as well as quantity. Hence the major process loads are hydraulic and solids application rates. The process is very flow sensitive and rapid changes in loadings cause inconsistencies in performance. The characteristics of the WAS and the associated need for polymer is usually based on manually implemented rise tests and the requirements may change more rapidly than can be detected by these tests.

Process Characteristics

The primary operating variables for flotation thickening are: recycle pressure, recycle ratio (flow), feed solids concentration, detention time, air/solids ratio and use of chemical aids. the process typically has three control degrees of freedom; polymer dosage, recycle rate and thickening time. The relationship between solids concentration and control settings are difficult to determine and cause the process control system to require labor intensive observation.

The long time lags of the process makes understanding of interactions difficult. Cause and effect relationships are not typically known in the field. Measurement of overflow and thickened sludge solids may be done with optical instruments. These instruments are, however, not often applied due to the frequent maintenance required.

CONTROL STRATEGY

Field observations indicate that the typical control strategy is frequently implemented manually. Refer to Figure 3-22 in the following discussion. The flow is distributed to on-line operating units (equally or unequally, depending on the thickener performance) by the operator. Overall (system) hydraulic changes are made slowly and infrequently. Solids loadings are calculated frequently and rise tests performed. These results lead to adjustment in polymer dose and/or recycle ratio. Also observations of the blanket thickness lead to changes in frequency and duration of collector operation. Smaller, rectangular flotation thickeners typically collect continuously (bottom and top).

Typically:

1. Feed flow is distributed (controlled to operating units).

2. Polymer dose is controlled by a ratio to mass flow or a ratio to flow.

3. Recycle flow is ratioed to feed flow.

4. Air flow is ratioed to recycle flow.

5. Blanket formation observations (rise tests) control need for adjusting above ratios.

The controlled variable for the process is thickened sludge concentration and secondarily, capture efficiency. Manipulated variables are polymer dosage, WAS flow to each unit, recycle flow and thickening time. Measured variables can include influent suspended solids and air flow. Suspended solids measurements on the floated sludge and the subnatant are becoming more prevalent with improvements in instrument reliability and maintenance

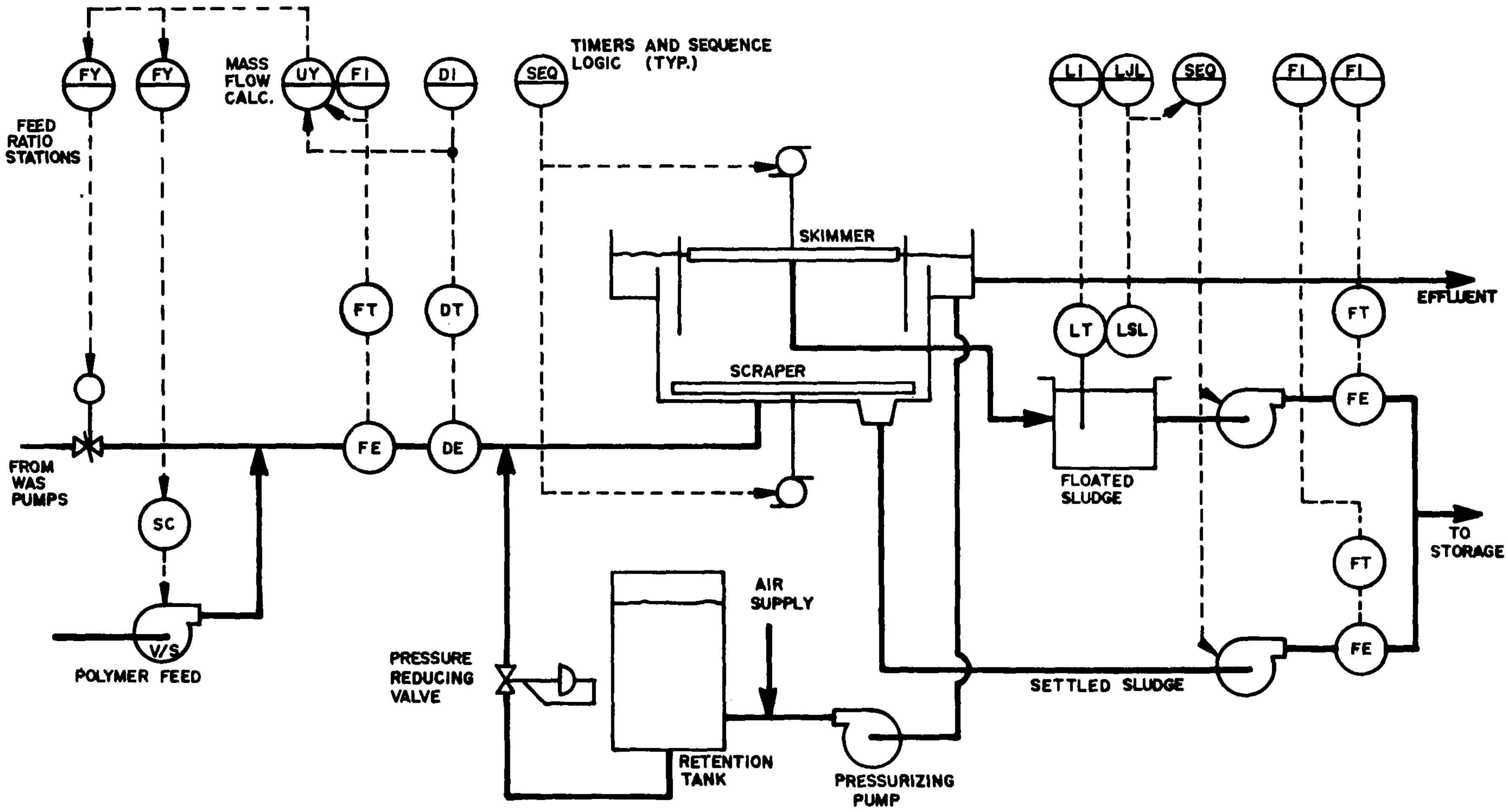


Figure 3-22. Flotation thickening control.

requirements. Implementation of a consistent control strategy is constrained by limited understanding of the process dynamics and the multitude of variables affecting it.

Thickener startup sequencing is usually carried out manually from gallery panels. The requirement for unit startup or shutdown is usually based on sustained changes in solids loading. Sludge is often allowed to remain in idle thickener for up to 48 hours if restart is anticipated within this time.

OTHER CONSIDERATIONS

Laboratory analysis for capture efficiency on each thickener is often used to make adjustments in control strategy and as a check on sensors. During sludge blanket rise tests, the operator observes clarity of subnatant and thickness of blanket which will also be factored into the strategy. Modified jar tests are also performed occasionally to determine optimum polymer dose. Odors and color of floated sludge are also observed.

INSTRUMENTATION UTILIZED

Instrumentation and control devices observed are as follows:

Sensors

1. Suspended solids - optical sensor located on influent and occasionally, on subnatant and thickened sludge.

2. Flow measurements - magmeters on influent, recycle and thickened sludge pump discharge lines; orifice for air flow and occasionally recycle flow.

3. Level transmitter - bubbler type located in sludge box.

On/Off Control Devices

1. Floated sludge collector mechanism (typically on timer).

2. Sludge pumps.

3. Air compressor.

4. Polymer metering pumps.

Controlling Devices

1. Ratio station for polymer feed.

2. Flow indicating controller for influent flow.

3. Ratio station - may be used for influent flow control, recycle control and polymer.

4. Timers and sequence controls.

Typical Annunciator Alarms

1. "No flow" output from magmeter transmitter.

2. High torque on collector mechanism.

3. Low recycle pressure.

4. High/low level in floated sludge sump.

VARIATION IN STRATEGY WITH PLANT SIZE

Control strategy remains consistent, regardless of plant size. Smaller plants have one or two units and do not require flow distribution controls. In larger plants, the number of process units dictates more process control either automatically or manually implemented.

EXPECTED PERFORMANCE

The Denver Metro plant and others have shown that desired thickened sludge concentrations can be met 96% of the time through close control of hydraulics, mass flow polymer pacing and control of thickening time based on sludge blanket rise tests.

ANAEROBIC DIGESTION

INTRODUCTION

In this process, the organic matter in the sludge is biologically stabilized in the absence of oxygen. Anaerobic digesters may be "low rate" or "high rate." For the purposes of this report, high rate will be addressed. Both single and two stage systems are utilized, depending on the nature of the material to be digested.

Modern systems are "high rate" systems utilizing one or two stages. The sludge stabilizes in the first stage, while the second stage provides settling and thickening. In a single-stage system, the secondary digester is replaced by some other thickening process. The digester is heated to 85 to 95°F and usually provides 10 to 20 days detention of the sludge.

The process has been successful when fed primary sludge or combinations of primary sludge and secondary sludge. The larger the fraction of secondary sludge, the lower the inherent dewaterability of the digested product.

The process converts about 40 to 70 percent of the organic solids to gas (depending on the biodegradability of the sludge) reducing the amount of solids to be disposed. About two-thirds of the gas produced in the process is methane. Anaerobic digester gas is frequently used as a fuel for heating digesters and buildings and for engines that drive pumps, air blowers and electrical generators.

OBJECTIVE

The primary goal in anaerobic sludge digestion is to stabilize the sludge so that it is easy to dewater and can be economically and aesthetically disposed of with minimal public health hazards. Secondary objectives include recovering the fuel generated and reducing the weight and/or volume of sludge to be dewatered.

FACTORS AFFECTING PERFORMANCE

Load Characteristics

The anaerobic process is mostly controlled by the substrate removal kinetics of the methane-forming bacteria. These bacteria grow slowly and have long generation times compared to those of aerobic or facultative bacteria. Thus, long retention times (SRT) are required in the reactor. Methane formers are very sensitive to the presence of oxidizing agents; pH, sludge composition and temperature. If the pH drops below 6.5, methane formation is severely retarded and the organics in the sludge are not stabilized. Temperature changes of as little as $\pm 5^{o}F$ will produce process upsets. Although detention times are long, the digester charging procedure should be carefully designed so large batches are not imposed each time a digester is charged. Composition changes, both in terms of organic makeup and density, lead to problems with operation. Realizing that these loads are generated from liquid train unit processes, the loads are unpredictable and often highly varying. Where industrial wastes are a substantial contributor, toxic components (i.e. heavy metals) impose an additional disturbance on the process.

Process Characteristics

Anaerobic sludge digestion progresses in two stages. First facultative anaerobic bacteria, called acid-forming bacteria, convert the complex organic material in the sludge to simple organic material, primarily organic acids. Some carbon dioxide is formed and some stabilization occurs during the first step. Second, the organic acids are converted to carbon dioxide and methane by anaerobic bacteria called methane-forming bacteria. Most of the sludge stabilization occurs in this step as the organics are converted into gas, water and a limited quantity of biological mass. A small amount of hydrogen sulfide may also be produced. The acid formers respond much more quickly to environmental and process changes than the methane bacteria. This often leads to pH upsets due to an imbalance between acid production and acid conversion to methane.

The process is primarily characterized, controlled and sensitive to the following variables:

1. Food supply (organic content, physical composition, density).

2. Hydraulic feed rate.

3. Time.

4. Temperature.

5. pH.

6. Mixing (homogenous environment).

Because of the slow growth of the methane bacteria, the process is dominated by a very long lag time. This necessitates careful control and monitoring of intermediate variables in order to recognize and react to upset conditions.

The process environment is such that measurement of any process parameter is difficult. Sampling for laboratory analysis of process variables is also difficult because of the large volumes involved in the unit process equipment.

CONTROL STRATEGY

In order to achieve the objectives of the process, the control strategy must address each of the following variables from a monitoring and control standpoint (refer to the process P&ID in Figure 3-23).

Food Supply

Organisms in the primary digesters are most efficient when sludge is furnished in small quantities at frequent intervals. If too much sludge is added to the digesters in a short time, the acid-forming step may be predominant. This will cause the volatile acids to increase and the pH to decrease, which is an unfavorable environment for the gas-forming step. Foaming may also occur. Incomplete digestion with accompanying odors will result from the lack of balance between the two steps. Thus, primary digester influent sludge should be pumped as continuously and consistently as possible over 24 hours; however, care must be exercised not to pump sludge which is too thin, to make sure that detention time guidelines (below) are not violated. Successful control systems observed in the field are designed to split the mass of incoming sludge as equally as possible between on-line digesters.

Detention Time

The design digester detention time typically is 15 to 20 days. The actual detention time can be calculated by knowing the quantity of sludge pumped to the digesters and the digester volume. A chart should be prepared to show the detention time with various influent sludge flow rates. Digesters should not be operated with a detention time of less than 10 days over an extended period, as the system tends to become biologically unstable under these conditions. Detention times longer than 25 days insure stability but may not be economically justifiable.

Temperature

Effective mixing of incoming sludge with the contents of the digester is necessary to provide the organisms with their essential food supply and to maintain a uniform temperature throughout the primary digesters. The primary digester temperature should be maintained within $\pm$ 5°F of the selected temperature. The temperature setpoint should be between 90 and 100°F for optimum operation. The control strategies observed showed that digester temperatures could be maintained within 5°F of setpoint.

pH

Anaerobic digestion can proceed efficiently with pH levels from about 6.6 to 7.4; however, the optimum range is from 6.8 to 7.2. Outside these limits, digestion efficiency decreases rapidly. The pH level in all systems is set by the bicarbonate buffer system. Since volatile acids titrate as alkalinity, volatile acid determinations are required to determine the actual bicarbonate alkalinity level. The bicarbonate alkalinity should

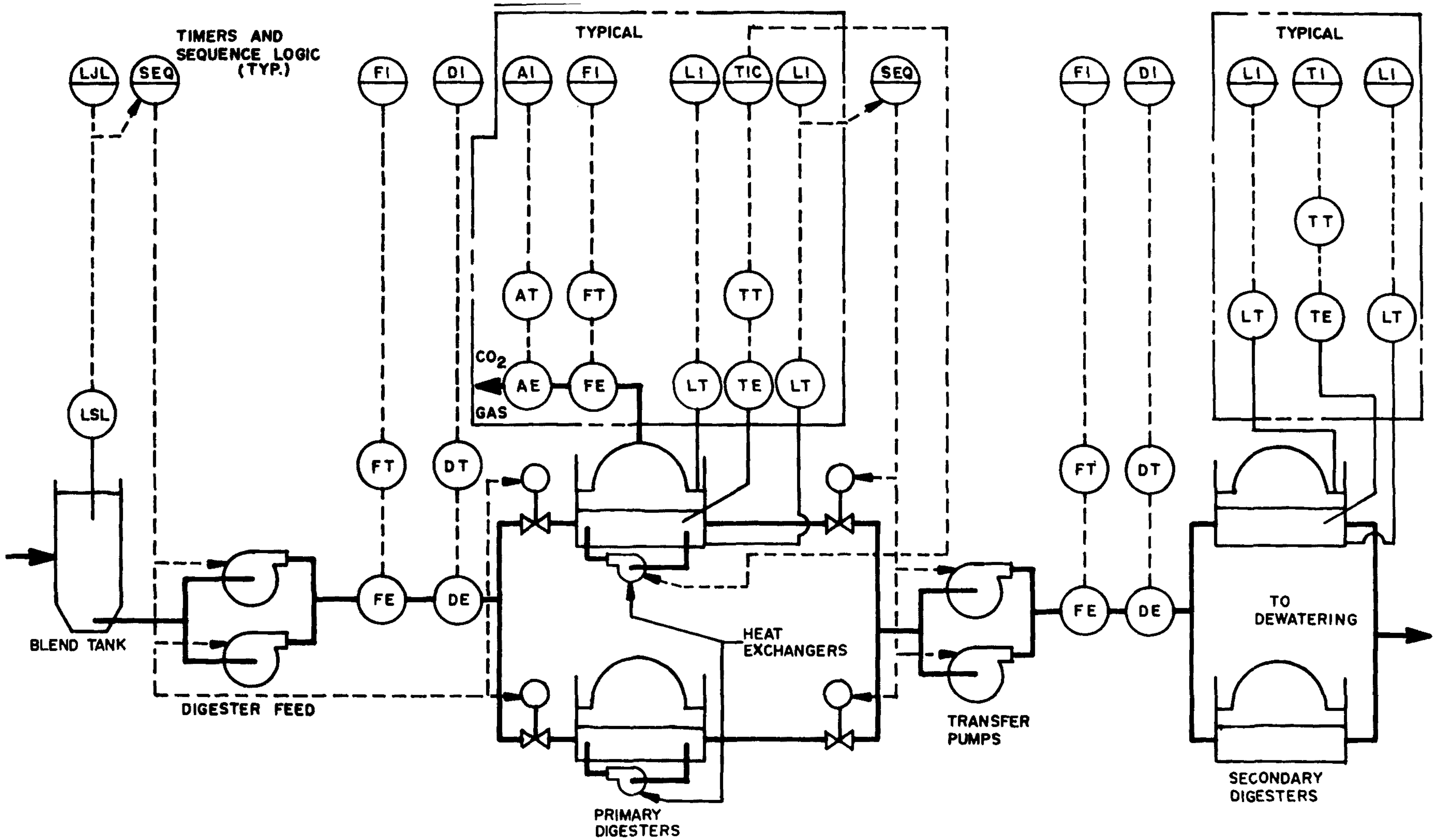


Figure 3-23. Digester control.

always exceed the volatile acids by at least 1,000 to 2,000 mg/l. Control strategies typically do not include pH adjustment although most all plants required adjustment periodically. If pH adjustment is employed, sodium bicarbonate or sodium carbonate should be used in preference to lime. The sodium salts are easily soluble so distribution in the digester is not a problem. Lime is difficult to dissolve and distribute in the digestion liquor.

Mixing

Proper mixing of the digesters is essential to ensure the raw sludge and heat is evenly distributed throughout the digester. Mixing also decreases the chances of a scum layer buildup. Most control strategies observed included provision for automatic gas mixing and some also included provision for concentrating the gas mixing in certain areas within the digester via rotary valves. Mechanical mixing is also successfully used.

Gas Production

The efficiency of the primary digesters is indicated by the volume and content of gas produced. Gas production from the primary digesters when 50 percent volatile solids destruction is being achieved has been found to vary between 12 and 18 sfm/lb volatiles destroyed. This usually produces a gas which is 65 to 50 percent methane. The control strategy should include daily calculations of gas yield and monitoring of gas content. The fraction of the gas which is methane is a function of the type of organic compounds fed to the digester. Carbohydrates yield a 50-50 CH_4 - CO_2 mixture. Fats always yield higher fractions of methane than carbon dioxide with the methane increasing as the length of fully acid chain increases. Proteins also yield higher fractions of methane than carbon dioxide with methane yield determined by the number of amino groups and the length of the carbon chain. An increase in carbon dioxide content of the gas can mean an upset is in progress or it can indicate a change in sludge characteristics. When the carbon dioxide fraction is greater than 50%, it is a sure sign of trouble. Generally, all of the gas which will be produced from a charge of feed will occur within 24 hours of the charge. Thus a significant decrease in gas production can indicate trouble unless the feed volatile solids have also decreased.

Supernatant Flow

Supernatant withdrawal and recycle must be considered in the control strategy, as the characteristics of the supernatant can overload the liquid treatment processes. It is best to return supernatant to other plant units at the time when it will have the least effect. Usually, it is best to do this when the raw wastewater flow to the plant is at its daily minimum; it is not good practice to add the supernatant load during peak flows. Inadequate digestion can result in poor quality supernatant which can lower overall plant performance when recycled. In systems where the digester is vigorously mixed at all times, anaerobic digestion yields no supernatant, rather the supernatant results from subsequent dewatering steps.

OTHER CONSIDERATIONS

In the digestion process, operator observations and laboratory data are extremely important. Volatile acids and alkalinity analysis should be performed every shift. Loads are calculated, cover and liquid level are observed to program digester feeding. The process is very .abor intensive with heavy operator involvement. Calculation of the methane production per unit of volatile solids charged is very indicative of system performance. Laboratory monitoring of pH, volatile acids, bicarbonate alkalinity and total alkalinity are neccessary to truly know the health of the digester. Volatile acid/total alkalinity ratios of less than 0.5 yield good operating results based on our field observations, provided alkalinity is in the range 1,500 to 5,000 mg/l.

INSTRUMENTATION UTILIZED

Sensors

1. Sludge flow - heated tube and ultrasonically cleaned mag meters.
2. Density - typically nuclear, optical is becoming more usable.
3. Temperature - resistance bulb in a thermal well.
4. Cover level - electromechanical devices.
5. Liquid level - flange mounted diaphragm sensor.
6. Gas flow - turbine or displacement meter.
7. Gas composition - (optional).
8. Lower explosive limit detectors.

Modulating Control Devices

1. Variable speed pumps - occasionally used.
2. Two speed or variable speed recirculation pumps.

On/Off Control Devices

1. All pump motors.
2. Valves.
3. Gas compressors.

Controlling Devices

1. Temperature controllers.

2. Sequence programmers.

Annunciator Alarms

1. Blending tank level.

2. Cover level - high and low.

3. Liquid level - high and low.

4. Temperature - high and low.

5. Recirculation compressor failure.

6. Heat exchanger recirculator pump failure.

7. All pump failures.

8. Valve failures.

9. Transfer pump high pressure.

10. Digester mixer (compressor) alarms.

11. Digester gas pressure.

12. Explosive limit alarms.

VARIATION IN STRATEGY WITH PLANT SIZE

Field observations indicate that small plants (less than 5 mgd, 220 dm^3/s) typically utilize single-stage digestion with drying beds. Use of instrumentation is minimal and operation of the digesters is sporadic. Performance is predictably inconsistent. Operation could be significantly improved with some manual measurements of volatile acids two or three times per week. Sludge pumping should not be conducted continuously at these plants unless it is monitored in some way.

For the intermediate sized plants (5 to 50 mgd, 220 to 2200 dm3/s) two-stage or single-stage operation is likely to be found with a relatively high use of instrumentation. The documented control strategy was observed (fully automated) in several plants. Use of on-line gas composition analyzers was not prevalent because normal laboratory techniques could be used for the moderate number of digesters involved.

For the larger plants (100 mgd, 4400 dm3/s, and larger) the number of digesters increased rapidly. Individual digesters are controlled as above, but the overall set of digesters needs inventory control. The sequence logic becomes complex and the inventory control strategy is more frequently manually implemented. More on-line use of gas composition is observed because of the number of digesters to monitor. The City of Philadelphia uses a strategy of inventory management.

EXPECTED PERFORMANCE

Anaerobic sludge digestion normally proceeds with minimum trouble if instrumented and controlled properly. Field observations indicate, however, that performance is highly variable in terms of frequency of digester failures, yield of gas (quantity), yield of gas quality and percent volatiles destroyed. A well operated digester can convert 50 percent of the organic solids to water and gas, can yield a gas mixture which is up to 65 percent methane having a heat value of up to 600 BTU/scf and can produce approximately 18 scf of this gas for every pound of volatile matter destroyed. Field results, however, show the following range of performance:

30 to 50 percent organics converted

45 to 65 percent methane in gas

400 to 600 BTU/scf

12 to 18 scf/lb volatiles destroyed

These variations could be due to improper operation or due to characteristics of the feed. A digester may produce a digested sludge (low in volatile acids, having a tarry odor, a humis-like consistency, and draining readily) while operating consistently on the low side of these ranges. This may indicate room for improvement or that the sludge being treated is high in nonbiodegradable organics.

VACUUM FILTRATION

INTRODUCTION

Vacuum filtration is the predominant method of mechanical sludge dewatering. Vacuum filters are made by several manufacturers with a variety of filter media available. All filters operate on basically the same principle and are similar, therefore they will not be differentiated in this section.

Filtrate from the process, which is very high in organics, is returned to the head of the plant. If vacuum filtration is followed by incineration, variability of cake moisture content can seriously affect the performance and fuel efficiency of the incineration units.

The operation of a filter is relatively unstable due to the large number of process variables. Typically holding tanks are sized such that there is little buffering capacity to handle the wide variability of feed. In addition, field observations indicate the process is very labor intensive and requires constant operator adjustment.

OBJECTIVE

The primary objective of vacuum filtration is to produce a consistently dry sludge cake while maintaining high production (yield) and economical use of chemicals. Field observations indicate that most filters are controlled based on yield with only secondary attention paid to solids content and solids capture.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

Vacuum filters are one of the last elements in the treatment process and as a result are subject to the loads imposed by all other elements of the process. Field observations indicate that the material normally dewatered by a vacuum filter is a mixed sludge. The composition of that sludge is highly variable between primary and waste activated. In addition, varying quantities of septic sludge and scum make the composition that much more unpredictable. The sludge age also changes the dewaterability characteristics. Chemical dose must be varied to compensate for variations in sludge filterability characteristics. The relationship between required chemical dose and characteristics of the feed is variable and not well understood. Poor understanding of the chemical interactions often leads to improper doses of chemicals and a reluctance to attempt optimization.

Process Characteristics

The vacuum filtration process is very complex due to the number of process variables (see Figure 3-24). The variables involved are:

1. Vat level.
2. Chemical dose (lime, ferric, polymer).
3. Feed rate.
4. Chemical - sludge mixer speed.
5. Drum speed.
6. Vacuum applied.
7. Vat agitator speed.

Vat level is very important in process performance and is a difficult parameter to control. The time lag between pump response and liquid delivery coupled with erratic waves caused by the vat agitator makes maintenance of a constant level difficult. The other process variables are very interactive and difficult to relate. The vat level is generally related to feed rate, vacuum applied and drum speed although the chemical conditioning must be correct so that the mat is formed in the cake. Effectiveness of chemical conditioning is dependent on pH, sludge age, mixing and filterability of raw mixture. Thickness of the cake varies with several of the parameters and yield changes dramatically with several parameters also. Field observations show that solids capture, yield and cake solids content all can and usually do vary dramatically during the day. Measurement of sludge parameters are difficult due to the nature of the material. Control devices are typically adequate to properly control the process.

CONTROL STRATEGY

Vat level is maintained by controlling sludge feed flow in a cascaded manner. Ferric dose is typically ratioed either to mass flow or volume flow. Lime is proportioned to ferric. Mixer and drum speed manual adjustments are infrequently performed. The mixer speed is typically not adjusted because the control relationship is not clear. Drum speed is not frequently adjusted because it affects the operation dramatically.

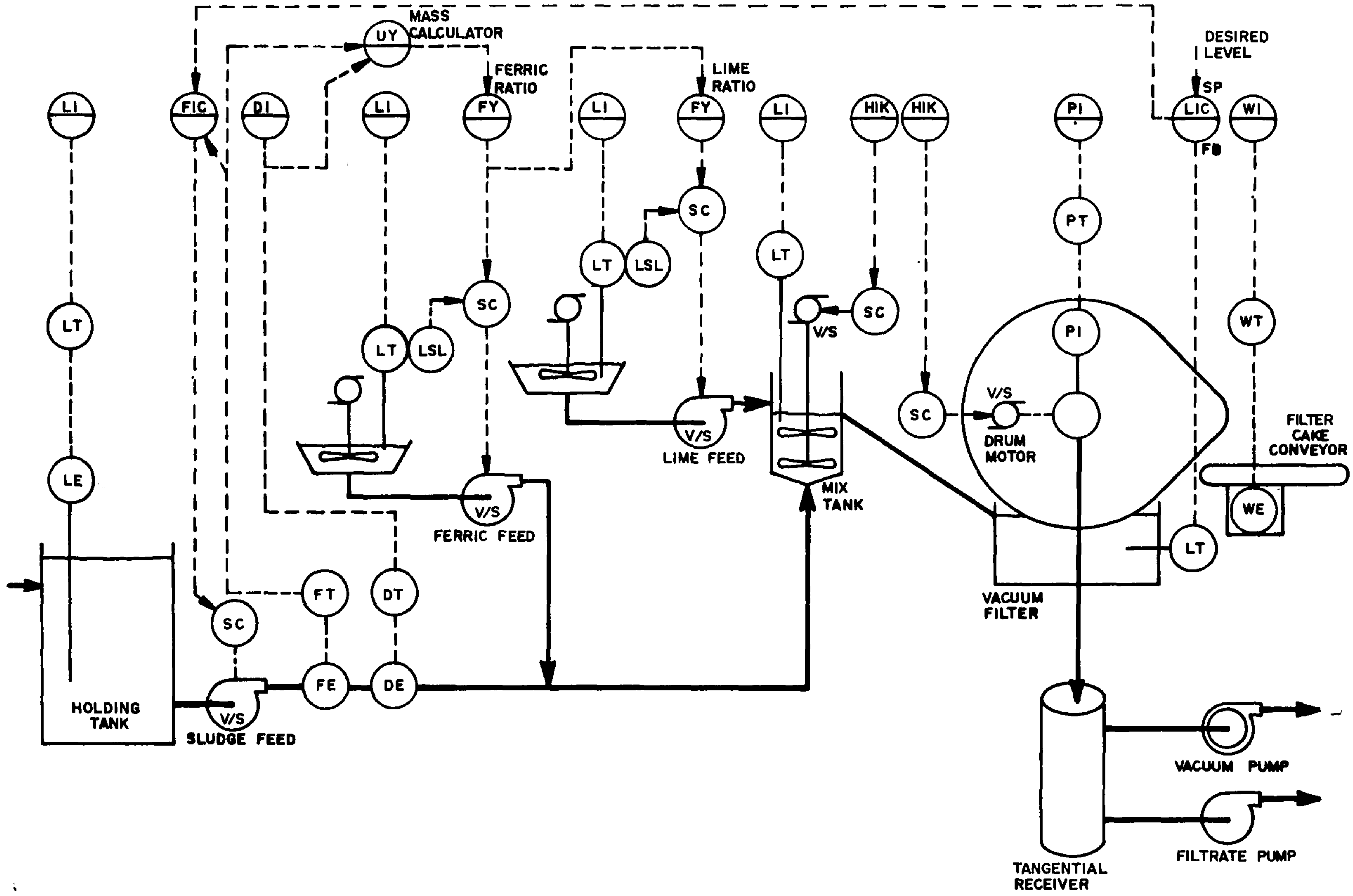


Figure 3-24. Vacuum filter control.

The primary controlled variables are total yield and cake moisture content. A secondary controlled variable is solids capture, although in the field only little concern is paid to this. The manipulated variables are feed solids flow, chemical feed, mixer speed, drum speed and vat level. Measured variables are the cake moisture content (lab), production rate, chemicals added, vacuum pressure, drum speed and feed flow.

Field observations show that consistent performance of a vacuum filter is constrained by the number of variables and their interactions. Yield can be measured but not the true yield--dry solids. Because of variable loads even the level is difficult to control in the field. Overflows are common. A filterability index which is easy to measure and use is needed for chemical feed control. This process is run in a crisis mode in the field.

Control of process startup and shutdown is typically manual. Drum drive speed is manually set based on desired yield of cake. Chemical doses are ratioed to flow based on Buchner funnel or filterability measurements performed in the laboratory.

OTHER CONSIDERATIONS

Operator input is crucial to performance due to the complexity of the process. Without the existence of a measurable filterability index, operators must be able to recognize changes in sludge and cake composition and tune the process accordingly. Chemical addition rates and vacuum level must be observed frequently to insure process stability. Lab tests and loading calculations must be performed every shift. Yield, cake solids content and solids capture must be the main concerns of the operator. In the real world, however, the operator's main concern is to maintain a uniform sludge cake discharge from the drum.

INSTRUMENTATION UTILIZED

Sensors

1. Level - bubbler or flange mounted diaphragm, used in holding tank and vat.

2. Feed flow - ultrasonically cleaned, heated tube magnetic flow meter.

3. Sludge density - optical or nuclear devices.

4. Weight - strain guage type on cake conveyor belt.

5. Tachometer for drum speed and metering pump speeds.

Modulating Control Devices

1. Feed pumps.

2. Chemical metering pumps.

3. Drum drive.

4. Mixer drive.

<u>On/Off Control Devices</u>

1. Vacuum valve.

2. Filtrate pump.

3. Vacuum pump.

4. Vat drain valve.

<u>Controlling Devices</u>

1. Ratio station for chemical feeds.

2. Level controller.

3. Flow controller.

4. Manual loading stations for drum speed, mixer, agitator.

<u>Annunciator Alarms</u>

1. Excess weight.

2. Low and high levels in holding tank, mixing tank and vat.

3. No flow in feed pumps.

4. Vacuum failure.

5. Zero speed on drum and pumps.

VARIATION IN STRATEGY WITH PLANT SIZE

Plants smaller than 1 mgd (44 dm^3/s) seldom use vacuum filters. In moderate sized plants (5 to 50 mgd, 220 to 2200 dm^3/s), the control scheme shown in Figure 3-24 can be considered typical and successful. Level control is occasionally manually implemented. Large plants employing numerous units are often reluctant to apply instrumentation due to process complexity. Inventory control and hydraulic distribution of sludge to on-line units become more important in the overall strategy.

EXPECTED PERFORMANCE

Consistency and repeatability are typically not observed in the field due to the difficulties in process control implementation. Product diurnal moisture content variations of over 20% were observed in a typical day at several treatment plants. The large constraints on controlling variables should be improved with better process understanding and maintenance schedules. The process is very labor intensive and expensive to operate.

CENTRIFUGATION

INTRODUCTION

The theory of the centrifugation process is well understood and has been applied very successfully in industry and wastewater treatment plants. Lack of a good fiber content or mat in wastewater sludges has discouraged centrifuge use in the past. With improved equipment and polymer addition, the use of centrifugation as a dewatering tool has been increasing in recent years. Disk and bowl type centrifuges are utilized with the bowl type used most often for sludge dewatering. Control of the units is usually provided by the manufacturer with provisions for manual startup and shutdown sequences. The necessity of costly polymer addition at most installations provides incentive for the use of a more careful control strategy.

The centrifugation process is typically used in the middle of the solids treatment train and typically is followed by incineration. If centrifugation is preceded by digestion, the capacity of the digester enables inventory to be programmed. Centrate from the process may present a significant load on the head of the plant as the centrate solids observed in the field are often over 1000 mg/l.

Centrifugation is a physical process with only two important process variables and should be stable if the load is stable. The process is controlled by two modulating devices which require adjustment to produce a stable product.

OBJECTIVE

The goal of centrifugation is to produce as dry a cake as possible and maximize the efficiency of solids capture. These two goals are in opposition to some extent as, field observations show, an increase in efficiency will decrease cake solids content. In most instances the costs associated with improved cake dryness outweigh the benefits gained by greater capture efficiency, although an acceptable tradeoff between the two must sometimes be made.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

Load to the centrifuge is determined by the upstream processes. In the field, pumping rates to the centrifuges are set daily based on the inventory to be processed. Dewatering characteristics of the sludge tend to vary depending on its origin and makeup. If the centrifuge follows heat treatment, the sludge load and consistency can vary considerably; but if digestion precedes, the sludge is more stable but much more difficult to dewater.

Field observations show that even if the feed rate is not changed very often, the sludge composition changes and this can impose a large disturbance on the centrifuge process performance. If the feed rate is highly variable, the load disturbances are more dramatic.

Process Characteristics

Field observations show that centrifugation is a predictable and reliable process when the sludge feed concentration is stable. The variability of the dewatered cake is reduced and the cake failures are less frequent than with vacuum filtration. The bowl speed is typically set high enough to handle composition load disturbances. Occasionally the conveyor speed is inadequate and pool depth gets excessive. The process is dependent on the following variables:

1. Bowl speed.
2. Conveyor (collector speed).
3. Pool depth (residence time).
4. Polymer dose (mat formation within cake).

Centrifuges require a large amount of maintenance due to the high rotational speeds and the mechanical equipment used. Collection of concentrated sludge is efficient. Centrifuges usually require the use of polymer addition. Process measurements are difficult to obtain and may interfere with process operation. Balance between capture efficiency and cake dryness is sensitive and the poor resolution in the control devices make optimization difficult.

CONTROL STRATEGY

Field observations indicate that typically feed rates to the centrifuges are set based on the sludge volume produced in the upstream process. Bowl speed and conveyor speed are manually set based on the desired solids content of the cake (see Figure 3-25). Capture efficiency is typically not considered initially. Polymer dose is ratioed to the volumetric feed flow rate and adjusted as the sludge characteristics change. Polymer is used to increase capture efficiency and hence, as the centrate solids increase the polymer ratio is increased by the operator.

The primary controlled variables are production rate and cake dryness. Both variables usually are determined in the laboratory tests. The secondary controlled variable is capture efficiency which is usually calculated on a daily basis. On-line calculation of capture efficiency would require measurement of flow rate and solids levels at three locations on each

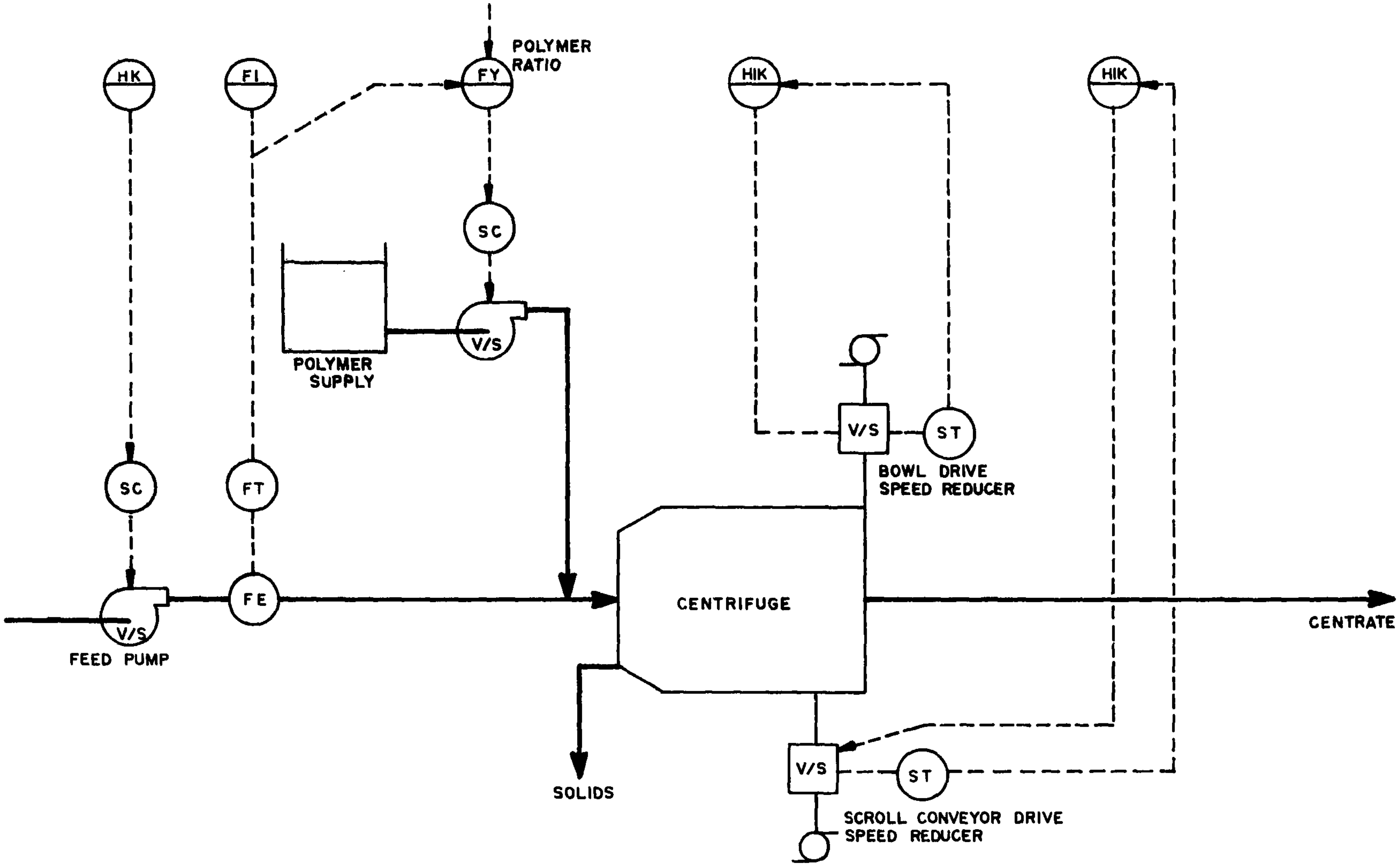


Figure 3-25. Centrifuge control.

centrifuge and hence typically is not done. Manipulated variables are the feed rate, polymer ratio, bowl speed and scroll speed. Measured variables are the flow and occasionally centrate suspended solids. Sludge solids content is usually determined in the lab.

Manual control adjustments typically utilize the following relationships:

1. Product (yield) is influenced by feed rate.

2. Solids content is influenced by bowl speed.

3. Capture efficiency is influenced by polymer dosage.

4. Pool depth (residence time) is influenced by conveyor speed.

OTHER CONSIDERATIONS

Centrifugation becomes very labor intensive when the consistency of feed sludge varies frequently. Operators will observe the centrate and perform solids analysis to aid in adjusting polymer controls. Pool depth or residence time is calculated from flow curves and used to adjust conveyor speeds. In some plants observed, the operator adjusts the polymer dose hourly based on a viscosity measurement of the feed sludge. Cake dryness, centrate suspended solids and solids capture are analyzed daily to check on instruments and process performance.

INSTRUMENTATION UTILIZED

The following instrumentation was observed to be in general use.

Sensors

1. Flow - mag meters, heated tube and ultrasonically cleaned.

2. Density - optical devices on feed.

3 Speeds - tachometer or SCR drive indicators (these were not always utilized).

4. Viscometer (not typical) on feed sludge.

Modulating Control Devices

1. Sludge feed pumps - variable speed, SCR drive.

2. Bowl speed - mechanically variable speed.

3. Scroll speed - mechanically variable speed.

4. Polymer metering pump - variable speed, SCR drive.

On/Off Control Devices

1. All motors.

Controlling Devices

1. Manual loading stations (on feed flow, bowl speed, conveyor speed).

2. Polymer pump ratio controller.

Annunciator Alarms

1. Drive "required/not running."

2. Bowl vibration.

3. Motor temperature.

VARIATIONS IN STRATEGY WITH PLANT SIZE

Plants with flows less than 1 mgd (44 dm^3/s) usually do not utilize centrifuges. Use of the control strategy discussed is typical in moderate size plants and the centrifuges are usually operated seven or eight hours per day. Many of the newer plants have been equipped with improved instrumentation for centrifuge control. Large plants may utilize many units and control of feed to each unit becomes more difficult. In the larger plants centrifuge operation is generally continuous on all shifts. As in other sludge handling processes, inventory control becomes important as both plant size and number of units on line increase.

EXPECTED PERFORMANCE

Field observations indicate that depending on the sludge to be dewatered, centrifuges can yield a 10 to 25 percent solids content cake. Solids recovery can be in the range of 80 to 95 percent with polymer. Diligent operation is needed, however, for consistent operation at the upper end of these ranges. This process typically requires a full time operator station if consistent performance is desired.

ROLL PRESS DEWATERING

INTRODUCTION

Roll presses have been used for years in the paper industry to dewater bleached pulp. The process is a combination of centrifugation and pressure filtration where two drums are rotated in a pressurized vat and a cake is formed between the two drums. One drum is movable and is positioned pneumatically to control the "press" function. There are a large number of control devices and controlled variables and the process and process interactions are complex. A good deal of the process tuning takes place in the field.

The roll press has the capability to form a very dry cake (30 to 40% solids) but must have a raw material with a high fiber content which is capable of forming a strong mat. Polymer can help to form this mat but field experience shows that if the fiber content of the raw sludge decreases, the polymer alone will not do the job.

This characteristic causes this process to have the potential of causing large disturbances in both the liquid and solids train. When the sludge cake fails, the moisture content of the product increases immediately. Sometimes the production stops completely. During this period the sludge is being forced into the rotating drum and returned to the head of the plant as pressate. The characteristics of this material approach the same characteristics as the raw material delivered to the unit during these times. Even under normal conditions, the pressate is a large load on the liquid train.

OBJECTIVE

The primary objective of this process is to produce the driest possible sludge cake in a consistent manner. Solids capture efficiency is not usually defined as an objective because typically the pressate contains an extremely high solids content. Typically the objective can only be met on a primary sludge which has substantial industrial inputs. Roll presses are not utilized on mixed sludges or waste activated sludge because the weakness of the floc making up these sludges makes it virtually impossible to retain a mat.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

Because the roll press is usually used to dewater primary sludge, the most dynamic load is volumetric sludge flow. Variations in sludge composition are less significant. The quantity of primary sludge generated during the day varies hourly. In addition, control strategies in primary treatment typically produce varying sludge concentrations which quickly destroy the fiber mat leading to process instability. The quality and quantity of the material fed to the roll press continuously imposes disturbances on the process and necessitates either intensive operational labor or automation.

Process Characteristics

The process itself has many process variables, many controlling devices and in addition, has a significant volumetric capacity (vat) which complicates the timing. The process requires a specific filterability characteristic (fiber content) which the polymer then magnifies. Without this characteristic, the process is difficult to operate. Each of the process variables is controlled by a different process measurement which causes any control strategy to be highly interactive, causing it to lean toward instability.

The use of on-line instrumentation is difficult due to the characteristics of the raw material. The required measurements of flow and solids must be maintained daily to assure operability. Key variables such as fiber content on flow material and solids content on end product cannot be measured on line but are determined in the laboratory.

CONTROL STRATEGY

A roll press is a highly instrumented process; however, even with the instrumentation, the process is labor intensive and requires a full time operator. The control strategy is illustrated in Figure 3-26.

Controlled variables are as follows:

1. Sludge feed flow.

2. Polymer feed.

3. Chemical mix tank mixer speed.

4. Vat pressure.

5. Roller speed.

6. Roller spacing (nip gap).

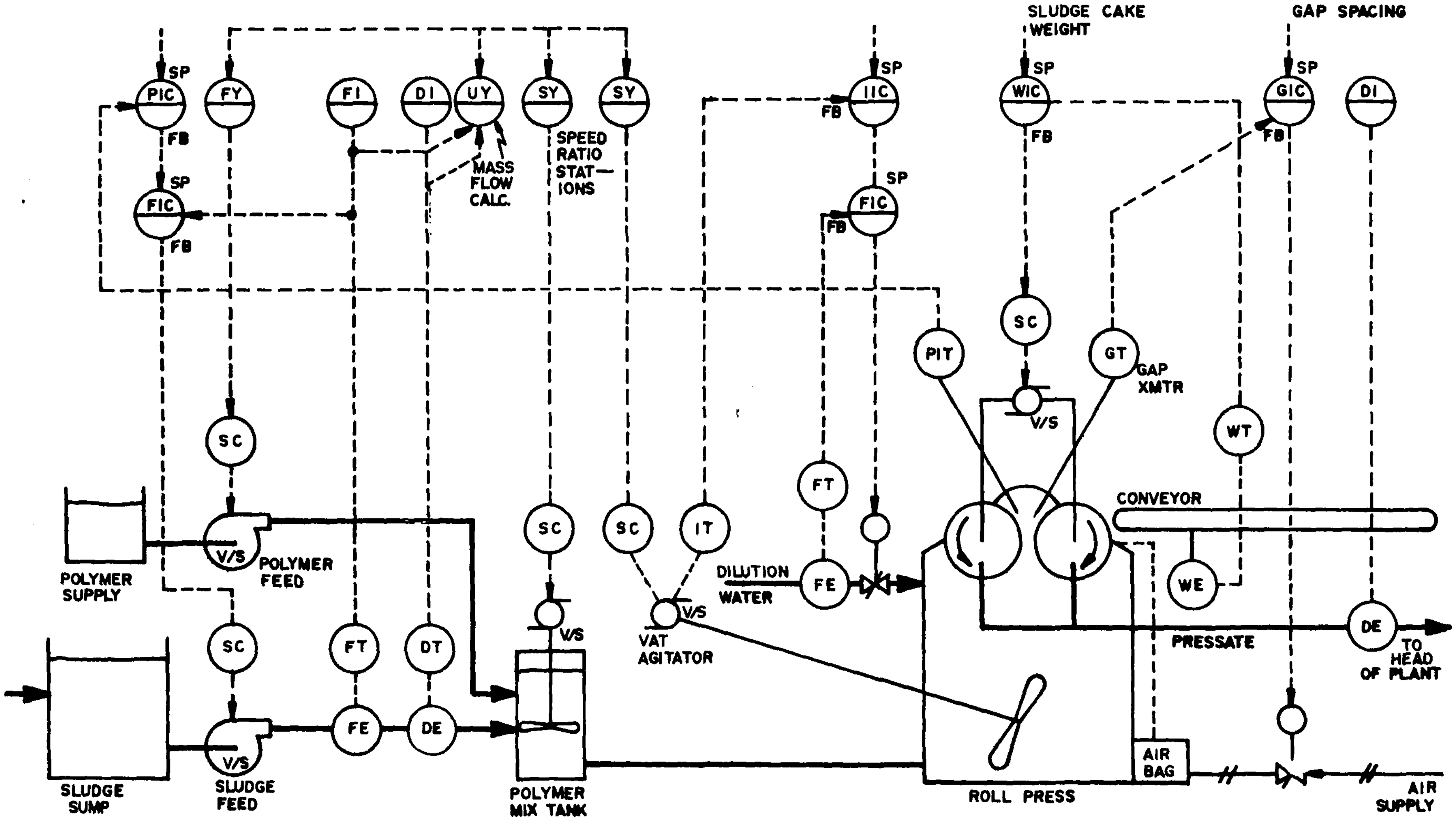


Figure 3-26. Roll press control.

7. Vat agitator speed.

8. Dilution water flow.

Additional variables which are typically measured include:

1. Pressate suspended solids.

2. Discharge cake weight.

The control strategy which is implemented in the field requires manual equipment startup and cake development. The formation of the initial mat is very important and must be done manually. Once a reasonable cake is produced, the control system is activated and the strategy is implemented automatically as follows:

1. A vat level controller setpoints a feed flow controller.

2. Roller speed is maintained at an operator setpoint based on cake production desired (open loop).

3. Polymer is ratioed to mass flow of the feed sludge.

4. Nip or roller spacing is controlled at an operator setpoint which is adjusted based on observed cake solids estimate. Operator observes pressate suspended solids and adjusts ratio up or down accordingly.

5. Dilution water controller is adjusted (setpoint determined) in a cascade fashion by an electrical current measurement on the vat mixer drive.

6. Speed of both the chemical conditioning mixer and the vat agitator mixer are controlled and the setpoint determined by the mass flow of feed solids.

OTHER CONSIDERATIONS

The system is labor intensive and full-time operator presence is required for multiple units. Care should be taken in setting roller speed and gap spacing to control sludge cake moisture content. Periodic observations should be made as well as lab tests on the sludge cake, filtrate, and raw sludge characteristics. Tests of filterability and jar tests for optimum polymer dose are typically performed weekly. Daily calculations of actual polymer dosage, suspended solids capture, and a solids material balance are performed.

INSTRUMENTATION UTILIZED

The types of instrumentation and control devices utilized in this application are as follows:

Sensors

1. Flow meters - mag meters with ultrasonic cleaning.
2. Density (suspended solids) analyzers - optical (feed sludge and pressate).
3. Pressure measurements - diaphragm force balance element and transmitter.
4. Gap measurement - position transducer.
5. Weight - strain gauge and transmitter.

Modulating Control Devices

1. Variable speed drives for pumps, tank mixers and press rollers.
2. Dilution water control valve.
3. Air control valve.
4. Polymer metering pump.

On/Off Control Devices

1. All drive motors.

Controlling Devices

1. Ratio stations (polymer, mixer speeds).
2. Multiplier/divider.
3. Controllers for flow, pressure, current, gap spacing and weight.

Alarms

1. Feed pump or flow.
2. Vat pressure.
3. Nip gap limit.
4. Roll press drive and vat agitator electrical current limits.
5. Weight limits exceeded.
6. Sludge sump level low.

VARIATION IN STRATEGY WITH PLANT SIZE

The strategy remains basically the same whenever this process is applied. Field observations indicate that the unit process has only been applied at larger treatment plants. Since the startup must be manual, there is no automatic sequencing between multiple units, even in the larger plants. Operator involvement during normal daily performance would be substantially increased if cascade and ratio control were changed to manual adjustment. This would be the case in application of the roll press in small treatment plants.

EXPECTED PERFORMANCE

The Metropolitan Waste Control Commission of Minneapolis-St. Paul has demonstrated that a roll press can operate with reasonable polymer dosages yielding a sludge cake of 30 to 35% solids as long as the raw sludge fiber content is high enough. The operation requires heavy labor intensity for monitoring with frequent controller adjustment. If the raw sludge to be dewatered varies greatly in consistency, the roll press performance relative to cake solids content and solids capture will be erratic.

PLATE PRESS DEWATERING

INTRODUCTION

Plate and frame press dewatering is a batch process which is utilized to dewater sludges to the driest state practically achievable. The process is utilized on difficult to dewater sludges or to provide a very dry sludge which can then be burned with little auxiliary fuel, or land filled economically. Polymer or other dewatering aids are commonly used.

Field observations show two types of plate and frame presses available. Both types are batch operations but one can be fully automated and one requires the presence of an operator for the plate separation and sludge removal steps.

Interviews with operators indicated that the labor intensity required with plate and frame presses is their biggest drawback. In addition, in the plate separation and sludge removal steps injury potential to the operator is high. For this reason, the fully automatic plate press will be described here although in the field the manual sludge separation method is prevalent. It is felt that fully automatic presses will dominate in the future.

OBJECTIVE

The specific goal of this process is to dewater sludge to produce a very dry sludge cake (as much as 40 to 50% solids). This sludge cake then is typically incinerated or disposed of on land (for comparison, vacuum filtration, a popular dewatering technique, produces a cake which is approximately 20% solids). Also, filtrate is much lower in suspended solids than from any other method.

Plate press operation interacts with both the solids and liquid trains. The degree of separation and concentration previously achieved in the solids train will affect the performance of the plate press. Incineration typically follows the plate press in the solids train and its performance is completely dependent on the dewatering process. The liquid train is usually less affected because of the pressate suspended solids content and volumetric amounts of the filtrate, since the filtrate is typically less than 100 mg/l suspended solids and the volumetric flows are not continuous.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

The load volume may change from day to day influencing the size and number of batch operations performed per day. The solids content of the load will affect the capture rate. The stability of the solids (in terms of ability to form a pressable cake) will affect the dewaterability.

Process Characteristics

The plate press process requires a sludge which forms a stable mat or else an auxiliary matting base is needed. In wastewater treatment processes, the sludge is typically treated either by heating or adding polymer to make the sludge more dewaterable.

The plate press is a physical process and, therefore, is inherently stable. The process itself is a batch operation. Each batch goes through a specific sequence--i.e. fill, press, remove pressed cake (repeat)- with significant dead time between filling cycles. Most sequence steps are timed.

CONTROL STRATEGY

The system consists of the plate press itself, sludge feed pump, pressurized water pump for dewatering (pressing) the sludge, cloth washing pump for cleaning plate cloths and air compressor and vacuum pump for clearing the lines (see Figure 3-27).

Due to the plate press batch having a sequential mode of operation, it is very compatible with automation. Operator assistance is requested when needed and the automated sequence involved in running presses is as follows. The initial step assumes the plates are open and clean.

1. Filter press feed pump sequence
   The filter plates are closed and the feed pump turned on with feed valve open. The pump is run until a timer times out, a high pressure is reached or the feed sump level is low.

2. Pressurizing pump sequence
   Once the press is filled with sludge, it is pressurized and squeezed through the filter cloth at greater than 200 psi pressures. This is based on time.

3. Core blow with water sequence
   The pressurization cycle is followed by cleaning out the core of pressate liquor with water. This usually lasts 15 seconds.

4. Core blow with air sequence
   Once the pressate is forced out, air is blown in to devoid the chamber of all liquid.

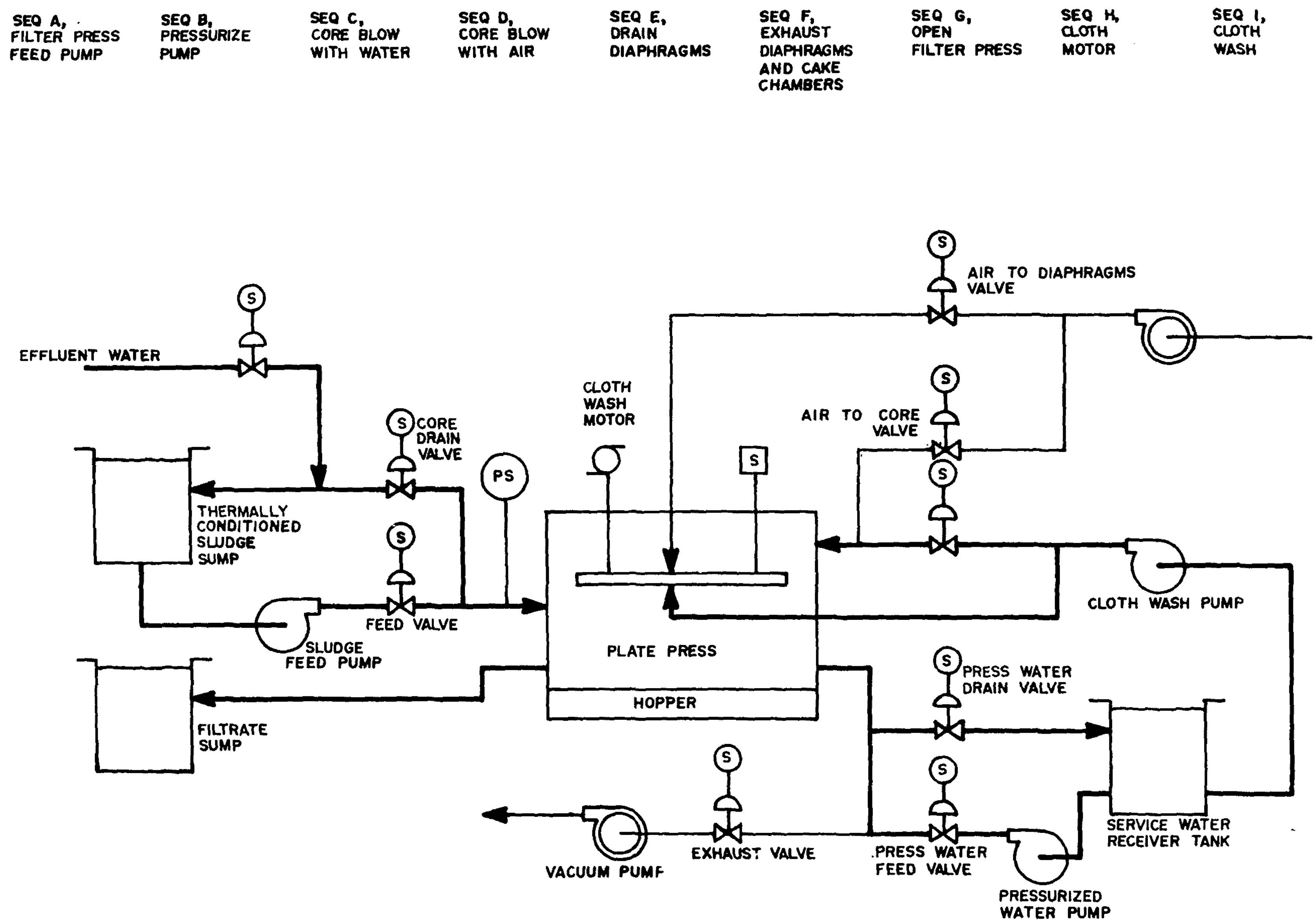


Figure 3-27. Plate press process diagram.

5. Draining diaphragms sequence
   With air in core, the diaphragms are drained by blowing air in sequence. This takes usually a few minutes.

6. Exhausting diaphragms and cake chambers sequence
   A vacuum pump is started to draw out all exhausted pressate to sump. This takes a variable time depending on the sludge dewaterability.

7. Open filter press sequence
   Once the diaphragms are evacuated, the plates are opened by hydraulic pump and valves.

8. Cloth motor sequence
   The cloth motor is started and moves the filter cloth down and releases cake. After a time, the cloth is moved back up.

9. Cloth wash sequence
   The cloth is now spray cleaned. The wash pump is started and the cloth is moved down again through the spray. Only 20% of the cloths are washed per cycle. A 50 gpm supply (per press) of service water is required to sustain a wash cycle.

This completes one plate press cycle. The plates are open and the unit is clean. A total cycle for a completely automatic press has a substantially reduced total cycle time compared to the standard two to four hours for conventional plate and frame presses.

For plate presses the primary controlled variable is the daily throughput and the secondary controlled variable is the percent solids in the sludge cake (moisture content). This is difficult to control since the process is a batch operation. The manipulated variables are batch time and pressure for operation. Additional measured variables are pressure, time (for sequence steps) and inventory conditions (e.g. sump level).

Constraints on the system include the requirement that the sludge be dewaterable (i.e. capable of forming a cake). Also for any sequence to operate requires that the previous process must be operating.

The required volume of sludge to be treated per day determines the number of batches. This is actually controlled by the time of a batch. The solids content of the discharge cake is controlled by the water operating pressure. The startup of a sequence can either be controlled by the ending of the previous sequence or manually started.

The operator must calculate the number of batches required each day and then set the batch time. Also, at least daily, laboratory observations of filtrate suspended solids and cake moisture/suspended solids content should be made to determine press efficiency or need for polymer addition to promote better filterability. A daily solids balance is usually performed and the dewatered cake percent solids is determined so that performance can be assessed daily.

INSTRUMENTATION UTILIZED

Sensors

1. Level transmitters for feed and filtrate sumps.

2. Pressure transmitters and/or switches for pressurized water, cloth wash and sludge feed.

Modulating Control Devices

1. Typically if polymer is added, a control valve or variable speed drive is utilized and a set dose rate utilized.

On/Off Control Devices

1. Feed pumps.

2. All valves.

3. Air compressor.

4. Hydraulic pump motor for opening/closing filter press.

Controlling Devices

1. Sequence programmers.

2. Sequence interlocking logic.

Alarms

1. Equipment not in status required (e.g. valve closed, but required to be open).

2. Sump level either high or low.

3. Pressure feed either high or low.

4. Electrical lockouts if plates out of place.

VARIATION IN STRATEGY WITH PLANT SIZE

There is little variation in strategy with plant size, since each press operates independently. On small plants the sequence interlocks may be missing so an operator is needed. On larger plants with duplicate trains the degree of complexity of the control strategy is increased due to common service water, compressor and sumps, but typically each press has an individual feed pump (common backup pumps). The strategy is usually totally automatic up to the plate separation step.

EXPECTED PERFORMANCE

If the sludge is stable (filterable) excellent results (approximately 40% solids) can be expected with moderate polymer addition. However, if the sludge is varying in dewaterability, large polymer additions are required. Performance of a plate press with highly varying sludge feed (volume and quality) will be poor based on field observations.

INCINERATION

INTRODUCTION

This control strategy describes a general approach to incineration control. There are several manufacturers of incineration processes, each with a method of control unique to their respective equipment and philosophy of operation. However, the intent of this document is not to describe specific equipment but simply to point out a usable strategy.

Other methods of control are feasible and frequently used, depending on the manufacturer and the type of equipment supplied. However, for the purpose of this strategy, the following method was chosen as a representative and successful form of control.

OBJECTIVE

The incineration process is a means of final disposal of sludge and scum. Combustion reduces the material to a sterile ash with approximately 10% of its original volume. Since a fuel supply in addition to the dewatered sludge (such as fuel oil or natural gas) is normally required, stable operation with minimal use of auxiliary fuel is the prime goal. Another benefit resulting from stable incinerator operation is lower maintenance costs, as thermal cycling speeds refractory breakdown.

FACTORS AFFECTING PROCESS PERFORMANCE

Process operation is affected by certain other process load changes and to a certain extent causes load changes in other processes.

Interaction of the incinerator with other processes centers mainly on its dependency upon upstream dewatering processes. Wet cake incineration dramatically changes the temperature of the upper hearths due to the additional water which must be driven off before combustion can occur. This not only places undo stress on the refractory of the affected hearths, but also increases the auxiliary fuel consumption and as a result, operating costs.

A byproduct of the incineration process is the offgas generated from the sludge combustion. To meet atmospheric emission requirements, the offgas is scrubbed by an impingement scrubber. This device uses effluent water to entrap the suspended particulates. The effluent water then flows to the head of the waste treatment plant, imposing a hydraulic load on the plant.

A control system designed to stabilize the incineration process is confronted by two problem areas: 1) The variation in sludge cake quality, as mentioned earlier, and 2) The large capacity of the incinerator itself, resulting in long delay times. The first will require an immediate response to maintain control. However, because of the capacity of the incinerator, the effect will be delayed.

Load Characteristics

Dewatered sludge quality consists of two dominant variables, percent moisture of the cake and fuel content of the solids. Each, if rapidly changed, will tend to disrupt process stability and performance. Wet cake will result in greater consumption of auxiliary fuel and lowering the burning zone which in turn will create a product which is not completely combusted and could lead to burning sludge in the incinerator cooling zone.

The fuel content of the sludge cake solids will also significantly affect the location of the burning zone. An increase in fuel content will raise the burning zone due to a lowering of the flash point resulting in combustion at a lower temperature. Low fuel content will require additional auxiliary fuel in order to maintain the location of the desired burning zone. Industrial waste dumps may change the fuel content. Industry shut-downs for weekends, holidays, etc. will contribute to complexity of this control strategy by causing significant changes in the sludge volatility.

Delivery of the sludge cake material is typically rather sporadic due to the manner in which cake is discharged from the vacuum filter. This will also affect process performance to a degree and make control more difficult.

Process Characteristics

The heart of this process is combustion which in itself is a complex phenomenon. In the case of waste sludge incineration, it is further complicated by a lack of knowledge of the fuel content or moisture content of the incoming sludge on a real-time basis. These measurements are not available to the control system. Therefore, feedback control is generally the method used. Due to the large capacity of incinerators, long time constants are the norm where temperature control is involved, making proper tuning of feedback control loops difficult to achieve. Figures 3-28 and 3-29 illustrate the control and instrumentation applied.

Not all aspects of the incineration process are sufficiently understood to allow completely automatic control. As an example, the incinerator temperature profile is typically controlled by modulation of the rabble arm drive speed, the idea being that the speed with which the sludge moves through the furnace will dictate in which hearth combustion will occur. The middle hearth is generally the most desirable location.

Should the upper hearth temperature be high enough to indicate that combustion is taking place, the rabble arm drive speed is increased in order to move the burning sludge to the middle hearths. However, increasing the

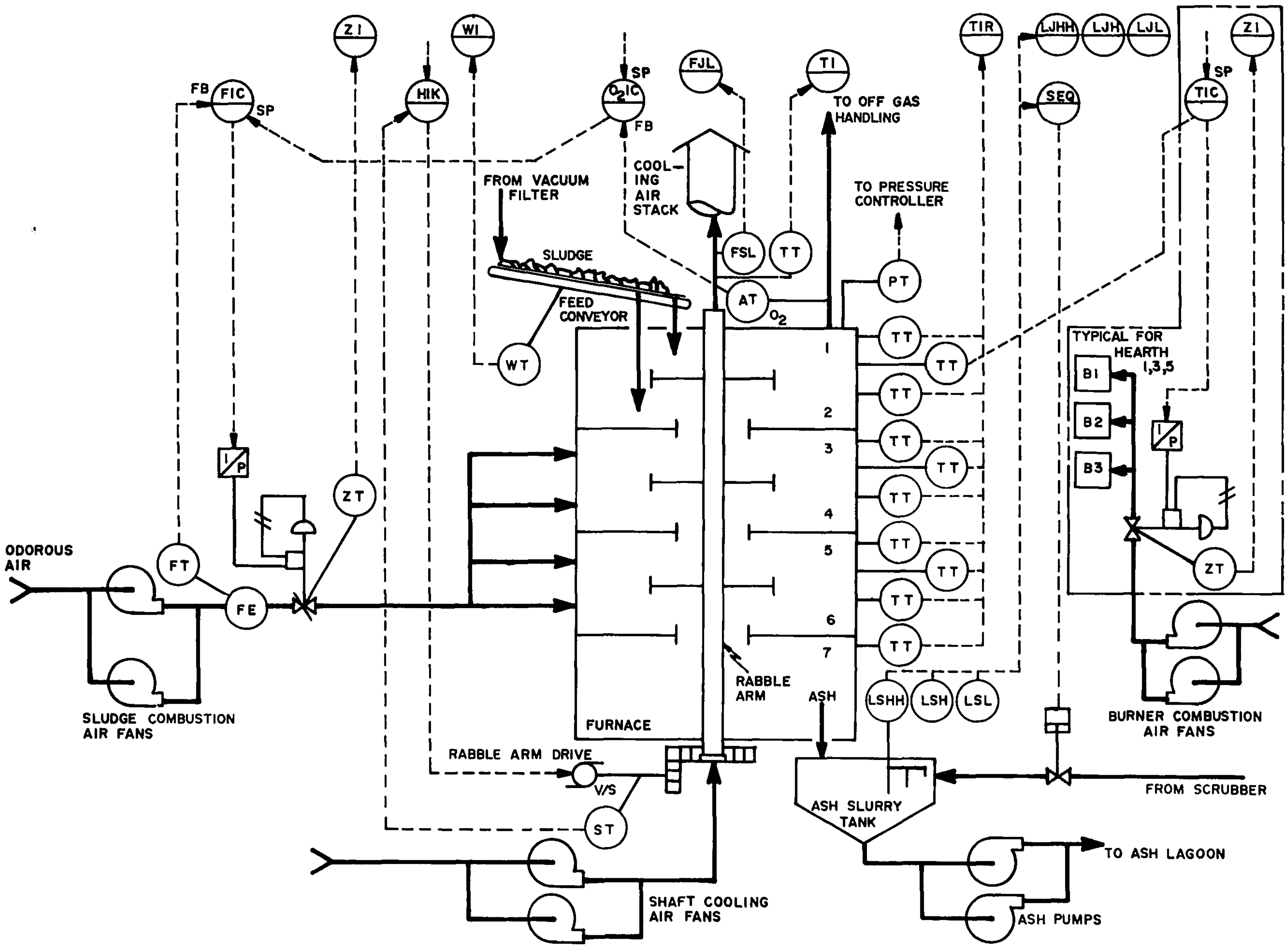


Figure 3-28. Incineration controls.

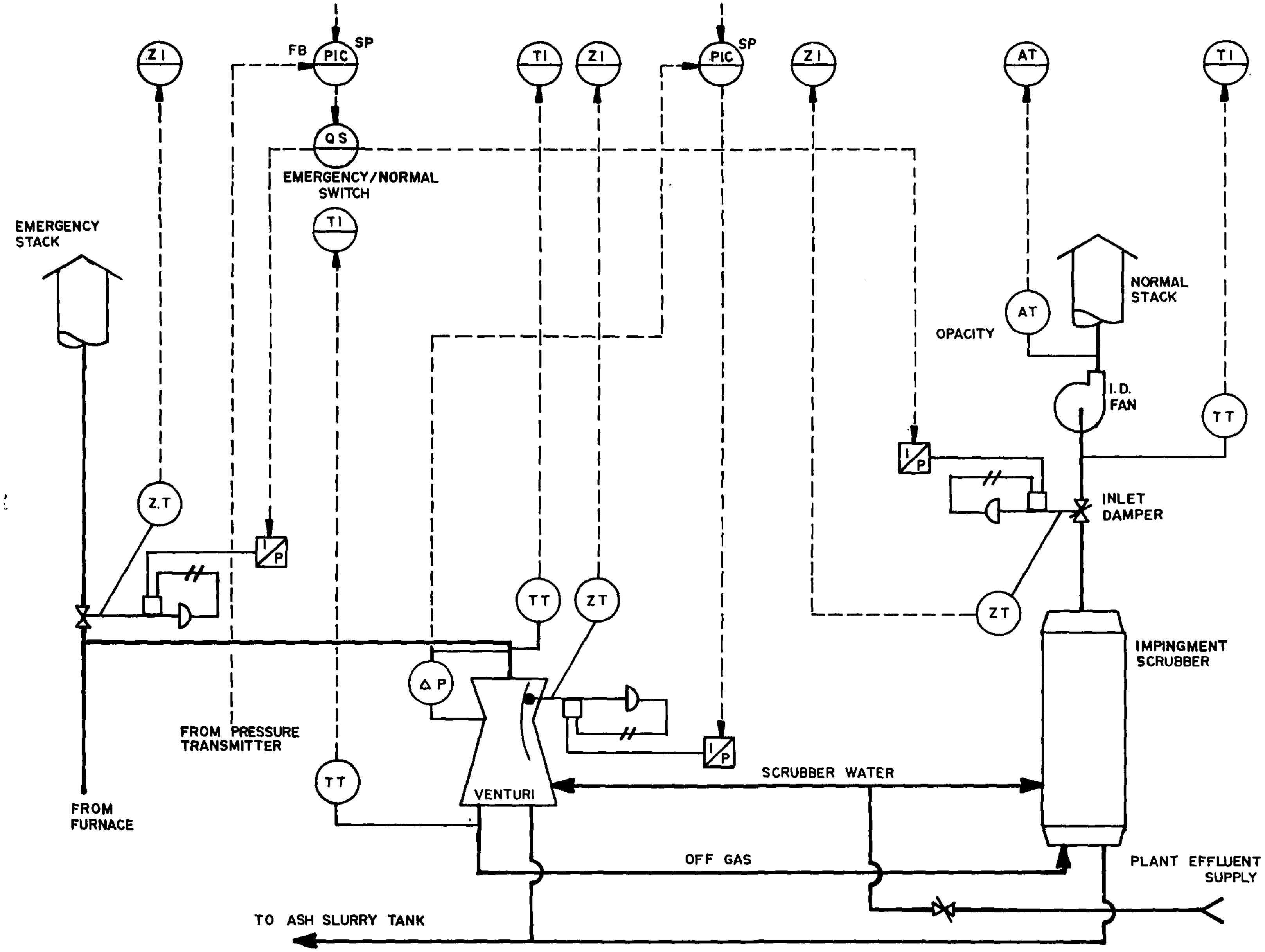


Figure 3-29. Incineration offgas handling.

speed of the rabble arm tends to break up the combustion material and expose more volatile material to temperatures greater than their flash point. The short term effect will be to increase the upper hearth temperatures, exactly opposite of that desired. In the long term, the burning zone will move to the lower hearths, but the rate at which this will occur is unpredictable.

As one might suspect in a process of this nature, process variable measurement difficulties hinder implementation of control. The instruments employed tend to be high maintenance items due to the extreme heat and the corrosive and abrasive ash particles to which they are subjected. Thermocouple burnout is not an uncommon occurrence. Offgas oxygen and flow measurement equipment will require regular cleaning due to dust.

Some measurement error may occur as a result of measurement of nonrepresentative material. For example, if burning sludge accumulates around a thermocouple, it will result in a measurement significantly higher than the actual hearth temperature (and shorten the life of the couple).

Most of the control devices used for the incineration process are air dampers which modify the combustion air and offgas flow through the furnace. Unlike most other control loops in the waste treatment plant, here consideration must be given to the compressability of the medium being controlled. This factor adds still another dimension of difficulty to the control.

The interrelation of the process loop is another important factor. For example, a venturi scrubber typically requires a pressure drop across the system in order to maintain proper operation. Modulation of a venturi throat provides the required differential pressure. This loop is tied quite closely to the incinerator pressure loop which modulates the induced draft fan inlet damper. Manipulation of the furnace pressure is performed by pulling more air out of the furnace and through the scrubber system . This directly affects the differential pressure across the scrubber.

CONTROL STRATEGY

The following description outlines a strategy employing excess oxygen in the offgas to adjust the amount of sludge combustion air entering the furnace. Burner control will be based on respective hearth temperatures. Temperature profile will be maintained by operator modulation of the rabble arm drive speed.

Hearth Temperature Control

A three-mode temperature control loop using the error between setpoint and the respective hearth temperature to control the throttling of burners should be provided for each hearth. The feedback (typically thermocouples) should be linearized according to the ISA standard. The output is direct acting and will control the burner combustion air valve. The fuel consumption rate is generally a mechanically fixed ratio to the combustion air flow and not automatically adjusted.

Sludge Combustion Air Control

A cascade control loop using an excess oxygen control loop to setpoint a flow control loop on the sludge combustion air supply fan will maintain a sufficient supply of oxygen for use in the combustion process. The percent of oxygen in the incinerator offgases is compared with the setpoint in the two-mode oxygen control loop. The direct acting output of the oxygen loop is used to setpoint a two-mode flow control loop on the sludge combustion air. Error between the combustion air flow and setpoint generates a direct acting output which operates the sludge combustion air damper in a manner to provide the required oxygen level in the offgases.

Incinerator Pressure Control

A two-mode negative pressure (vacuum) control loop using the error between setpoint and furnace top hearth pressure to control the position of the induced draft fan inlet damper will maintain a negative pressure in the furnace and keep the offgases within the incineration system. In most cases, upon failure of the induced draft fan or the scrubber system, the output of this control loop would control the position of a damper in the emergency bypass stack.

Scrubber Venturi Control

Differential pressure developed across the scrubber venturi throat is compared with the setpoint in a three-mode control loop. The direct acting output of the control loop modulates a positioner in the throat to control the differential pressure and maximize particulate removal.

Scrubber Water Flow Control

The scrubber system typically requires a controlled supply of effluent water to insure proper equipment operation. A two mode control loop compares the flow in the scrubber water header with setpoint and generates an output to position the scrubber flow control valve.

Ash Tank Water Level

A portion of the spent scrubber effluent water is typically used to produce an ash slurry to facilitate pumping to an ash lagoon. Control of the ash tank water level is via a two probe system with water being added in a batch mode of operation.

Shaft Drive Speed Control

This is a manual control loop with the closed-loop control within the variable speed drive unit. The operator selects the desired speed based upon the temperature profile.

OTHER CONSIDERATIONS

The operator may improve control by introducing his own feedforward control based on various observations. General characteristics of the sludge cake such as moisture content could allow the operator to anticipate the effects this will have on the furnace. A moisture content lab test should be performed each shift. In addition, ash organic content and sludge fuel content lab tests should be performed regularly.

Observation of the color and location of the burner flame could alert the operator to potential slag buildup on the burner. Maintenance of that burner could be scheduled in a timely manner and avoid a potential hazard.

Examining the ash for completeness of combustion gives the operator an indication of the detention time requirements. He may increase or decrease the detention time of the sludge by changing the rabble arm drive speed. Lowering of the speed results in the sludge remaining in the furnace longer, increasing the speed has the opposite effect.

The operator should confirm the excess oxygen analyzer operation on a regular basis using the ORSAT procedure. Regular cleaning will also be in order for this particular analyzer.

Observation of the stack gas color excursions may also provide insight into general incinerator performance, particularly scrubber performance. Measurement of opacity on line or simple observation using a visual (Ringleman chart) approach will serve to be a warning of poor combustion and particulate formation and/or removal.

INSTRUMENTATION UTILIZED

Sensors

1. Strain gauge weight conveyor - this instrument weighs the sludge on the feed conveyor and, in conjunction with the conveyor speed, provides a signal representative of the sludge feed rate.

2. Temperature - Type K thermocouples are generally used to measure the following: each hearth temperature, cooling air exit temperature, venturi scrubber entrance and exit temperatures, ID fan inlet temperature.

3. Pressure - system pressures are required of the following: top hearth furnace, differential across venturi filter.

4. Excess oxygen - offgas immediately exiting furnace. Analyzer indicates percent oxygen remaining over and above that used in combustion.

5. Opacity - monitors stack gas after ID fan. Indicates effectiveness of scrubber system.

6. Gas flow - sludge combustion air flow is typically measured using an annubar with an appropriate differential pressure transmitter.

7. Damper position - The following damper positions are typically required for operator use in the manual mode: sludge combustion air damper, burner throttling valve, bypass stack damper, venturi throat damper, ID fan inlet damper.

Modulating Control Devices

The following valves, dampers and motors will require control via a PID type controller:

1. Sludge combustion air damper (two controllers for cascade operation).

2. Burner throttling valves.

3. Bypass stack damper.

4. Venturi throat damper.

5. ID fan inlet damper.

6. Rabble arm drive (manual loading station only).

7. Scrubber effluent feed water valve.

8. ID fan motor, if variable speed (manual loading station only)

On/Off Devices

The following devices will require start/stop or open/close control:

1. Sludge combustion air fans.

2. Burner air fan.

3. Burner oil pumps.

4. Feed conveyor.

5. Shaft cooling air fan.

6. Shaft drive.

7. Ash slurry pumps.

8. ID fan.

9. Each burner.

Alarm Points

1. High temperature in furnace.

2. High temperature at scrubber inlet.

3. High temperature at ID fan inlet.

4. Low water flow to scrubber.

5. Low speed switch on rabble arm.

6. Low air flow on cooling air.

7. High temperature on cooling air.

8. High level in ash tank.

9. Zero furnace pressure.

Controlling Devices

In addition to the PID controllers described previously, sequence control of the following items will be necessary:

1. Switching network for multiple blowers and pumps.

2. Burner control logic.

3. Emergency bypass logic to control furnace pressure in shutdown.

4. Startup sequence logic.

5. Ash system control logic.

VARIATIONS IN STRATEGY WITH PLANT SIZE

There is no variation in actual control strategy with plant size. The above described strategy is representative of what is required for plants in the 5 to 50 mgd (220 to 2200 dm^3/s) range. Plants less than 5 mgd (220 dm^3/s) typically do not use the incineration process for sludge disposal as it is not economically feasible. Plants greater than 50 mgd (2200 dm^3/s) must in addition cope with the problem of routing sludge to multiple incinerators and incinerator maintenance.

EXPECTED PERFORMANCE

In most incinerator installations observed, the goal of final disposal of dewatered sludge is attained, however, not in the most economical fashion. Due to the instability of the process (for the reasons outlined above), controls are typically in manual mode with auxiliary fuel flow at maximum and sludge combustion air at maximum. This meets the process objective, but at the expense of extreme and frequent temperature excursions (causing refractory damage) and much higher operating costs.

RETURN LIQUORS

INTRODUCTION

Field observations indicate that treatment of the return liquor from the solids treatment unit processes is becoming a necessity. All plants visited acknowledged that return liquors from the various solids train processes imposed large hydraulic, organic and solids loads on the liquid train. These loads comprise up to 3 to 5% of the plant flow, 10 to 20% of the solids load and 10 to 20% of the organic load. Not many operating plants exist where the problem is properly handled. Two methods were observed (in various stages of implementation) which can be considered typical for the immediate future. They are: 1) treatment of liquors separately from the main plant flow, and 2) storage of liquors with programmed release during off-peak hours.

These two methods will be discussed in general terms with no detailed proposed strategy because the strategy is so dependent on the approach used to handle the return liquors.

OBJECTIVE

The objective of the return liquors treatment is to treat or control the material to be returned so that it does not disrupt the liquid treatment process. Return liquors represents a major disturbance on the process and this disturbance, if coinciding with a diurnal load, will yield a process upset which field observations show can last for weeks. The liquid train is susceptible to short term and/or long term disruptions caused by hydraulics, organics and solids. The goal of a return liquors treatment is to minimize the affect of this known disturbance through control.

FACTORS AFFECTING PROCESS PERFORMANCE

Load Characteristics

Loads may be from the gravity thickeners, vacuum filters, sludge concentration tanks, flotation thickener, digesters, centrifuges or heat treatment. The waste liquid portion of these processes determines the hydraulic load from liquors and the frequency of the loading. These processes are usually dynamic, and may be operated on a batch basis, which results in shock loads. In addition, the shock loads and continuous loads somewhat follow the plant diurnal pattern.

Process Characteristics

When return liquors are stored prior to discharge into the liquids, the storage capacity must be large enough to dampen the return liquor flow peaks. Based upon field observations, the detention times provided are too small, so that the method is usually not successful. At least three hours detention time of return liquors storage (at peak plant flows) should be provided.

Treatment of the return liquor is usually divided into two trains. Heavily solid-laden wastes are treated by physical/chemical means while liquids containing high concentrations of organics such as heat treatment return liquors are treated by biological means. High costs are involved in physical/chemical treatment. Measurements are difficult and sensors other than flow measurement are seldom used. The process must be able to handle widely varying loads which may at times be difficult to treat. Sufficient buffering of return liquors is the objective and with consistent control, a reasonable return liquors performance has been demonstrated in the field.

CONTROL STRATEGY

If the storage method is used, return liquor is collected in a separate return liquor wet well. A level control system, with a deadband in the controller, is used to manipulate the flow from the wet well into the liquids train.

Treatment of return flow acts as a buffer and reduces the impact of the return liquors on the plant. If chemical feed is used, it is ratioed to the return flow. If biological treatment via rotating biological surfaces is used, the number of shafts on line is varied. If activated sludge is used, the unit process is always kept on line and the return sludge rate is varied.

In both control strategies, the solid and organic contribution of the return liquor is the manipulated variable. The release of return liquor flows when the diurnal flows are low has been attempted, but is difficult to successfully achieve in practice. The manipulated variable in the storage strategy is the flow valve that regulates the return liquor released into the headworks of the plant. In the treatment strategy, the chemical dose or number of biological units running, is the manipulated variable. Return liquor flow is measured continuously with suspended solids or organics usually measured in the laboratory.

Extreme variation in both the characteristics and quantity of return liquors is a severe constraint on the process. In the storage system, the wet well volume is generally not sufficient to effectively buffer loads.

INSTRUMENTATION UTILIZED

These instruments have been observed in general use:

Sensors

1. Flow - mag meter.

2. Density - optical or nuclear instruments are occasionally used after treatment.

Modulating Control Devices

1. Variable speed chemical feed pumps.

On/Off Control Devices

1. Chemical pump drives.

2. Biodisks drives.

Controlling Devices

1. Flow indicating controllers.

2. Chemical ratio controllers.

3. Level indicating controller for wet well level with wide deadband. This may include pumping logic.

Annunciator Alarms

1. Failed devices.

2. High wet well level.

VARIATION OF STRATEGY WITH PLANT SIZE

Handling of return liquors is not an important problem in small treatment plants because they generally do not have complex solids treatment trains. Storage strategies were observed in predominant use in moderate size plants having return liquor handling facilities. Large plants tend to use separate treatment facilities to process return liquors. At the Minneapolis-St. Paul Metro Plant, biological and physical/chemical processes are utilized to treat a 10 mgd (440 dm^3/s) return liquor flow.

EXPECTED PERFORMANCE

Although not many return liquors installations were observed, the results are promising. With adequate return liquors storage and good plant management, timed release of return liquors can be successful. At least three hours of return liquors storage is necessary based on field inputs.

Treatment of return liquors is expected to reduce the solids load and organic load on the liquid train by well over 50% at Minneapolis-St. Paul.

SECTION 3
BIBLIOGRAPHY

Allen, R. K. and C. O. Victor, Plant to Disinfect Wastewater with Ozone, Water and Sewage Works. July, 1978.

Andrews, J. F., Control Strategies for the Anaerobic Digestor Process, Water and Sewage Works. March, 1975.

Belich, M. and F. N. VanKirk, California Plant Gets Straight A's in Computer Control, Water and Wastes Engineering. March, 1975.

Bishop, D. F. and W. W. Schuk, Control Strategies for Automation of Advanced Waste Treatment Systems, AICHE Symposium Series 145, Vol. 71, 1975.

Bollyky, L. J. and B. Siegal, Ozone Disinfection of Secondary Effluent, Water and Sewage Works. April, 1977.

Brachen, B. D., What's Up With Oxygen? Parts I and II, Water and Wastes Engineering. March and April, 1977.

Ching, D. L., D. M. Heimsted and P. W. Gilligan, Computerized Control of the Primary Sedimentation and Air Activated Sludge Process, Proceedings of the Instrument Society of America conference Advances in Instrumentation, March, 1977.

Environmental Protection Agency, Field Manual for Performance Evaluation and Troubleshooting at Municipal Wastewater Treatment Facilities, EPA-430/9-78-001. January, 1978.

Environmental Protection Agency, Flow Equalization, EPA Technology Transfer Seminar Publication May, 1974.

Environmental Protection Agency, Operations Manual-Sludge Handling and Conditioning, EPA-430/9-78-002. February, 1978.

Environmental Protection Agency, Process Design Manual for Aerobic Biological Treatment Facilities, EPA-430/9-77-006

Environmental Protection Agency, Process Design Manual, Wastewater Treatment Facilities for Sewered Small Communities, October, 1977.

Etchart, D. Y. and B. Mishra, Survey on an On-Line Computer Control System at Metro Denver, Proceedings of the Instrument Society of America conference Advances in Instrumentation. March, 1977.

Fair, G. M., J. C. Geyer and D. A. Okun, Elements of Water Supply and Wastewater Disposal, Second Edition, 1970.

Fertek, H. A., A Computer Control Strategy for Breakpoint Chlorination, Proceedings of the Instrument Society of America conference Advances in Instrumentation, March, 1977.

Flanagan, M. J., Control Strategies for the Activated Sludge Process, Instrumentation Technology. June, 1977.

Flanagan, M. J. et al, Design Procedures for Dissolved Oxygen Control of Activated Sludge Processes, Environmental Protection Technology Series, EPA-600/2-77-032. June, 1977.

Genthe, W. K., J. F. Roesler and B. D. Bracken, The Case for Automatic Control of Dissolved Oxygen, presented at 49th Annual Conference of Water Pollution Control Federation, Minneapolis, Minnesota, October 3-8, 1976

Lesperance, T. W., A Generalized Approach to Activated Sludge, Water & Wastes Engineering. April-December, 1965.

Lieberman, N., Instrumenting a Plant to Run Smoothly, Chemical Engineering. 1977.

Molvar, A. E., J. F. Roesler and R. H. Babcock, Instrumentation and Automation Experiences in Wastewater Treatment Facilities, Environmental Protection Technology Series, EPA-600/2-77-032. June, 1977.

Molvar, A. E., Selected Applications of Instrumentation and Automation in Wastewater Treatment Facilities, Environmental Protection Technology Series, EPA-600/2-76-276. December, 1976.

Metropolitan Waste Control Commission, St. Paul, Minnesota, Evaluation of Wastewater Treatment Process Control Systems, Case Study: Metropolitan Plant. June, 1976.

Nagel, C. A., State of the Technology Semi-Automatic Control of Activated Sludge Treatment Plants, Environmental Protection Technology Series, EPA-600/2-75-058. December, 1975.

Ortman, C., TOC, ATP and Respiration Rate as Control Parameters for the Activated Sludge Process, Environmental Protection Technology Series, EPA-600/2-77-142. 1977.

Petersack, J. F. and R. G. Smith, Advanced Automatic Control Strategies for the Activated Sludge Treatment Process, Environmental Protection Series, EPA-670/2-75-039. May, 1975.

Rice, R. E. and G. A. Mathes, A Demonstration, Direct Digital Control of a Vacuum Filter, Proceedings of the Instrument Society of American conference Advances in Instrumentation. March, 1977.

Rice, R. E. and G. A. Mathes, Direct Digital Control of a Vacuum Filter Part II, presented at the Instrument Society of America conference on Advances in Instrumentation, Philadelphia, Pennsylvania, October 16, 1978

Roesler, J. F., The State-of-the-Art for Automation of Sludge Handling Processes, Proceedings of Third National Conference on Sludge Management, Disposal and Utilization, Miami, Florida, December 14-16, 1976.

Roesler, J. F., Status of Instrumentation and Automation for Control of Wastewater Treatment Plants, Proceedings of the Fourth United States/Japan conference on Sewage Treatment Technology, October 28-29, 1975, Cincinnati, Ohio.

Roop, R. N. Evaluation of Residual Chlorine Control Systems, Journal Water Pollution Control Federation. 1977.

Woodruff, P. H., Dissolved Oxygen Control of the Activated Sludge Process, Progress in Water Technology, Vol. 6, Pergamon Press 1974.

Zickefoose, C. and R. B. Hayes, Anaerobic Sludge Digestion, Operations Manual, EPA-430/9-76-001. February, 1976.

SECTION 4

ALTERNATE CONTROL APPROACHES

PURPOSE

A multitude of alternatives exist from which a selection can be made when designing the control system of a wastewater treatment plant. This section will address those considerations which are vital to this selection, and the general attributes of each alternative, relative to the selection criteria. In general, the following will be accomplished:

1. Development of a basic familiarity with the various control alternatives.

2. Identification of specific considerations relative to the particular requirements of a given process or control problem.

3. Identification of the alternate(s) which should be considered for a particular plant application.

This section is intended to allow the reader to subjectively reduce the entire set of alternatives to a relative few which will meet a given set of requirements. The reader may then perform a complete analysis of this subset and do it within a practical time frame. More extensive information to assist in this formal evaluation is contained in Sections 5 and 7 of this publication.

Scopè

The common types of control systems in use today are detailed here as well as the more subjective or "gray-area" qualities of each. The latter, while not always quantifiable, must certainly be considered when evaluating the alternatives. Any evaluation which ignores these considerations, selecting based solely on costs and ignoring these other aspects of cost/benefit, may lead to the wrong choice.

This section is not intended to pinpoint one control philosophy which will be best for a given application, nor is it intended to be a "cookbook" or "formula" which will automatically determine the solution to a control problem by merely plugging in certain information. Furthermore, it will not attempt to apply any specific dollar values to costs or savings; these depend far too much on specific configurations and process variables. The reader is directed to Section 5 for a more objective discussion of costs and savings.

Assumptions

The discussions presented in the section make two very important assumptions. First of all, the control of a plant is viewed as an integrated system. Whenever an alternative is discussed, it will be discussed on a plant wide basis; application of the alternative to an individual loop will be addressed by way of explanation but all discussion with respect to the advantages/disadvantages will imply a systems approach.

Secondly, each alternative will be addressed as if the treatment plant is entirely controlled by a single method. In practice, this is seldom the case. Control systems in most plants are, in actuality, combinations of several of the cases presented. The rationale for the procedure used is that at each plant one method is dominant, even if several are in use.

SELECTION CRITERIA/CONSIDERATIONS

Many factors go into the selection of the "best" means of meeting the control objectives of a process. The following topics should be considered in any evaluation. They are not presented in any specific order, i.e. there is no order of importance attached to their sequence. They are all very important considerations.

Costs

The costs associated with any control alternative include:

Capital Equipment - the cost of any hardware necessary, such as panels, computers, peripherals, etc.

Instrumentation - the cost of any sensors or control elements within the process.

Installation - the cost of installing the capital equipment, the instrumentation and the wiring between them.

Software - the cost of the computer programs which might be necessary.

Operational Costs - the costs associated with the day-to-day operation of the control system, including operators, supplies, etc.

Maintenance - the costs associated with keeping the control system fully operational, including maintenance of the capital equipment, the instrumentation and the software.

Expansion - the costs required to expand the control system beyond the initial configuration.

Savings

There are many areas of potential savings related to any selected control alternative:

Labor - Staff reductions may be considered with certain alternatives. This is particularly possible with respect to maintenance and operational personnel. Clerical labor is another potential area for savings.

Chemical - Chemical usage may be reduced by some control alternatives. This is particularly important in larger plants and in heavily treated processes but is also an important factor in smaller plants.

Energy - Selection of an alternative which is capable of controlling energy demand, both total and peak demand, will produce savings.

Equipment Life - Equipment life may be extended by preventing such things as short-cycling or by alternating usage with backup devices or by more rigorous performance of preventive maintenance.

Intangibles

Reliability-
The reliability of a control system must be evaluated with respect to the overall process objectives. This requires that the following topics be addressed:

Risks - What will happen if the control system fails and is not available? Can the process survive? How long? What will it cost?

Backup - What type of backup control is available? What is required in order to switch to the backup mode?

Process Variability-
Different types of processes require different degrees of control. In general, the following components determine the variability:

Strength - is the influent strength generally consistent or does it vary from hour-to-hour or day-to-day? Is the influent primarily one type (e.g. domestic, industrial) or does it change?

Flow - does the flow change dramatically over time? Is there a significant storm flow?

Expandability--
Very few processes are static in terms of control requirements or capacities. Future growth may not be fully identifiable but must almost always be considered. Growth may include additional process units, additional process trains, additional sensors or, at least additional information requirements.

Flexibility of Control--

Past experience dictates that flexibility in control strategy is an absolute must for most processes. Except for very small and static plants, it is generally not practical to offer the operator only one control alternative. He must be able to apply a variety of strategies, depending upon the particular combinations of conditions with which he is faced at any point in time.

Optimization of Results--

The typical wastewater treatment process is being pressed by two almost opposite influences, one requiring more tightly controlled effluent characteristics while the other demands a reduction in operating expenses. These two influences are not mutually exclusive. The control system must be evaluated in terms of its ability to assist in the identification of these complex relationships and then be "tuned" to make optimal use of the results.

Physical Space Requirements--

Any control system will require some physical space. How much is necessary versus how much is available needs to be considered. Additionally, environmental conditions required in the control room should be reviewed and considered.

Operator Qualifications--

Critical to any control system is the operating personnel. This staff will be vital to the system's operation, and the specific requirements for competent personnel must be considered. How much training must they have? How much education?

Operator Acceptance--

The acceptance of the control system by the operators must also be considered. A very sophisticated system may be installed, but if the operator won't use it (or cannot understand it), it will be of no practical value and will certainly not solve the control problems it was intended to solve.

Management Information--

Every plant requires some degree of management information. This may include reports generated for various government agencies, operation summaries for plant management review/monitoring, cost data for financial reporting and the like. Much of the data included in these reports must be obtained from the control system. Report requirements of the plant must be considered and matched to the various alternative's ability to provide the necessary data.

Methods of Control--

The operator of a plant or process must make a variety of decisions every day. These decisions range from a simple selection of what device to start, to decisions related to sudden device failures or significant load changes. The manner of response and the amount of information presented to the operator by the control system is an important consideration.

Essentially, there are two control extremes which may be considered. If the primary mode of control is to wait for something to go wrong and then react, it is termed "crisis control." The opposite of crisis control requires that the operator be able to plan for change or be able to foresee a problem before it is serious. This is termed "anticipatory control" and is the more desirable.

Certain control alternatives provide a much better potential for reducing or eliminating the occurrence of crisis control situations. When evaluating control alternatives, consider the potential for crisis control and the costs of such situations.

CONTROL SYSTEM ALTERNATES

Various methods of control are available and in use today. The basic field equipment generally used in today's systems is usually the same for each system type, and is considered the same in this report. The equipment is usually electrical in the more sophisticated systems and includes the instrumentation, the final operators, motors and motor controls, and other electrical devices. All nonelectrical equipment will be controlled by transducing the electrical signals to the required mode and vice versa. Pneumatic instrumentation is still common in small or less sophisticated control systems.

The field instruments, which include many different types of devices, are mounted near the variables to be measured. The primary elements, such as flow tubes, are mounted for proper measurement of the desired variables. The accompanying transmitter is mounted as near as possible to the primary device to send the desired signals back to the control location by direct hard wiring and/or multiplexer telemetry equipment. The field instrumentation measures such common things as flow, temperature, level and pressure, and includes analyzers for different process variables, including dissolved oxygen, total organic carbon, chlorine residual and others.

The final control of variables such as flow is normally done by motor control with electric operator (as described below), pneumatic operator or hydraulic operator. The pneumatic and hydraulic operators require local transducing of the control output signal to these devices.

The motors are controlled through motor control centers, which include starters and related control circuits. The motor control center is in a location central to the unit process being controlled. The control circuits are hard wired to the local maintenance type motor control stand, and they are hard wired and/or multiplexed back to the various control locations. Control circuits include variable speed controls, as well as the normal start/stop functions, motor overload and motor running type signals.

Several types of devices such as pressure switches, control switches and limit switches are used to sense the current state of various processes and equipment. These discrete signals are worked into the logic and alarm circuits of almost all types of control systems.

The following paragraphs describe the basic parts of several control systems now in use in various wastewater treatment plants:

- Manual Control
- Analog Control
  - Local Analog
  - Central Analog
  - Distributed Analog
- Digital Control
  - Central Digital
  - Distributed Digital
- Hybrid Control
  - Loggers
  - Digitally Directed Analog (DDAC)

The field instruments and control devices are considered to be common to each system unless otherwise noted.

Each type of control will be discussed relative to a single process situation (Figure 4-1). This example will show the application of each control alternative to a sludge pumping process containing two pumps feeding a common header. One of two pumps will be required to deliver the necessary sludge flow. The flow is controlled by a motor operated valve and measured by a flow meter.

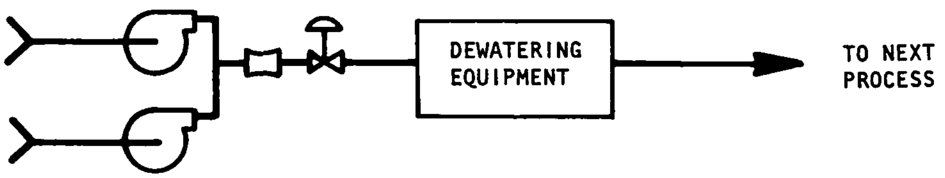


Figure 4-1. Dewatering feed system.

Manual Control

DECISION MAKER: Human Being
CONTROL LOCATION: The Physical Equipment

Manual control is a method of control where all process adjustments are made by an operator. The control points are concentrated on panels near the process or subprocess controlled. The panels are arranged with groupings of controls as related to specific functions or processes. This type of control is considered open loop and requires manual interpretation of meter and chart readings with subsequent manual adjustment of knobs or valves. Operator communication between panels is necessary to allow this type of control.

Figure 4-2 shows the application of manual control to the sample sludge flow control loop being considered. The operator starts the correct pump(s) via the panel pushbuttons. He observes the flow on the flow meter and modulates the control valve until the desired flow is attained. If a single pump does not produce the required flow, the operator must start the second pump and vice versa. Similar panels exist for each small unit process to be controlled.

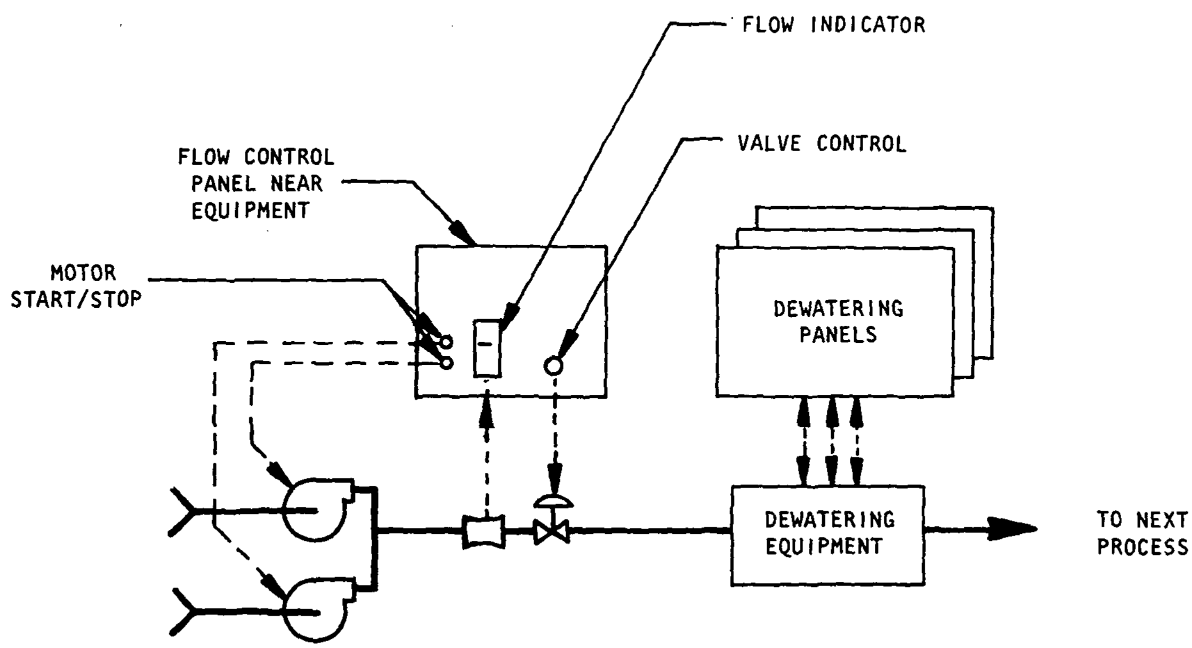


Figure 4-2. Manual control.

Analog Control

"Analog" control systems, as discussed in this section, refer to any alternative which combines various discrete hardware components into a control system. These discrete components include a variety of devices ranging from simple analog logic to sophisticated sequence control logic. This includes three-mode controllers, relays, adders, subtractors, compositors and the like. This definition, while not completely correct from a pure control theory point of view, is practical when categorizing actual control systems in use today.

The analog logic component of "analog control" refers to the use of hardware which monitors a process variable and performs control adjustments continuously.

For example, a desired process condition such as flow, level or temperature (called the setpoint) is compared to the actual value of that condition (called the feedback or process variable). A mathematical calculation between the two, executed by the analog hardware, determines if any correction must be applied to the control element (pump speed, valve position, etc.).

The sequential logic component of analog control refers to the use of hardware which performs a series of discrete control adjustments. For example, pumps are started or stopped based on a set of wet well level setpoints or an air blower is placed on line by performing a series of discrete startup steps.

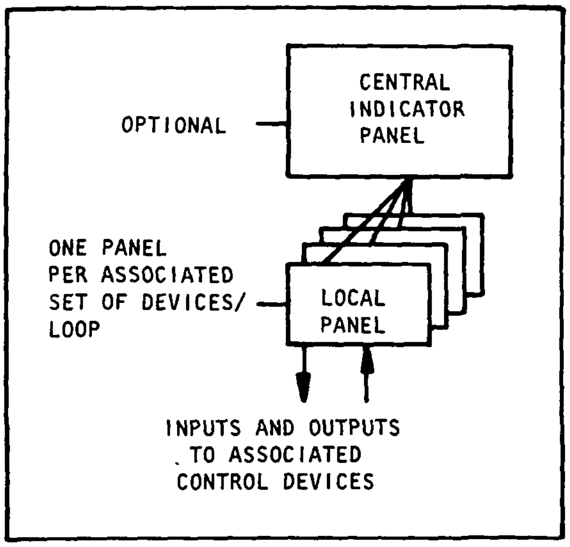
Other than simple manual systems, process control utilizing analog instrumentation is the most common form of control in use today. All control (manual and automatic) eminates from panels located within the plant. The number of panels depends on the type of analog control implemented and the size of the plant. Figure 4-3 summarizes the functions of the various panels. The major types of analog systems are Local Analog, Distributed Analog and Central Analog.

Local Analog--

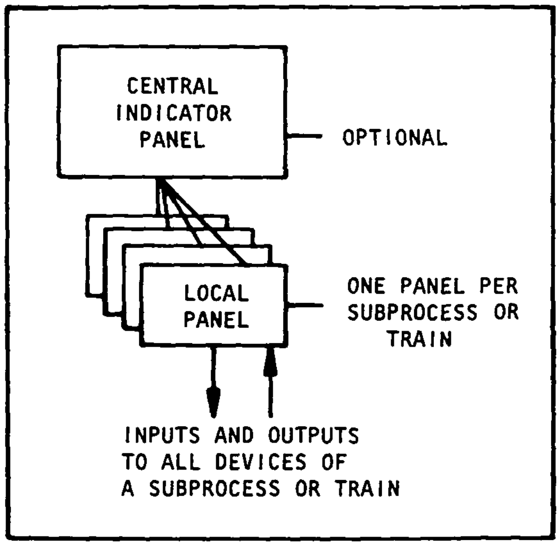
DECISION MAKER:	Analog Hardware and Human Being
CONTROL LOCATION:	The Physical Equipment

The local analog or localized control systems are common at small wastewater treatment plants. In these systems, panels are located in the vicinity of the equipment to be controlled. The panels are arranged with groupings of instruments, pushbuttons, switches and controls as related to specific functions or processes. The analog control portion of the panel is usually a closed-loop type of control. The measured process change is used to control a valve or other device through the action of individual controllers. These controllers may be a pneumatic type where all signals are pneumatic in and out of the controller. Predominantly, however, the controllers and support instrumentation are electronic.

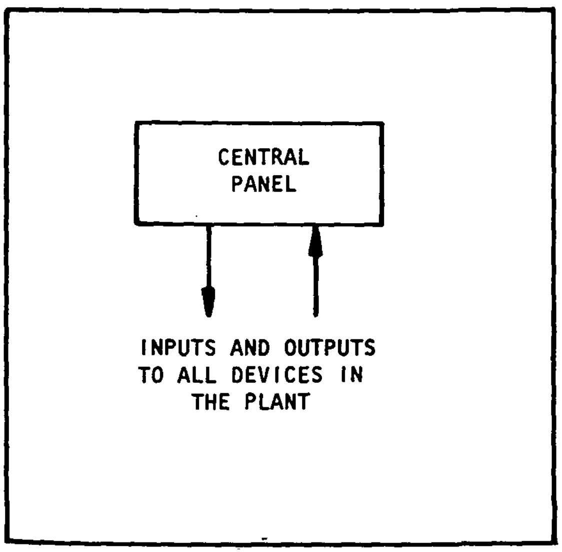
The analog equipment mounted on the panel includes indicators of the process variable and of the final control element. The indication of these variables is a controller in a compact arrangement. The controller also has switches for selecting auto or manual mode, adjustments for a setpoint to the controller, adjustments for output in a manual mode, and other various functions. Signal conditioning sometimes applied includes square root extraction for differential pressure type of flow devices, thermocouple junction compensation, multiplication and division. Integration of flow signals is performed for a totalization of a given flow stream, or for outputting a signal to activate a sampler at a given quantity of flow rather



Local Analog: Control is spread throughout the plant in small, local panels. Each panel typically controls one or more similar devices. Manual sequencing and operator setpointing are typical. Interpanel communication is extensive. Decisions are made at the equipment level. The central panel provides indication only.



Distributed Analog: Control of unit processes is concentrated into panels located throughout the plant. All devices associated with a subprocess are controlled from one panel. Automatic sequencing and cascade control is typical. Interpanel communication requirements are reduced. Decisions are made at the subprocess level. The central panel provides indication only.



Central Analog: Control of the entire plant is consolidated into a central panel. Automatic sequencing and cascade are typical. Decisions are made in the control room so that communication requirements at the local level are minimal.

Figure 4-3. Analog Control Characteristics.

than time. Automatic sequencing of various pieces of equipment or the starting and stopping of control functions within a process are typically not included. These generally remain as manual (operator) functions.

The motor control on these panels is usually a set of start and stop pushbuttons for starting and shutdown operations. The hardware typically provides the required equipment safety interlocks necessary to ensure that related conditions are in the correct state prior to permitting action. For example, the operation of a secondary motor is physically prohibited if the seal water valve is not open. Additionally, the motor is monitored for such things as whether or not it is running, motor overloads, motor speeds, etc. and the results are indicated on a small field panel by lights or panel meters.

The location for local analog panels is usually at or near the devices being controlled. Communication between the panels is required to assure material transfer between subprocesses and to allow proper operator monitoring.

Figure 4-4 shows the application of local analog control to the sample sludge flow loop being considered. The operator manually starts the desired pump(s) just as was done in the manual control example. However, instead of manual modulation of the control valve, the operator sets the desired flow into the analog controller. The controller will automatically adjust the valve and continue to adjust it such that the actual flow matches the set-point. Again, similar panels would exist for all unit processes.

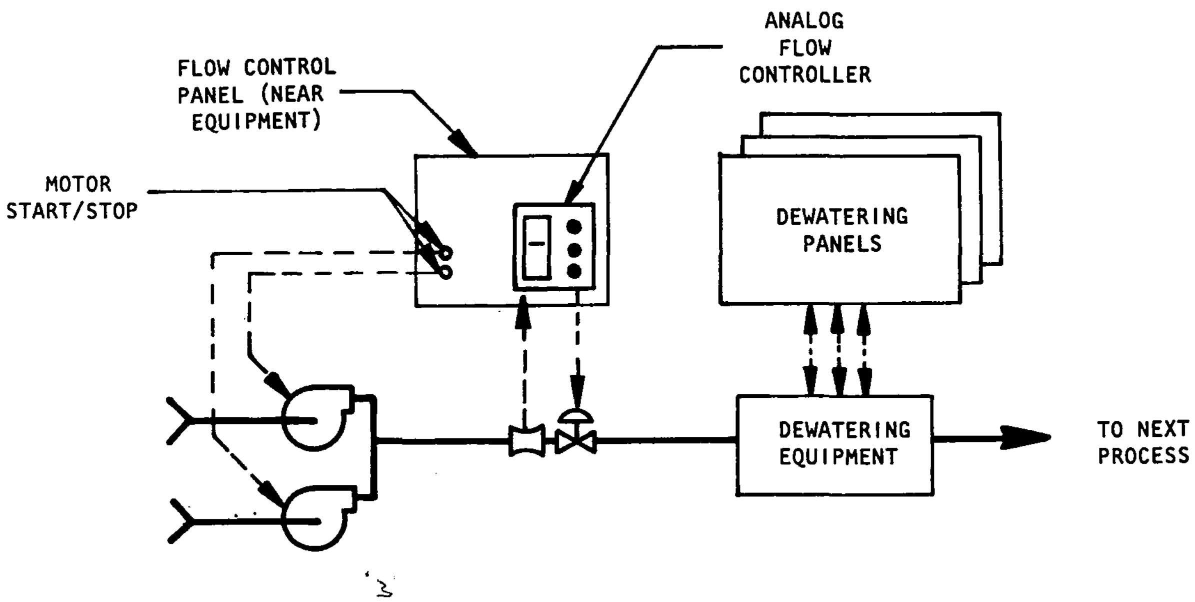


Figure 4-4. Local analog control.

Distributed Analog--

DECISION MAKER: Analog Hardware (some human intervention)
CONTROL LOCATION: Subprocess

Distributed analog control involves the use of larger panels designed to allow complete control of a complete unit process from a single field location. The panels include controllers, square root extractors, indicators, recorders, switches and all other equipment necessary to allow the subsystem to be controlled. These individual control panels typically retransmit a small number of critical variables (alarm, status, analog) to a centralized panel for monitoring. The plant is divided into various major processes to minimize the effects of operation from many locations, and to maximize the efficiency of quality control within the individual unit processes. A process should have all the necessary controls and operating information available on a panel so that an operator can control the process. The signals wired to a central location communicate key information to the plant engineer to monitor the performance of the unit process operators and to evaluate their performance and that of the entire process.

Instrumentation used in the field is brought back to the unit process or building control panels. This instrumentation is electronic, except in hazardous and explosive areas where pneumatic instrumentation should be used. The controls and electronic devices make cascade control possible and grouping of various control functions to minimize the required operator interface. The discrete information such as whether or not a pump is running, overloads or critical alarms are shown on the unit process panel with lights and annunciators. The start-stop on the manual and other control functions necessary on a control panel are pushbuttons and selector switches. Automatic sequencing may or may not be included as each distributed panel is usually manned 24 hours per day.

Required interprocess operator communication and control, such as secondary treatment, primary treatment, chlorination and the solids train, is usually difficult. Communication between these panels is usually verbal (via telephone), and requires strict regulation and enforcement of rules. In some cases, key process variables could be wired to multiple panels in order to reduce the severity of the problem. A central control panel would optionally be included for monitoring important flows, alarms and status of devices. This would give the plant engineer the opportunity to monitor the operation of various subprocess panels, analyze overall system needs, and to call for the required process control changes.

Figure 4-5 shows the application of distributed analog control to the sludge flow example. In this case, all elements of the dewatering process are consolidated on a single panel near the process. A single operator controls all devices from this location. Automatic sequencing of the pumps and control of the flow is the same as for central analog. A similar panel exists for each subprocess or train.

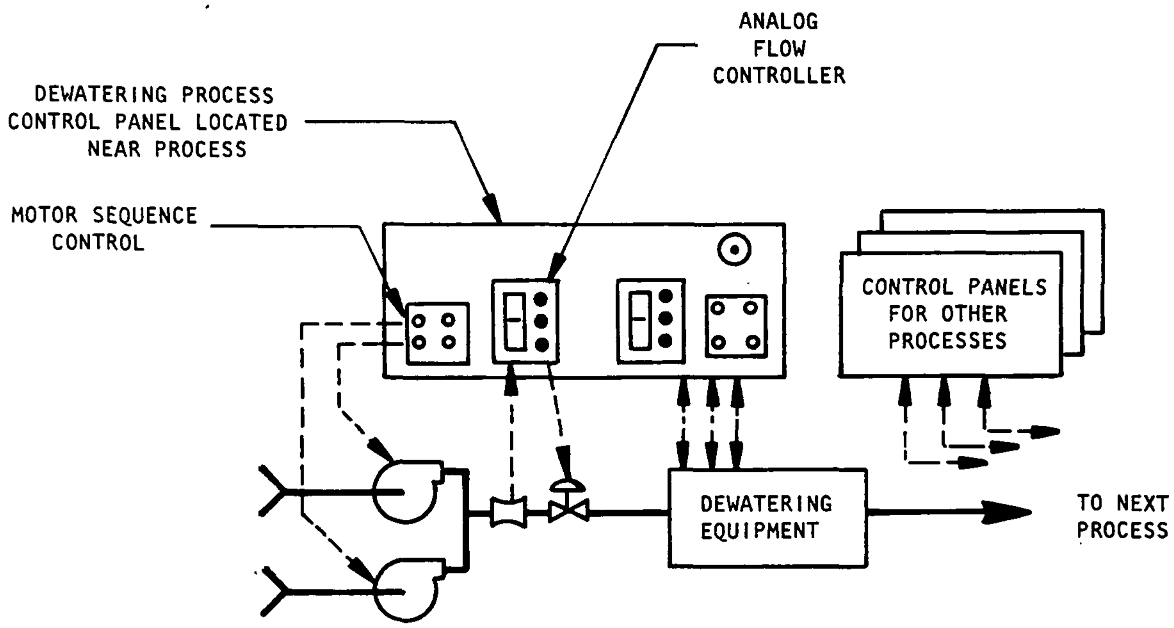


Figure 4-5. Distributed analog control.

Central Analog--

DECISION MAKER: Analog Hardware (some human interaction)
CONTROL LOCATION: Central Control Room

Central analog control is defined as the system where all control operations of importance are controlled from a central location. Typically, central analog control systems have manual backup by the use of small maintenance panels in the field. The analog controllers can be in the field with remote setpoint stations in the central control room or the controllers can be in the control room. Central analog control systems generally include full sequence control.

The central control panel is located in a room with environmental control. The motor control or discrete type of signal handling for a central control system is available from the panel as an override of the automatic sequencing. Alarm annunciators are located on the panel and can be acknowledged by the operator in the room.

The analog portion of the control system allows for more complex control schemes when located in a central location. Cascaded control from a primary variable to several controllers, possibly in a separate unit process controlling a secondary variable, is possible. This improves communications between process panels.

Figure 4-6 shows the application of central analog control to the sample sludge flow loop being considered. The control is moved from local panels located near the particular equipment to a central control room. The start-stop pushbuttons for the pumps have been replaced by sequencing logic which will start and stop the devices automatically as flow requires. The control instrumentation is located on a much larger panel with similar devices for all of the plant.

The operator activates the sequence control logic and enters a setpoint into the controller. Modulation and sequencing is automatic from that point on. Alarms (e.g. device failures) are annunciated on the panel.

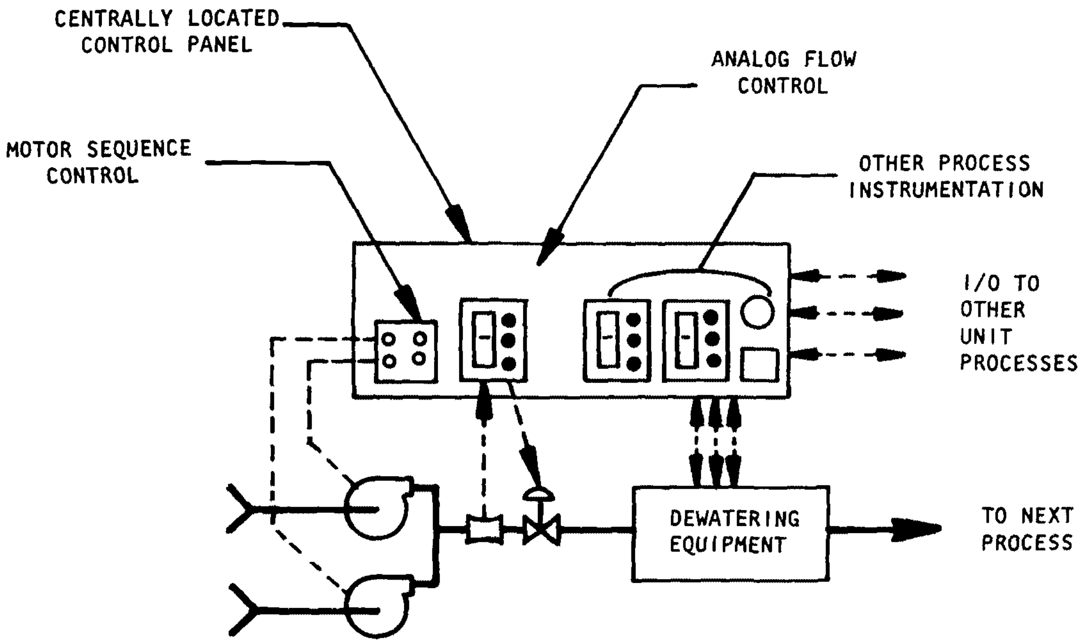


Figure 4-6. Central analog control.

Digital Control Systems

Use of the digital computer to control industrial processes has increased rapidly over the past 15 to 25 years. Certain industries, notably petrochemical and pharmaceutical, have been in the forefront of development and application. These industries have made very complete and sophisticated use of the digital computer in order to achieve complete control of entire process trains, plants and even distribution networks (in the case of pipeline systems). Analog signals representing flows, pressures and so forth, are converted to a form which can be read and understood by a digital computer. The computer makes control decisions and issues field compatible control outputs.

In early application of the digital computer to process control, the thrust was usually to replace analog control with the digital counterpart. While this was usually of great economic benefit, it soon became apparent that this was not to be the most far-reaching advantage of the digital computer. The fact that the digital computer could be programmed to perform massive calculations and to make complex decisions, and to do them very rapidly and consistently, proved to be the most important feature. Because of this ability, it is almost impossible to find certain unit processes, such as a distillation column, which are not controlled by digital computers.

Utilization of computers in many industries has greatly increased since the advent of the minicomputer in the 1960's. This technology offered an economical alternative to manual and analog control systems even for small installations and thus has proven to be the catalyst necessary for widespread application of the digital computer to smaller, lower margin processes. This phenomenon is manifest in the wastewater treatment industry, which has essentially experienced the birth and maturation of computer control since about 1970.

Another revolution began in the late 1970's with the advent of the microcomputer. This technology has greatly increased in recent years and has made the "computer on a chip" an economically feasible alternative. The term "micro" refers to the physical size of the processor and has little to do with describing the capabilities, since many microprocessors have more instruction capacity than did early minicomputers. However, microcomputers do tend to have less capacity overall because of limited memory capacity. Also, the number of circuits which will fit on one chip requires the use of slower but more compact logic alternatives.

Initial application of microcomputers has been to bury the processor in a device, such as a terminal or a multiplexer, and to use it as an "engine." The microcomputer controls the device, while usually enhancing its capabilities, and would communicate the appropriate information to a higher form of computer. As capabilities increased, more and more logic was included and today the microcomputer is being utilized as an individual process controller within a network and, in some cases, as a stand-alone computer.

The application of the digital computer within treatment plants has matured very rapidly in the past 10 years. The synergistic interaction of computer economics and control/reporting requirements has forced this evolution. New developments will undoubtedly continue to expand the computer's application over the coming years.

While there are nearly as many different hardware configurations in use today as there are installations, there are essentially two different types of systems: 1) central digital, and 2) distributed digital. Each type is discussed below in greater detail.

Central Digital--

DECISION MAKER: Computer
CONTROL LOCATION: Central Control Room

In the case of a central digital control system (Figure 4-7), all of the control with the main plant is brought back to a single computer location. This single computer location, with redundancy, performs all computation and control within a single central processing unit (CPU). Field signals are brought into the central location on either individual wiring or telemetered in on a multiplexing scheme. A multiplexer, or MUX for short, is a hardware device which receives many field signals and routes them, one at a time, to the computer in a manner similar to the way in which the phone company transmits many calls over a single cable. Control computations and logic are performed upon the data and the control output is sent to final control elements. Figures 4-7 (a) and (b) show some of the "flavors" of this configuration.

When the number of points being monitored and controlled in any single plant exceeds 1,500 to 2,000, a single computer system becomes overburdened and unresponsive. When this occurs, multiple computers may be used, thereby "sharing" the load. Usually, each computer will be assigned to monitor and control one or more logical portions of the process, e.g. primary treatment, secondary treatment, sludge handling, etc. Figure 4-7 (c) shows this configuration. For example, the "A" sensors may be connected to the primary treatment, while the "B" sensors are connected to the secondary section of the plant.

The computers may operate autonomously. That is, they may each monitor and control their own portion of the process and have no knowledge of, or interaction with, the remainder of the plant. However, this will cause communication and coordination problems similar to those discussed with respect to analog control.

In most applications, the computers are linked together via communication lines and share various pieces of information. Data obtained from one subsystem and required by another is transmitted as needed. Typically, all reports are printed by one computer and contain data from all subsystems. That data is also transmitted via the communications network from all subsystem computers to the computer designated as the report printer.

The computers also monitor the status of each other and serve as backup for one another, should either fail. When one computer takes over complete control, it typically operates in a degraded mode; that is, essential control actions are continued while nonessential or less critical control is suspended in order to maintain responsiveness and data integrity.

In a central digital control system, microcomputers may be included as part of the multiplexer. Typically, they would perform all process input and output, error checking, conversion to or from engineering units, etc. Some sequencing logic and other analog replacement logic might be included.

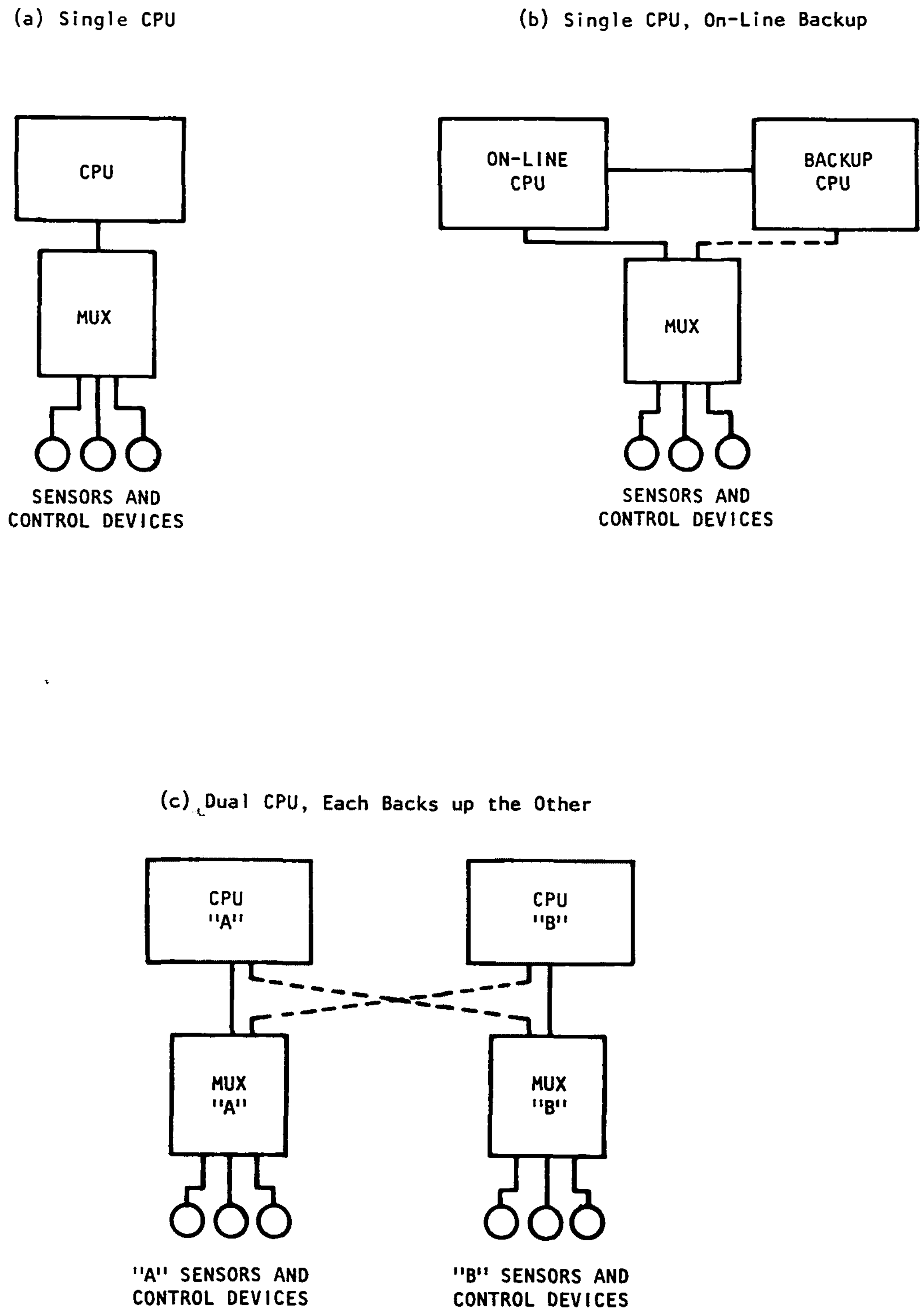


Figure 4-7. Central Digital Configurations

Figure 4-8 shows the application of central digital control to the sample sludge flow loop being considered. The entire dewatering process train is wired to a central computer system through a common multiplexer. All other process elements are similarly connected to the same computer. This computer system performs flow control and pump sequencing based on operator entered values or other processing information. For example, when the flow increases from the sludge thickener, the computer will automatically adjust the setpoint of the flow control loop.

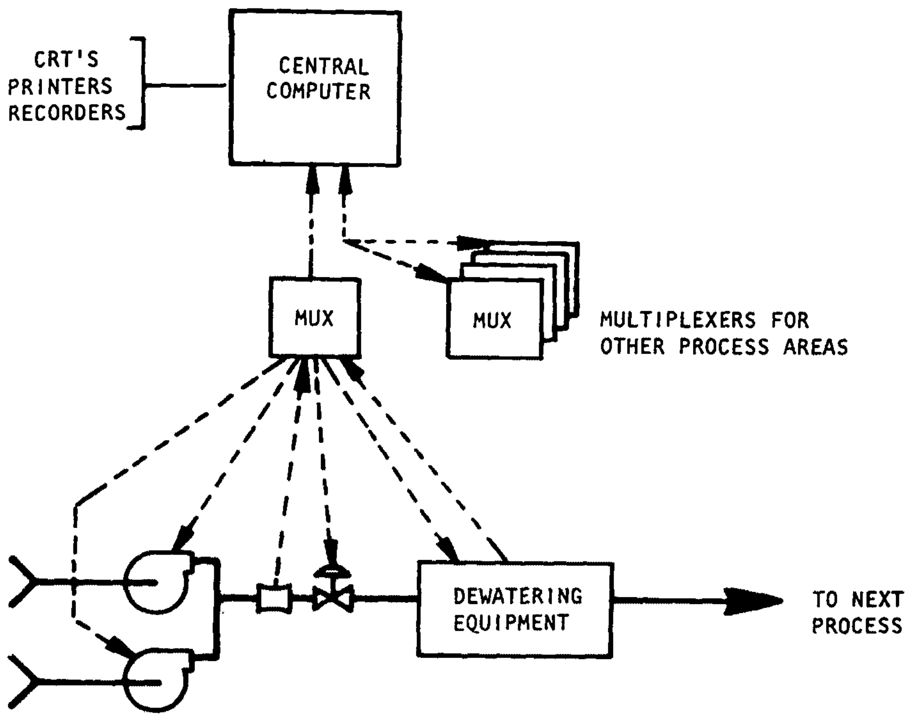


Figure 4-8. Central digital control.

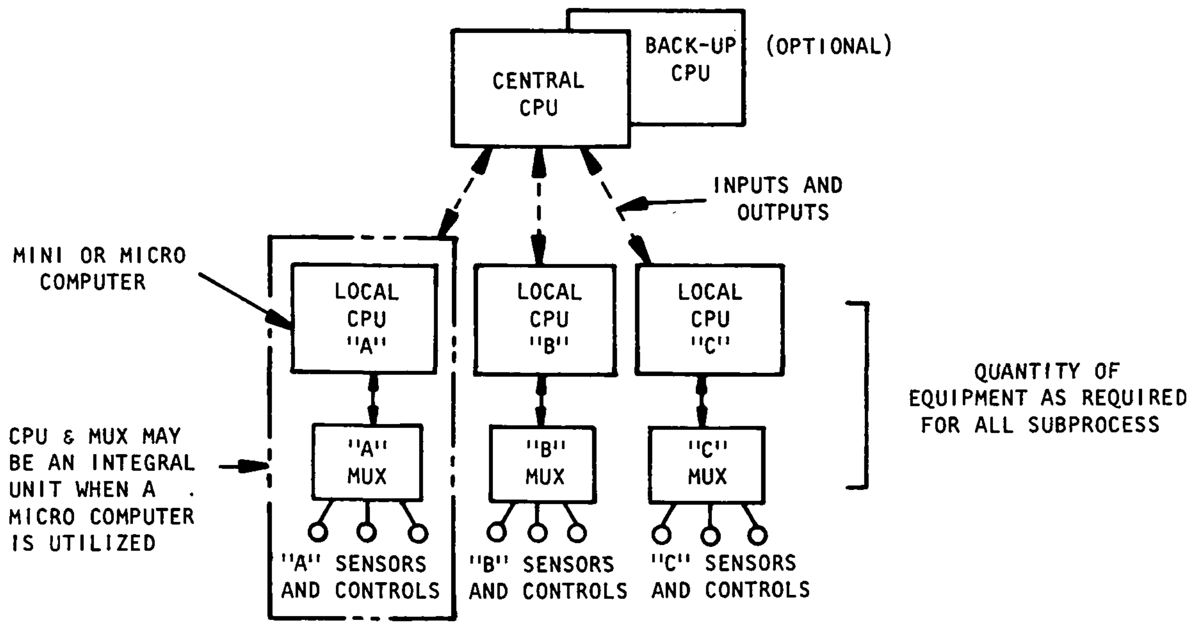
Distributed Digital--

DECISION MAKER: Computer
CONTROL LOCATION: Subprocess

Distributed digital control refers to a hierarchial system which includes multiple levels of control and control decisions. The distributed system is composed of a number of individual computers which control unit processes or process trains. These process control computers are connected (hardwired or telemetry) to a central computer system (see Figure 4-9). The local or process control computers may be mini or micro computers. The central or master computer is a mini.

Different types of control and process decisions are made at each level. The objective is to distribute the execution and processing among the various computers in order to increase control responses and to increase

(a) Non-Redundant Local CPU



(b) Fully Redundant Local CPU

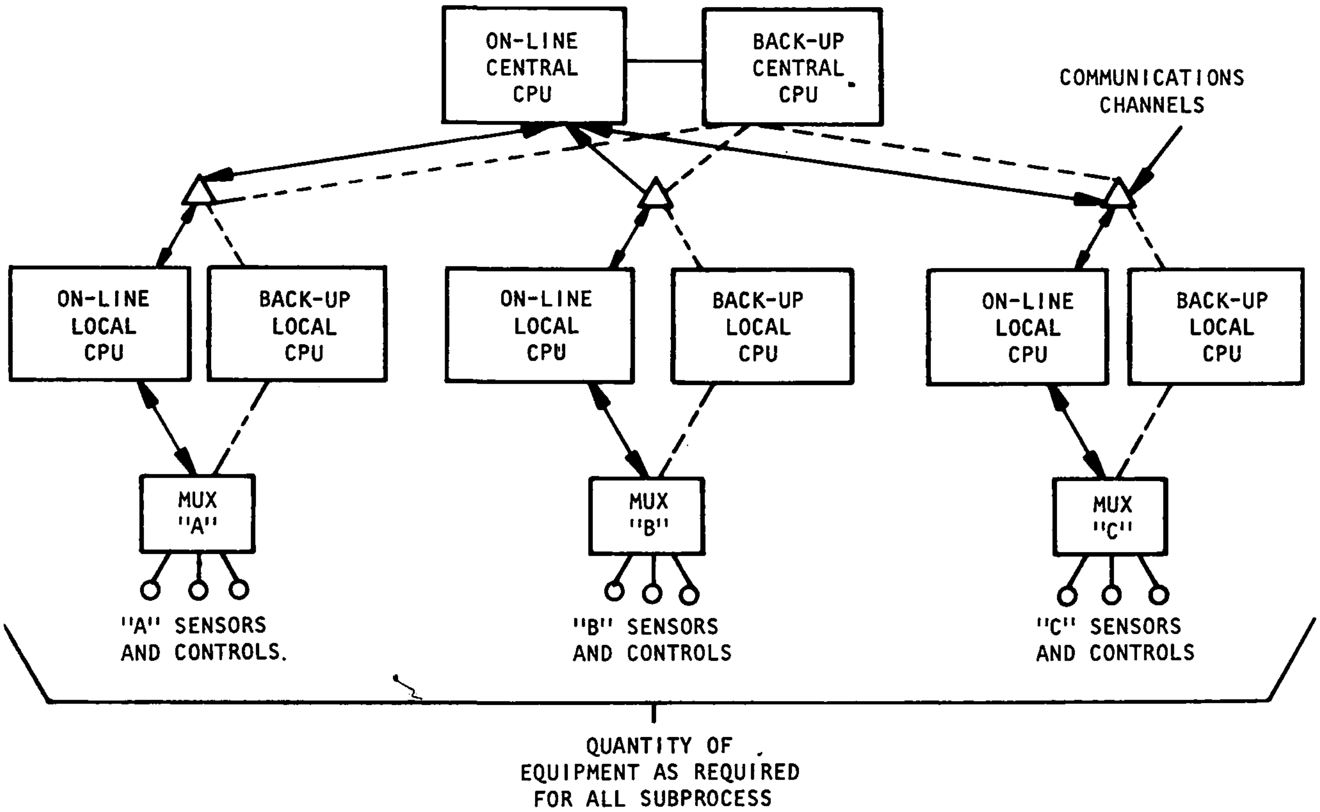


Figure 4-9. Distributed Digital Configurations

reliability and availability. Each processing subsystem shares the processing load and, because it stands alone, is unaffected by failures of the other systems.

The subsystem computer's primary purpose is the control of the processes for which it is responsible. The subprocess computer will exchange data with the central machine as required to learn of related conditions in other subprocess sections of the plant. All of the data gathered will be sent to the central machine for the data collection and recording responsibilities. The central machine will transmit control functions to the individual subprocess machines, allowing direction of the total plant operation.

The central computer is used for linking the entire control system. This includes the basic optimization changes necessary to achieve high performance in the total plant. Power demand monitoring and control are established from the central machine, giving direction to the subprocess centers for various actions in starting and stopping of motors. The reporting of all data for operations or regulatory agency reports is performed at this level.

Figure 4-10 shows the application of distributed digital control to the sample sludge flow loop being considered. Again, the entire dewatering process is wired to a computer system. However, in this case, only the sequencing logic and flow control loop logic is contained in the local computer. Other local computers contain similar logic related to the other subprocesses within the plant.

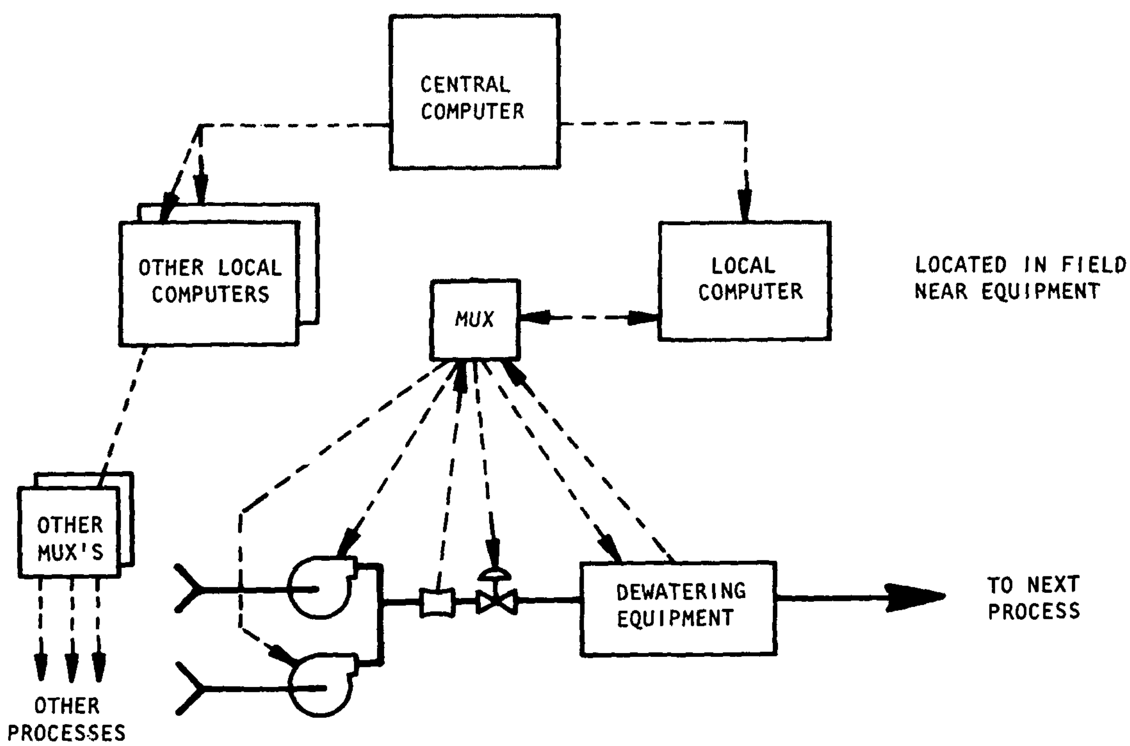


Figure 4-10. Distributed digital control.

Each local computer is connected to a centrally located master computer. Current flows, device status, etc. are transmitted by the local computers to the central computer which will be responsible for such things as data collection and optimization. If, for example, an increased thickener flow was detected from one local computer, central would direct the dewatering local computer to increase its present setpoint for flow.

Hybrid Control

A combination of analog and digital control is sometimes accomplished in the hybrid control systems. In these cases, it is common to have a computer that will receive data parallel to an analog control panel. The hybrid control situation can take two forms: 1) Data Logging and, 2) Digitally Directed Analog Control.

Data Loggers--

DECISION MAKER: Analog Hardware and/or Human Being
CONTROL LOCATION: Unit/Subprocess/Central

The use of the digital computer for data acquisition is very common in the United States. These systems are quite often used in out-of-plant type problems such as monitoring the flows within a waste control district. All of this monitored data can then be processed for such purposes as billing the contributing communities and industries.

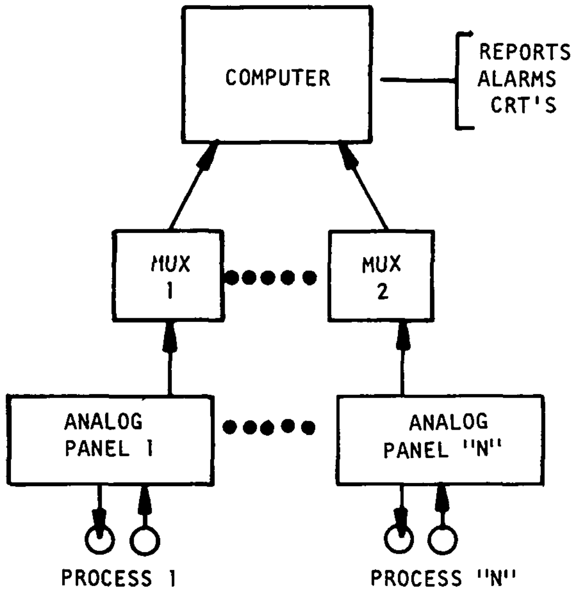
This system of data acquisition has also become quite common in the operation of wastewater treatment plants (see Figure 4-11). Here, the principal advantage is the recording capabilities of the computer. The data, which can be gathered on as little as one second intervals, can be stored for later reporting and calculation. For a medium to large wastewater treatment plant where there are many flows, the volume of paperwork required to keep good operating data becomes difficult and expensive. With a data acquisition system, it is possible to do this work on a continuous and rapid basis.

The computer may also be used to log process occurrences and to annunciate alarm conditions. Audible alarms and printed messages can alert the operator to current or potential problems

The data acquisition system is usually a single computer which monitors the various analog and discrete inputs. No control is issued by the computer. The data may be hardwired to the computer interface modules or it may be telemetered, in the case of a large plant or out-plant situation, to the computer center.

The control of the process is accomplished by either manual control or by one of the previously discussed analog systems.

(a) Data Logging System



(b) Digital Directed Analog Control (DDAC)

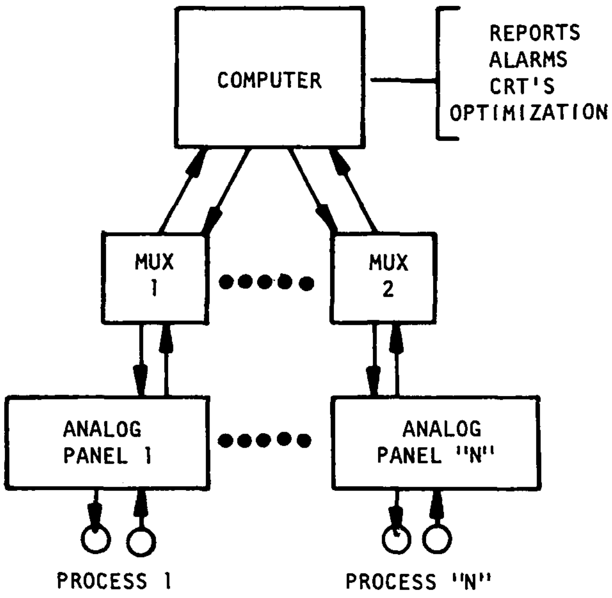


Figure 4-11. Hybrid Control Systems.

Figure 4-12 shows the application of a logger system to the sample sludge flow loop being considered. In the example, control is shown through a distributed analog panel, but this could be via a manual analog panel just as well. The panel provides control in the same manner as discussed previously under distributed analog control. Flows, device status, etc. are transmitted from the panel to a central computer. All other panels do the same such that all data capture and reporting functions, as well as alarming functions, occur at the computer.

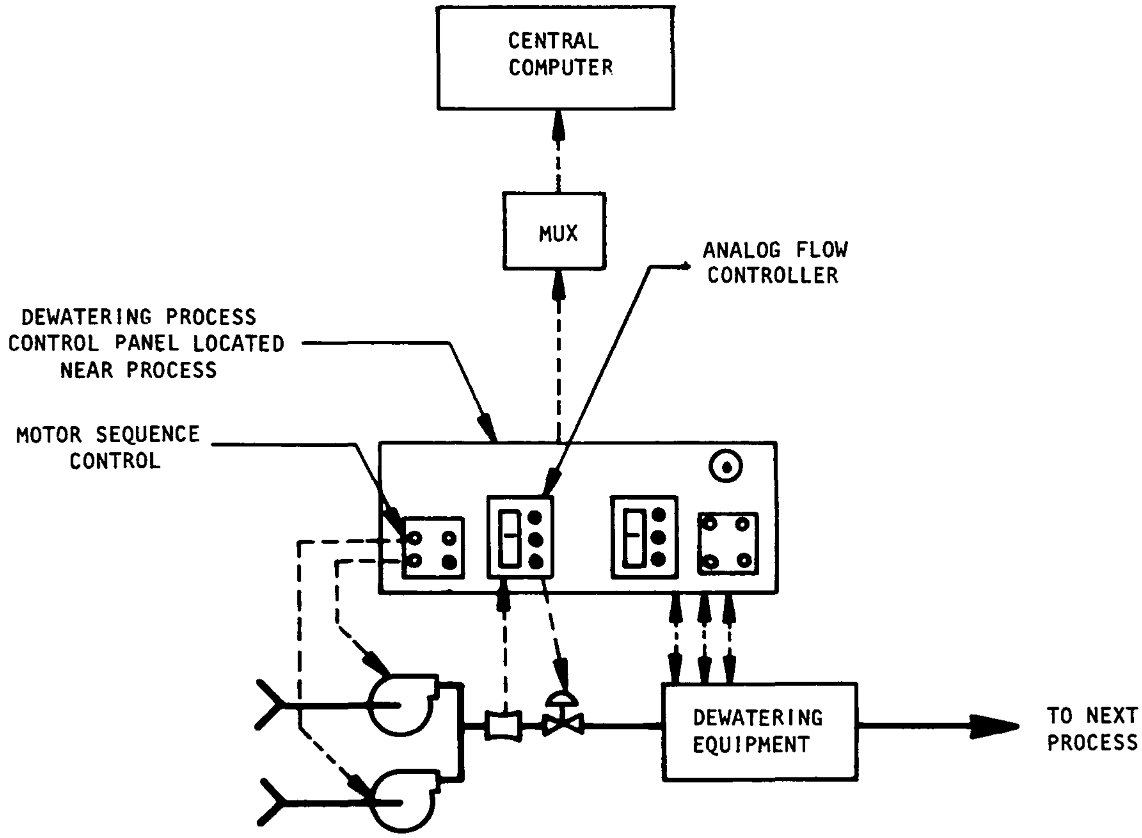


Figure 4-12. Analog control with digital data logging.

Digitally Directed Analog Control (DDAC)--

DECISION MAKER: Computer and Analog Hardware
CONTROL LOCATION: Central Computer and Analog Panel

This method of control combines local analog control with the data reporting and calculating capabilities of the computer. In DDAC systems (see Figure 4-11), all control of the unit processes is accomplished by local analog control, including conventional controllers and sequencing logic, but control decisions can be initiated by the digital system.

Process inputs are transmitted in parallel to the panels and to the computer. The computer will log and retain the information, as described under data logger above. It will prepare all reports and annunciate alarm conditions as they appear.

The computer will also contain programs which will analyze the process inputs and will decide when certain process changes or adjustments are necessary. Typically, only loops which can be benefited by optimization will be included. Computer control outputs will be to the analog panels and will be in the form of analog controller setpoint changes and sequence logic initiation. Direct outputs to field devices would be included only for complex sequences where the computer could improve performance.

Figure 4-13 shows the application of DDAC to the sample sludge flow loop being considered. It is identical to the discussion above under data loggers except that the computer may also make control decisions and output them to the local panel. For example, if an increased thickener flow is detected by the computer, it will output a setpoint change to the analog controller at the dewatering panel. The controller will then control to the new setpoint until the operator or the computer directs otherwise.

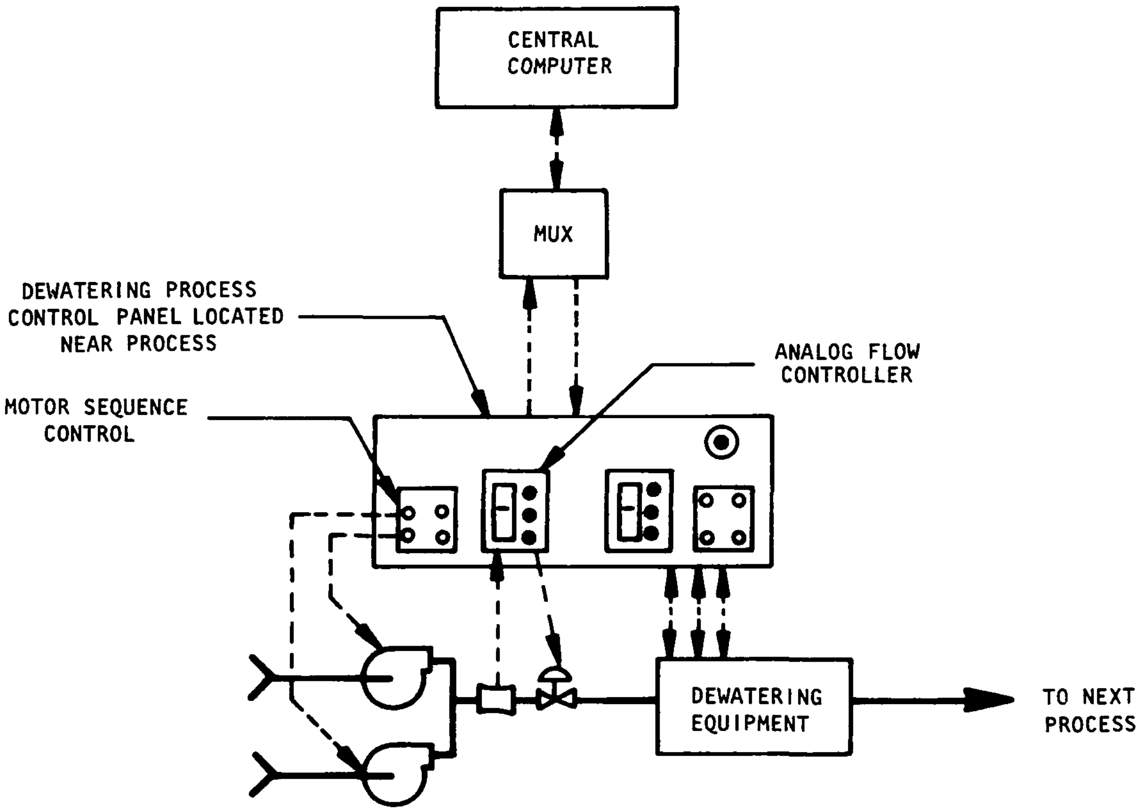


Figure 4-13. Digitally directed analog control (DDAC).

COMPARATIVE EVALUATION

This section presents a combination of the previous two discussions and will put the benefits and drawbacks of each alternative into perspective. Each important consideration outlined earlier will be addressed for each general control alternative. A summary of the discussion is found in Table 4-1. The reader is cautioned that this summary contains certain terms which are used for overall comparison and should not be construed to imply any relative magnitudes. For example, installation costs for a manual system are shown as LOW. This does not necessarily mean that it is inexpensive to install such a system, but rather that the costs are low compared to other alternatives.

Manual Control

Costs--

In general, manual control is the least expensive alternative in terms of the seven cost factors discussed previously:

Capital Equipment - Local panels with pushbuttons, gauges and annunciators (audible and visual).

Instrumentation - Flow meters, chlorine analyzers, thermocouples, etc.

Installation - The lack of equipment would, of course, reduce the installation costs. Since all panels are near the unit processes, there would be "minimal" wiring costs.

Software - None required.

Operating Costs - This will depend largely upon the variability of the process and the size of the plant. In a small, stable plant, one or two operators per shift could get to all panels within a reasonable time. In a large, variable process, it might require one operator per panel per shift which could necessitate 50 or more personnel. A 10 mgd (440 dm^3/s) secondary plant, for example, might require five or more persons to operate it per shift.

Maintenance - Sensor and panel maintenance. Typically, two or more mechanically-oriented persons would be required.

Expansion - Simple expansion can cause problems and increase costs, depending upon the amount of modification required to the various panels. Addition of another pump is inexpensive if there is space for it on the panel and relatively expensive if a new panel must be built. Wiring is direct between process and panel, thereby necessitating new wiring.

Savings--

There are no savings associated with manual control as it is the basic alternative and is the standard against which all others will be measured.

TABLE 4-1. CONTROL COMPARISON SUMMARY

Consideration	Manual	Analog			Digital		Hybrid
		Local	Central	Distributed	Central	Distributed	
Costs: - Equipment - Instruments - Installation - Operating - Maintenance - Software - Expansion	 Low Low Low High L None Low	 Moderate Moderate Moderate High High None High	 Moderate Moderate Moderate Low High None High	 Moderate Moderate Mod/High Moderate High None High	 High High Mod/High Low Moderate Moderate Moderate	 High High High Low/Mod Moderate High Moderate	 High Mod/High High High High Moderate High
Savings: - Labor - Chemical - Energy - Equip Life	 None None None None	 Some Some None None	 Some Some None None	 Some Some None None	 High Moderate Moderate Some	 High Moderate Moderate Some	 Some Some Some Some
Reliability	High	Moderate	Moderate	Moderate	Low/Moderate	Moderate	Moderate
Flexibility	Complete	Low	Low	Low	High	High	Low
Optimization	None	None	None	None	High	High	Some
Space Requirements	Low	Moderate	Moderate	Moderate	High	High	High
Operator Qualifications	Low	Moderate	Moderate	Mod/High	Mod/High	Mod/High	Mod/High
Operator Acceptance	Good	Fair/Good	Fair/Good	Fair/Good	Good	Good	Good
Management Information	None	None	None	None	Complete	Complete	Moderate
Methods of Control	Panels. Crisis Control	Panels. Crisis Control	Panels. Crisis Control	Panels. Crisis Control	CRTs. Anticipatory Ctl	CRTs. Anticipatory Ctl	Panels/CRTs. Crisis Control
Automatic Control Available	None. Human Intuition	Feedforward, Feedback	Feedforward, Feedback, Cascade	Feedforward, Feedback, Cascade	Feedfwd, Feedback, Cascade, Adaptive	Feedfwd, Feedback Cascade, Adaptive	Feedfwd, Feedback, Cascade, Adaptive

Labor - In moderate to large plants, manual control requires far more operators than other alternatives. In very small plants (less than 1 mgd - 44 dm^3/s), however, labor costs would be comparable to other alternatives.

Chemical - Chemical addition is largely uncontrolled, unless an operator(s) continually adjusts dosage rates. Excess chemical usage generally results.

Energy - No practical consideration may be made. Energy consumption will be essentially uncontrolled.

Equipment Life - No improvement. Device alternation will be left up to the operator and preventive maintenance will be manually controlled and scheduled.

Reliability--

The control of the plant will be as reliable as the operator(s). Operator intuition and experience will be the order of the day. Sensor failure will result in operator "guesstimates" of the current process variable. Control hardware failure is generally unlikely.

Process Variability--

Manual control is practical in small volume, consistent processes. When the flow fluctuates a great deal or when the influent characteristics change, an operator cannot react quickly enough or often enough to ensure consistent effluent. Manual control generally cannot be expected to produce stable or consistent effluent in treatment plants unless the influent characteristics are very constant and the plant very small.

Control Flexibility--

In one sense, manual control is very flexible; the operator may do whatever he wishes. While this does provide flexibility, it also leads to inconsistent control. Each operator will have his own mode of control and will essentially operate the plant differently.

Optimization of Results--

Little, if any, optimization is possible. Each unit generally operates independently of every other unit. There are no data capture capabilities, short of manual recording, and any attempts at optimization must be manually developed and controlled.

Physical Space Requirements--

Space for the control panels is required. This requirement will vary depending upon the number of control elements within each panel. A large, central panel may be included at a central location for process monitoring.

Operator Qualifications--

The operators will need to be experienced in the particular plant being controlled. They must be well schooled in the treatment process and well versed in the plant dynamics. Operators at manual plants must be disciplined to be on constant vigil for changes. The training period is likely to be a relatively long apprenticeship. Therefore, cross-training of operators and the use of one or two "floaters" is prudent in order to cover illness, resignations, etc. Mechanical aptitude is a necessary criterion for operator selection.

Operator Acceptance--
Manual control systems are usually quickly accepted because of their simplicity.

Management Information--
Very little assistance is offered by this concept. Data may be recorded on strip or circular recorders and manually transcribed. All calculations must be manual as is all report preparation.

Manner of Control--
Crisis control is generally the norm. The operator cannot readily discern any trends in the process but rather must react to a situation after it occurs. More likely, peaks and valleys will come and go and no modification of control strategy will occur at all because the operator has no vehicle available which will alert him unless a crisis condition occurs.

General Usage--
Manual control is generally only practical in small plants (0 to 5 mgd - 0 to 220 dm^3/s) or for unit processes. Packaged plants are typically manually controlled. It is often found in physically small plants and in primary treatment plants with relatively constant flow and weak influent characteristics. It is generally not practical in larger plants or in unit processes which are 1) critical, 2) time dependent or, 3) multivariant. There is a limit to the number of variables a person can comprehend, evaluate and respond to over a period of time.

Analog Control

Since the general considerations of local, central and distributed control are very similar, they will be addressed in the same section. These comments apply to all three unless specifically noted.

Costs--
Full analog control generally increases the overall cost of the control system. Typically, a central system costs more than a distributed configuration, while a local analog system is the least costly.

Capital Equipment - Includes local panels, central panel (if needed), analog controllers, control elements, remote setpoint stations, cascade controllers, sequence logic, etc. Interpanel communication is also necessary via telephone, radio or the like.

Instrumentation - Flow meters, chlorine analyzers, thermocouples, level sensors, etc.

Installation - Installation costs are higher than manual control since controllers must be wired and installed. Centralized systems include more hardware and require more installation.

Software - None.

Operating Costs - Generally speaking, one operator per shift is required per analog panel or panel grouping except in small plants where an operator can handle several panels due to low flow or intermittent operation. A central analog configuration in a large plant would require more than one person in the control room. When two or three panels are in close proximity of each other, one operator can effectively manage all of them as long as the dynamics are reasonable.

Maintenance - Maintenance of the control system elements is extremely critical to analog systems. A good preventive maintenance program is necessary. A large number of maintenance personnel are required to maintain the sensors and controllers. This staff should be mechanical in orientation; some electronics experience would be necessary for the maintenance and repair of analog controllers, sequencing devices, etc.

Expansion - Simple expansion can cause problems and increase costs. Large analog panels are very rigid and difficult to change. Signal wiring is typically direct between process and panel and changes will necessitate additional wiring.

Savings--

Labor - Fewer operators are needed but additional maintenance personnel will probably be required. However, the net should be an overall reduction over manual control.

Chemical - Chemical feed can be paced by flow, thereby reducing total usage. Dosage rates generally remain operator entered setpoints.

Energy - Little energy savings may be realized. Consumption may be monitored and manually curtailed during peak times.

Reliability-

Because of the number of devices, reliability can be a significant problem. Backup, in the case of a controller failure, will be manual control from the appropriate panel. Sensor failure would require an operator to "guess" at current process conditions and make manual corrections accordingly.

Failure of the feedback signal in an analog control loop can cause process upsets. The controller cannot detect such occurrences and will either drive the control output closed or will "wind up" and go to full signal output. The problem with sensors "holding" a value as they become coated is severe with analog controllers.

Process Variability--

Since closed-loop control is included with this alternative, process variations may be sensed via feedback variables and appropriate adjustments made automatically. In general, this will affect variations in flow. It is still impossible to compensate for variations in the influent characteristics unless cascaded loops are included. Feedforward control is not practical.

Under local analog control, certain variations, even in flow, cannot be compensated for without operator intervention. For example, if a single variable speed influent pump is being controlled by a wet well level signal and the influent flow increases above that which a single pump can handle, the operator must manually bring a second pump on line.

Process stability and the attainment of treatment standards is not easily assured with this control system. Experience has shown that process stability is not a strong point. Each shift usually applies different theories of operation and adjustments lead to process instabilities and inconsistent results.

Control Flexibility--

The flexibility of the control system is somewhat questionable. After the panels and controllers are mounted, even a change from a flow control loop to a mass control loop is not easy. This kind of change would require the purchase of a new hardware device and reconfiguration or redesign of a panel. Hence, it is generally difficult to attain a great deal of flexibility in the control system. However, much like manual control, the operator has a great deal of flexibility in determining control strategy, device configuration and setpoint changes.

Optimization of Results--

A certain degree of optimization is possible, particularly if cascaded control is utilized. However, any attempts at optimization will be a result of manual data capture and analysis. Because of the great amount of effort required to implement any type of optimization, and the necessity of continuing it over a long period of time, it is doubtful if any great amount will, in reality, be accomplished.

Physical Space Requirements--

Substantially more space is necessary than under manual control because of the space required by the controllers. Local control panels, each with a similar requirement, and a central panel will require space.

Utility services required at each panel would typically be power air, instrument air and electric service (120 VAC). Larger panels may require environmentally controlled rooms. Location of the panels becomes a critical factor in any plant. The Occupational Safety and Health regulations will heavily affect the location because an operator will work in the vicinity of the panel for 24 hours per day. This will affect other designs such as lighting, ventilation, noise, etc. in addition to obvious problems when located in potentially wet, hot or hazardous locations.

Operator Qualifications--

The operator will need to be knowledgeable in the particular plant dynamics and process control system. Training will need to be "system" oriented and thorough. Operators must feel comfortable with the system. The operator need not be technically oriented beyond basic mechanical skills and process knowledge.

Operator Acceptance--

Operator acceptance is high. They usually feel part of the control system.

Operator acceptance quickly diminishes, however, when the number of panels and/or the complexities of each reaches a point where the operator cannot cope with the magnitude of the task. This is particularly likely in a centralized plant which grows to the point that the central control room contains a large maze of panels with many operators trying to comprehend and manage the process.

Management Information--

Data is manually gathered, calculated and reported.

Methods of Control--

The operator interfaces with the process via the various panels, and typically does not react to trends but rather to alarm events. Crisis control is very much evident. Interactions of process units are impossible to detect, much less control. Deviation alarms, indicated by the analog controllers, assist the operator in reacting to upsets. Discrete alarms (high temperature, vibration, etc.) can be audibly annunciated.

Because this system has no higher level control, off-line analytical measurements cannot generally be used to automatically correct the process. They can only be used to correct for the future and they must be analyzed and interpreted by the local panel operator.

General Usage/Local Analog--

Local analog control should be considered a viable alternative for small plants (0 to 5 mgd - 0 to 220 dm^3/s) and for specific unit processes in other plants. (For example, a plant may be all manually controlled except for chlorination which may be put under analog control because of its critical nature.)

Small plants with variable influent may utilize this alternative. Unit processes with a moderate number of control points are prime candidates.

Local analog control is generally impractical in medium or large scale plants. Communication, coordination and downtime risks are often serious drawbacks of this type of control. Labor costs can become a factor in larger plants.

General Usage/Central Analog--

Centralized analog control is applied to medium size plants (5 to 50 mgd - 220 to 2200 dm3/s). It provides coordinated control with minimal communication problems. It may become too expensive for larger processes or in geographically spread out plants where wiring costs would surpass savings.

It generally is not applied to larger plants. As the plant size increases, so do the number of control loops, the variability of the process, the reporting requirements and the process costs. Central analog control in a large plant often results in a massive control room with many long, dense and cumbersome panels which are difficult to comprehend and nearly impossible to use. Data collection alone becomes a major consideration.

General Usage/Distributed Analog--

Distributed analog control is generally applicable to medium to large scale plants (10 to 100 mgd - 440 to 4400 dm3/s). It offers centralized coordination and data collection with less wiring expense and generally more reliable operations. Maintenance can be centrally controlled and overall plant operation observed and managed.

Distributed analog is typically not applicable for smaller plants; local analog or central analog are probably better alternatives. Very large plants (100 mgd - 4400 dm^3/s and over) are probably operating under such severe cost, quality and reporting constraints that a more sophisticated alternative is warranted, although in practice distributed analog is used.

Digital Systems

Digital systems, both centralized and distributed, are discussed below. All comments are relative to both unless otherwise indicated.

Costs--

In general, digital systems cost more than do analog systems. However, this is not true in a large plant where, for example, the wiring costs of a central analog system are much greater than the cost of a digital system with remote multiplexers. Similarly, a single CPU digital system would probably cost less than an extensive distributed analog system with many different control rooms and comprehensive sequencing logic. However, the costs of developing computer software usually result in a higher cost for the digital system. Furthermore, distributed configurations typically cost more than centralized systems except when comparing a fully redundant, multiprocessor centralized system to a simple distributed application.

Capital Equipment - Includes all computers, multiplexers, maintenance panels (if needed), CRT's and other peripherals.

Instrumentation - Generally includes more on-line analyzers since the computer can make more extensive use of the information than can other alternatives. Other instrumentation (flows, levels, etc.) are the same except that all nonelectrical signals must be transduced.

Installation - Must include installation of the computer hardware, any panels and all wiring. If remote multiplexing (i.e. placing multiplexers near the process unit) is utilized, wiring costs can be reduced.

Software - Will be a significant portion of the costs. Magnitude depends upon the amount of control required.

Operating Costs - Operating personnel will depend upon process size and control system type. A single processor centralized configuration, for example, can be run by a single operator per shift. A dual processor configuration requires two. A large distributed system would probably be staffed by one operator for each subsystem and a process engineer at the central computer. One or more laborers per shift would be necessary in all instances. In general, a reduction in operating personnel can be planned for because of the centralized capability.

Maintenance - Maintenance of all sensors is critical, just as for analog and manual systems. In addition, the computer hardware requires maintenance, as does the software. A hardware maintenance contract from the computer vendor is often utilized, although larger configurations will probably warrant hiring an in-house staff. Similarly, changes to the programs (or new programming) may be contracted for with a control system supplier or an in-house capability may be developed.

Expansion - Modification of the control system is easier than with other alternatives. Control points can typically be added to the computer software in a matter of minutes; modification of control programs requires one to five days time. Wiring costs are generally the most significant cost of expansion, unless major additions to the process necessitate additional control system hardware or completely new programs.

Savings--

Significant savings may be realized over all other control alternatives.

Labor - Fewer persons are required to run the plant than with other alternatives. In addition, reports and data analysis can be handled by the computer, thereby reducing the clerical staff required.

Chemical - Chemical optimization is practical since application may be paced as a function of not only flow but of a complex set of influent characteristics as well.

Energy - Total energy costs can be reduced using a digital system. This is accomplished by minimizing consumption (reducing device starts and load balancing) and by load shedding when current consumption approaches the economical peak demand level.

Equipment Life - Process equipment life may be extended by utilizing a digital control system. The computer can minimize equipment damage due to frequent cycling and/or long periods of continuous operation. It can automatically alternate usage of redundant devices in order to even wear, and it can record run times and automatically schedule preventive maintenance tasks based on calendar time or device usage.

Reliability--

Digital control systems are generally as reliable as other alternatives. Backup can be accomplished by redundant computers or from maintenance panels. Sensor failures can be sensed and either 1) the last control output is held or, 2) an estimated value is calculated (e.g. flow calculated from a level signal). Nearly fail-safe reliability (99.9% uptime) can be achieved if necessary.

Process Variability--

A well defined and tuned digital control system can generally handle most ranges of process variability. Changes in flow, and in influent characteristics (assuming proper sensors), can be compensated for utilizing a wide variety of control techniques (feedforward, feedback, adaptive, cascade). Very tight, stable and consistent control can be achieved. Relationships between processes, process variables and laboratory data can be programmed such that effluent quality standards can be consistently achieved.

Control Flexibility--

Flexibility is provided because the control is implemented in software. Points and control algorithms may be specified on line without disturbing the process. If design errors are encountered, the previous control mode can be used without hardware changes. Typically, reports and graphic CRT displays can be altered without any disruption of the process and without significant costs.

Optimization of Results--

Because of the data capture and analysis capability of the computer, optimization is feasible and practical. Complex relationships may be determined and utilized in complicated control strategies because of the flexibility provided. Distributed systems provide the ultimate possibilities because the central computer has plant-wide data available for optimal load balancing, sludge routing and other critical and complicated subsystems.

Physical Space Requirements--

Environmentally controlled space is typically required for the computer hardware. Multiplexers require less stringent conditions. A room of approximately 10,000 square feet per central computer subsystem is generally required. Isolated power (120 VAC) is normally needed as well as a separate electrical ground. Temperature and humidity controls are necessary.

Operator Qualifications--

Operating staff, while fewer in number, must receive a significantly different type of training than with analog systems and manual systems. This is particularly true in a centralized system and at the central computer of a distributed configuration where process interactions and trends must be determined and handled.

Operator Acceptance--

Because of the ease of data display and control operations, operator acceptance comes rapidly. This is particularly true in new plants with new personnel. "System" training and knowledge is the key. Acceptance is slower when upgrading an old system (e.g. analog control to digital control), largely because of the unfamiliarity with the new methods.

Management Information--

The ability to automatically capture and report data is one of the greatest benefits of digital systems. They offer plant management the opportunity to easily and quickly collect, display and analyze current and past process data in order to determine control problems, interactions and solutions. Various governmental reports can be generated automatically.

Method of Control--

The operator of a digital control system views the process and interacts with it via a CRT display (TV tube type display and typewriter-like keyboard). Existing systems use black and white displays while most new installations utilize color displays.

Older systems use all alphanumeric displays while recent installations are depending heavily on graphic capabilities where color denotes certain conditions such as running, not running, etc., and flashing characteristics show unacknowledged alarm conditions. All conditions and readings appear in real time.

Crisis control is minimized with digital systems. The computer can sense trends, rate of change, operating limit violations, etc. and notify the operator or take independent action before an alarm condition appears. Graphic displays allow the operator to view overall trends and conditions.

General Usage/Central Digital--

Centralized digital control is most common in medium range plants (10 to 100 mgd - 440 to 4400 dm^3/s). Some application in larger plants is possible when multiple computers share the load or when applying control to only certain process units. The controlling factor appears to be the number of process data points, with 2,000 points per computer system being a practical design standard. On-line backup capabilities further increase the reliability of the system.

Today even smaller plants can justify a digital control system, as indicated in the cost effective section. Larger plants may find that the coordination necessary between multiple computer systems is too difficult, or costly, to attain and other alternates should be considered.

This control alternative should also be considered when process variability is great, regardless of plant size, since it offers more complex control ability. Data reporting requirements warrant consideration and plants which can anticipate future changes or expansion should consider this option.

General Usage/Distributed Digital--

Distributed digital appears to be the most applicable for large to very large processes (100 mgd - 4400 dm^3/s and over) and for processes with very critical uptime requirements. Applicability to smaller plants will become more practical as the use of microcomputers in "process controllers" becomes better defined and developed.

The use of this alternative should be considered when cost and reporting constraints are great, as well as when plant size and variability increase. Optimization possibilities make this type of system very attractive.

Hybrid Control Systems

Since data loggers and digitally directed analog control (DDAC) are very similar, they will be addressed in the same comparative analysis. Additionally, since hybrid control is a combination of analog and digital, references will be made to the corresponding discussions whenever possible.

Costs--

Hybrid control is generally more expensive than other alternatives since it requires the components of analog control plus a digital computer.

Capital Equipment - Includes local panels, analog controllers, control elements, pushbuttons, sequence logic, recorders, readouts, interpanel communication, computer, multiplexers, peripherals.

Instrumentation - Flow meters, analyzers, thermocouples, level sensors, etc.

Installation - Includes not only the cost of panel installation, but also the costs of installing a computer. Additionally, wiring from all field inputs must be run from the panels to the multiplexer.

Software - Software for input scanning, conversion, logging and alarming is necessary. Additionally, DDAC systems require control programs capable of analyzing process inputs and outputting control modifications.

Operation - Operating staff would be comparable to the staff requirements of the analog component of the system. The computer system will typically be a focal point for the plant or process engineer to monitor the process and will not add to the staff.

Maintenance - Maintenance can be considered as the arithmetic addition of the analog control maintenance and the costs associated with the computer system hardware and software, the latter being slightly higher for DDAC systems than for straight data loggers.

Expansion - Expansion will require that both the analog system and the computer system be expanded. The already high costs of analog expansion are increased by the digital component.

Savings--

Labor - Hybrid systems typically do not reduce labor costs beyond the savings already discussed under analog control. The possible exception to this might be in larger plants where clerical staff reductions might result from the data collection and reporting components of the computer.

Chemical - Data loggers will provide little in the way of savings beyond that offered by analog control. DDAC systems, on the other hand, will be able to make use of complex control algorithms which include capabilities to adjust dosage rates based on process analyzers.

Energy - Like chemical savings, DDAC systems offer the opportunity for load balancing and energy monitoring and control over those abilities of the analog component. Data loggers do not.

Reliability--

In general, the hybrid control system is as reliable as the analog system doing the control. Since the only interface with the process is through the analog panel, and since it is doing most of the process control, it can be considered to be the critical link. Failure of the computer system will result in a loss of data and, in the case of DDAC, a loss of the higher level control.

Process Variability--

Comments relative to analog control are appropriate to data loggers, since they provide no additional control capabilities. DDAC systems, however, do increase the capacity of the system to handle variations. These capabilities, which are the same as for digital systems, relate to the optimization and sophistication possible because of the programming aspects of the computer.

Control Flexibility--

Data loggers offer no additional flexibility over straight analog control. Even DDAC is limited, since the final output to the control elements is no more flexible than the analog panels permit. However, the fact that the computer can be programmed to provide a variety of, say, set-point calculation alternatives, will increase the flexibility.

Optimization of Results--

Data loggers will provide some assistance in plant optimization since they offer data capture, analysis and reporting abilities. Implementation would still be manual as would followup.

DDAC systems usually offer a reduced scope of capability in relation to the digital systems.

Physical Space Requirements--

The same space would be required for hybrid systems as for analog systems plus a central computer room.

Operator Qualifications--

Same as analog.

Operator Acceptance--

Same as analog, since the process operator is still located at the local panels.

Management Information--

Hybrid systems will generate the same information as the digital system will.

Methods of Control--

In general, the operator still interfaces with the process through the local panels. The process engineer will be able to oversee the entire plant via CRT displays on the computer and will be alerted by the computer to potential problems before they occur. Crisis control will be greatly reduced.

General Usage--

Hybrid systems can be generally found in plants ranging from 50 to 300 mgd (2200 to 13000 dm^3/s) and are used with manual and all forms of analog control. It offers decentralized control with full reporting abilities. They are generally too expensive for very small plants. Future growth of the microcomputer may make these systems more practical for the smaller size processes.

SECTION 4
BIBLIOGRAPHY

Amrehn, Dr. H., Report on Two Computer Installations With DDC Application. Proceedings of 22nd Annual Instrument Society of America Conference, 1967.

Amrehn, Hermann and Otto Winkler, Backup for Process-Control Computers, Chemical Engineering. March, 1970.

Bailey, S. J., Direct Digital Control-A Status Report, Control Engineering. November, 1972.

Bakke, Roger M., Theoretical Aspects of Direct Digital Control. IBM Control System Development Center.

Davis, Guy E., Jr., Hybrid Digital-Analog Power Plant Control, ISA Transactions. Vol. 9, No. 4, 1970.

Etchart, David Y. and Bipin Mishra, Survey of an On-Line Computer Control System at Metro Denver, Advances in Instrumentation, Vol. 32, Part 3. ISA, 1977.

Fraade, David, 10 Years After-A Word to the Wise, Instrument Practice. July, 1969.

Gutshall, T. L., C. F. Koch and G. Nines, DDC Initial Cost Justified, Control Engineering. January, 1969.

Harrison, T. J., Micros, Minis and Multiprocessing, Instrumentation Technology. February, 1978.

Lloyd and Anderson, Industrial Process Control. Fisher Controls Company, 1971.

Lombardo, J. M., The Place of Digital Backup in the Direct Digital Control System. Spring Joint Computer Conference, 1967.

Marks, Charles H., Digital Process Control System Development, Pipe Line Industry. June, 1967.

Minimizing Process Computer Maintenance, Instrumentation Technology, Vol. 15 No. 1. January, 1978.

Miller, James G., Introduction to Digital Control, Instruments and Control Systems. March, 1971.

Nagel, Carl A., State of the Technology Semi-Automatic Control of Activated Sludge Treatment Plants. National Technical Information Service, U.S. Dept. of Commerce, 1975.

Parsons, J. R., M. W. Oglesby and D. L. Smith, Performance of a Direct Digital Control System. Applied Automation, Inc.

Poisson, Normand A., Interfaces for Process Control, Textile Industries. March, 1970.

Rice, Raymond E. and George A. Mathes, A Demonstration Direct Digital Control of a Vacuum Filter, Advances in Instrumentation, Vol. 32, Part 3. ISA, 1977.

Roesler, J. F., Evaluation of the Effectiveness of Automation, Research Needs for Automation of Wastewater Treatment Systems. USEPA, 1975.

Senstrom, Michael Knudson, A Dynamic Model and Computer Compatible Control Strategies for Wastewater Treatment Plants. Clemson University Doctoral Dissertation, 1975.

Shinskey, F. G., Process Control Systems. McGraw Hill.

Skaggs, W. L. and R. M. Johnson, Economic Application of Direct Digital Control. Workshop on the Use of Digital Computers in Process Control, Louisiana State University, March 10, 1967, The Foxboro Company.

Smith, Cecil L., Digital Computer Process Control. Intext Educational Publishers.

Systems Control, Inc., Demonstration of Digital Computer Application in a Wastewater Treatment Plant, City of Palo Alto, California, 1974.

Williams, T. J., Computers, Automation and Process Control Annual Review, Ind. Eng. Chem.

Zikas, Algirdas J., Hardware Requirements for a Typical DDC System. The Foxboro Company.

SECTION 5

COST EFFECTIVE ANALYSIS

INTRODUCTION

When automating a wastewater treatment plant, several alternate control approaches, described in Section 4, are available to the design engineer. Field observations during the plant visits revealed that the use of multiple conventional control areas often leads to poor operation and an unmanageable situation. Centralization can alleviate these problems and may be used if the additional capital costs are offset by savings in operating costs.

Although centralization of control has not been widely used to date in wastewater treatment facilities, there are a few installations in the field which have utilized the approach and have documented the savings. (1)(2)(3) The installations have shown that with centralization there is a substantial decrease in the number of operating positions, some increase in maintenance positions resulting in a net decrease in manpower costs. For example, the new Cedar Rapids, Iowa 39 mgd treatment plant with centralized digital control is a more complex plant and treats twice the flow of the two conventionally controlled treatment plants it replaced. However, the new plant operational staffing requires only one more person than staffed at the two old plants. The centrally controlled plant staff consists of 20 operators, a reduction of two operators and 20 maintenance personnel, and an increase in three maintenance people.

A cost effective analysis should be performed to determine which control approach would be the most economical solution for the application. Once this economic information is obtained, the design engineer can then analyze other control design features and capabilities that may be less tangible but no less important in selecting the control design approach. These areas of consideration were discussed in Section 4.

This cost effective analysis should be prepared on a "systems" basis reflecting the estimated capital investment, operation, maintenance, materials (chemicals) and energy costs for the alternate control systems accomplishing the same control functions. The potential savings in operation, maintenance, chemicals and energy costs obtainable by the application of varying levels of automation and centralization should be examined in relation to the associated capital investments required for the control systems.

This section documents a technique for performing a cost effective analysis of alternative control systems. The procedure is presented by comparing the costs of three types of commercially available control systems (distributed analog control, centralized analog control and centralized digital control) for five plant sizes (5, 10, 50, 100 and 300 mgd) with the same general unit process flow sheets. The flow sheets were modified only to reflect the appropriate unit processes for each plant size.

The cost information utilized in this section is for these generalized treatment schemes and should not be used for application to any other specific analysis. The numbers are presented as a method of demonstrating the cost analysis technique. A control system cost effective analysis must be customized to an actual process flow sheet and an actual staffing plan with all local conditions considered.

TREATMENT PROCESSES SELECTED

Two types of wastewater treatment processes were selected by the EPA for use as example applications for automation in this cost effective analysis (Figures 5-1, and 5-2). The processes selected for the various treatment plant sizes include: 1) conventional activated sludge, anaerobic sludge digestion (sludge stabilization), sludge drying beds; and 2) conventional activated sludge, anaerobic sludge digestion, sludge incineration (sludge disposal). Both include a main lift, diffused aeration, chlorine disinfection, plant water pumping, return liquors pumping and scum handling. The conventional activated sludge process includes bar screens, aerated grit chambers and primary treatment.

The treatment process configurations developed for the five plant sizes are hypothetical, but are in accordance with current design practices and standards (4)(5). The processes are configured as nearly alike as possible so that general comparisons between control systems and trends can be clearly indicated.

Piping and instrumentation drawings (P&ID's) are included in this section to illustrate the treatment process and the application of automation for the five plant sizes. A symbol sheet and device lettering table (pages xi, xii) describe the equipment shown on the P&ID's. For simpilicity, analog control instrumentation symbology is used in the schematics. For the digital systems however, much of the control hardware shown would be replaced by software control programming in the central computer.

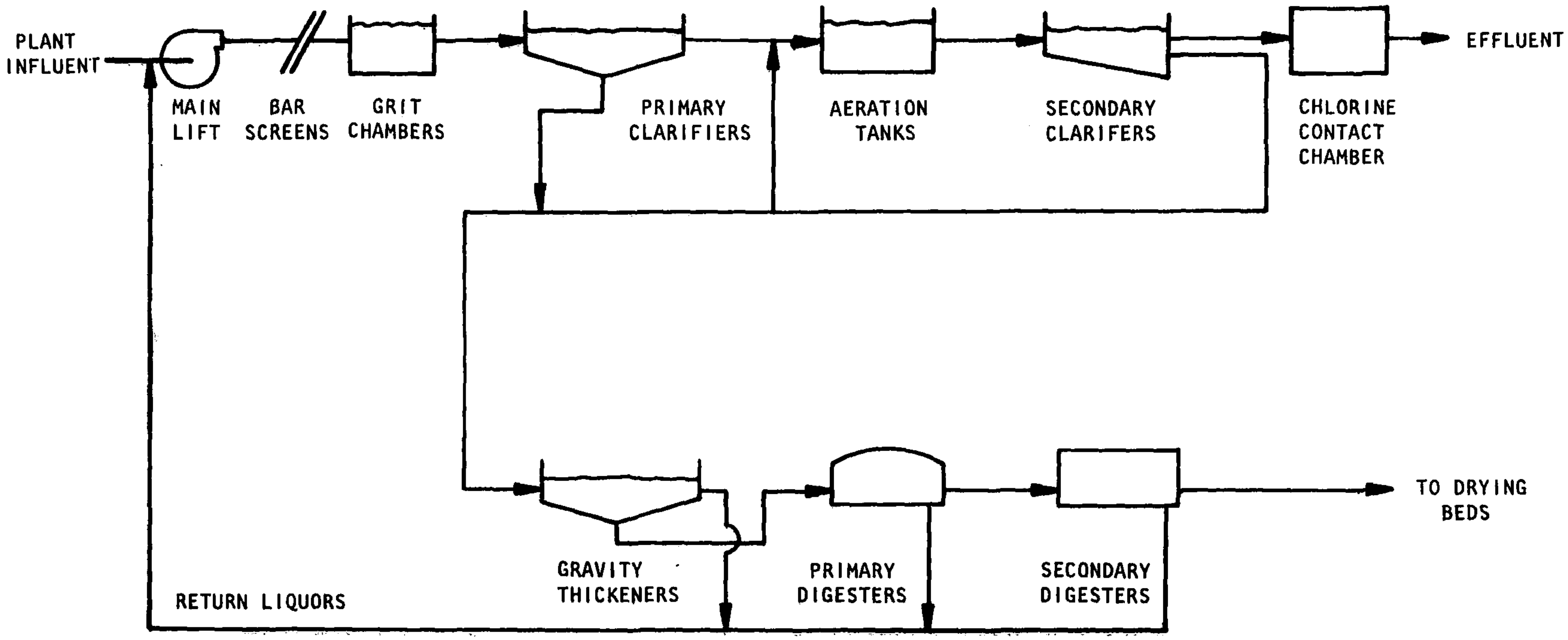


Figure 5-1. Conventional activated sludge with drying beds.

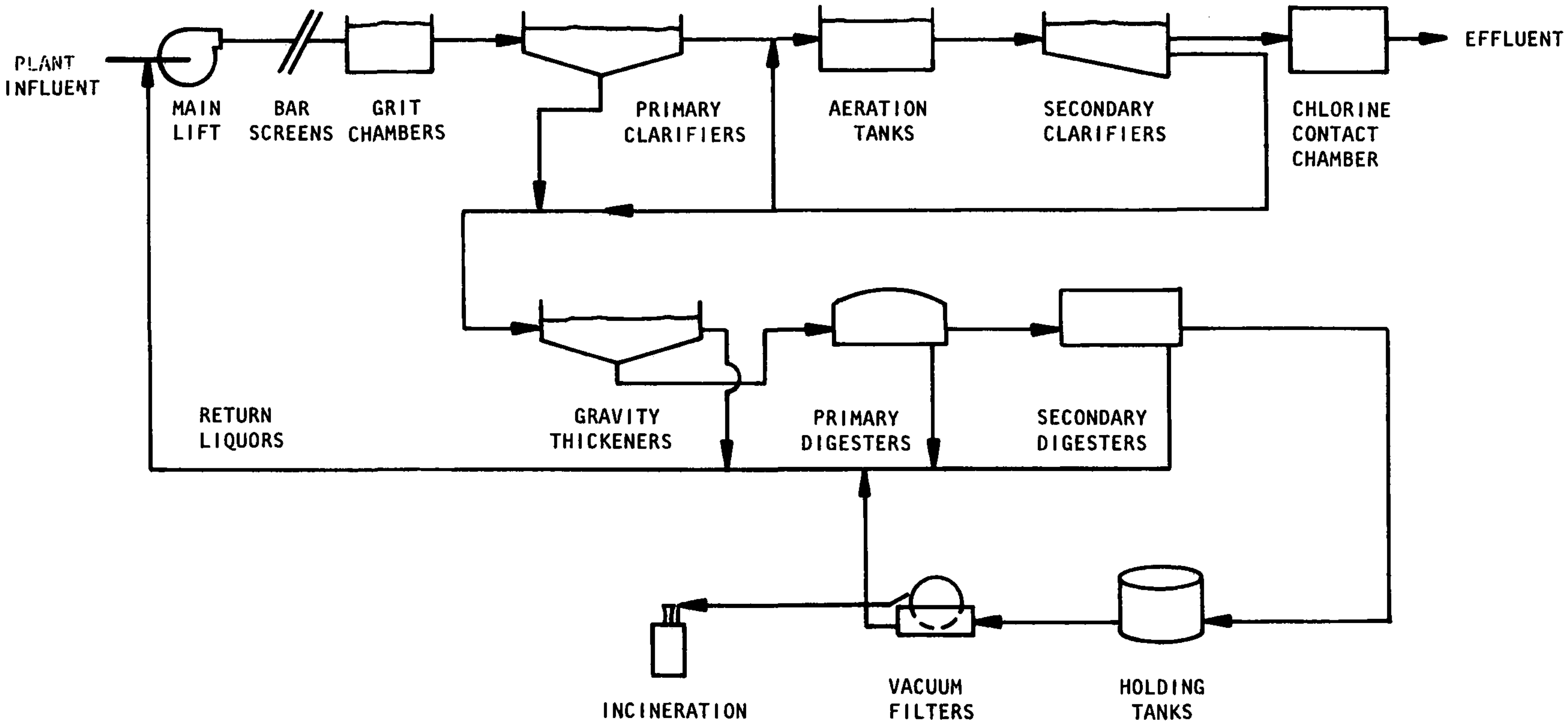


Figure 5-2. Conventional activated sludge with incineration.

Conventional Activated Sludge With Drying Beds

The 5 mgd (220 dm^3/s) plant is detailed in Figures 5-3 and 5-4. Raw sewage and return liquor is lifted from respective wet wells by dual variable speed pumps. Preliminary treatment consists of mechanically cleaned bar screens and aerated grit chambers. Variable volume centrifugal compressors supply air for the grit chambers. The flow is split between two circular primary clarifiers. Clarifier overflow is mixed with return activated sludge and passes to plug flow diffused air aeration chambers. The mixed liquor flow is split between two rectangular secondary clarifiers. The plant effluent is disinfected with chlorine before discharge. Secondary clarifier underflow is discharged into a sludge wet well. Return activated sludge is boosted by dual variable speed pumps. Plant water is supplied by two constant speed pumps. Solids handling consists of gravity thickening, anaerobic digestion and sludge disposal on drying beds.

Conventional Activated Sludge With Incineration

Figures 5-5 and 5-6 detail the liquid and solids train piping and instrumentation for the 10, 50, 100 and 300 mgd plants (440 through 13000 dm^3/s). The liquid train processes are the same as the 5 mgd (44 dm^3/s) plant with changes only in equipment sizes and quantities to match the flow. Sludge is stabilized via anaerobic digestion, vacuum filtered and incinerated.

PROCESS CONTROL STRATEGIES

The following brief process control descriptions establish the level of control for each unit process in the various treatment plant sizes. Not all process control strategies described apply to all treatment plant sizes. Refer to the process piping and instrumentation drawings, Figures 5-3 through 5-6, for the unit processes applicable to each treatment plant size.

Influent Pumping

Multiple, variable speed lift pumps are controlled by the raw sewage wet well level. Pump speed ramps up or down and pumps are sequenced on or off in response to wetwell level.

Preliminary Treatment

Bar Screens--

Bar screen cleaning is controlled by a time clock or high level differential across the screen on the larger plant sizes.

Grit Chambers--

Degritting equipment is controlled by a time clock. Air flow is controlled in relation to hydraulic flow in the larger plants.

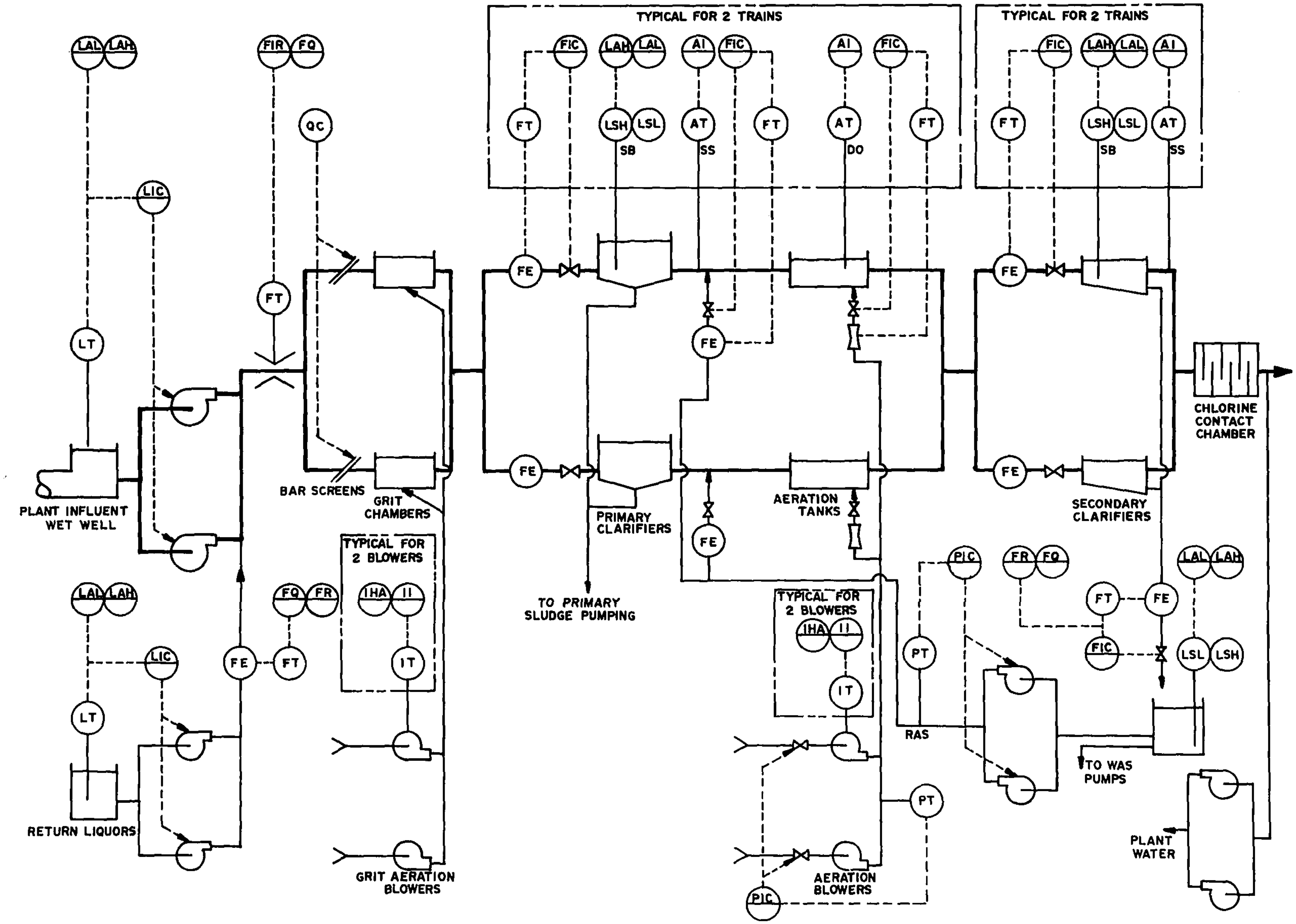


Figure 5-3. Liquid train P&ID - 5 mgd.

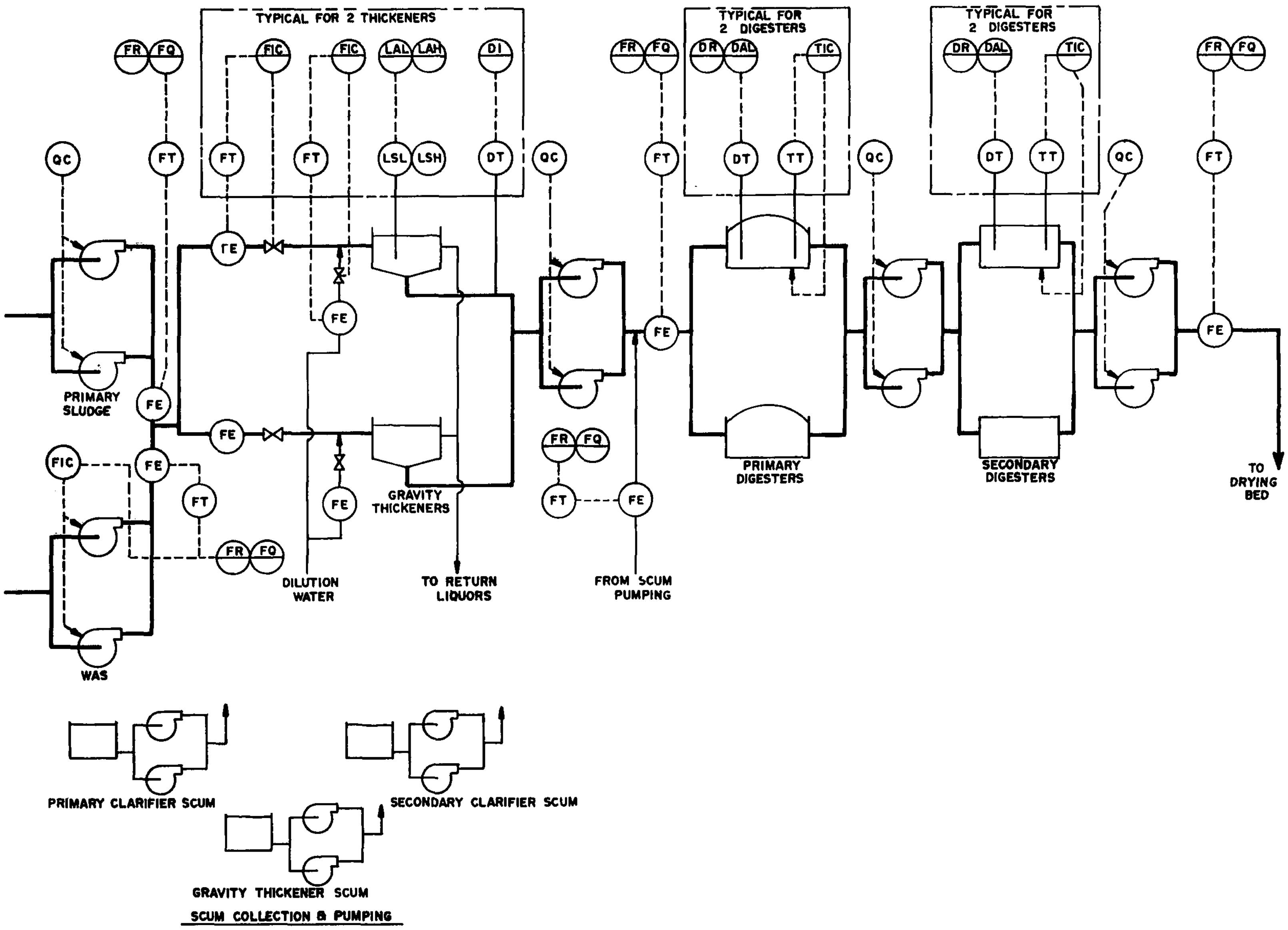
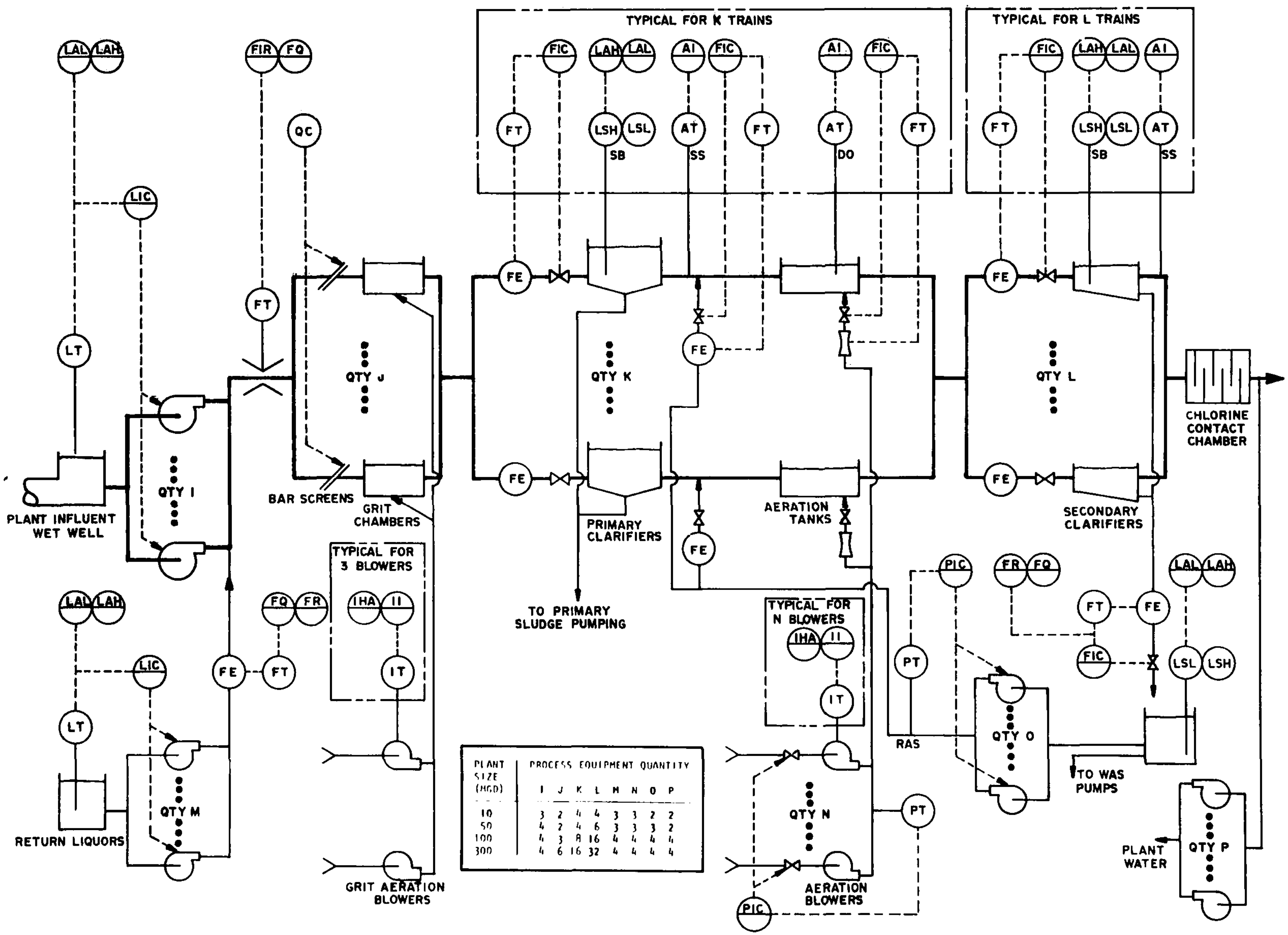
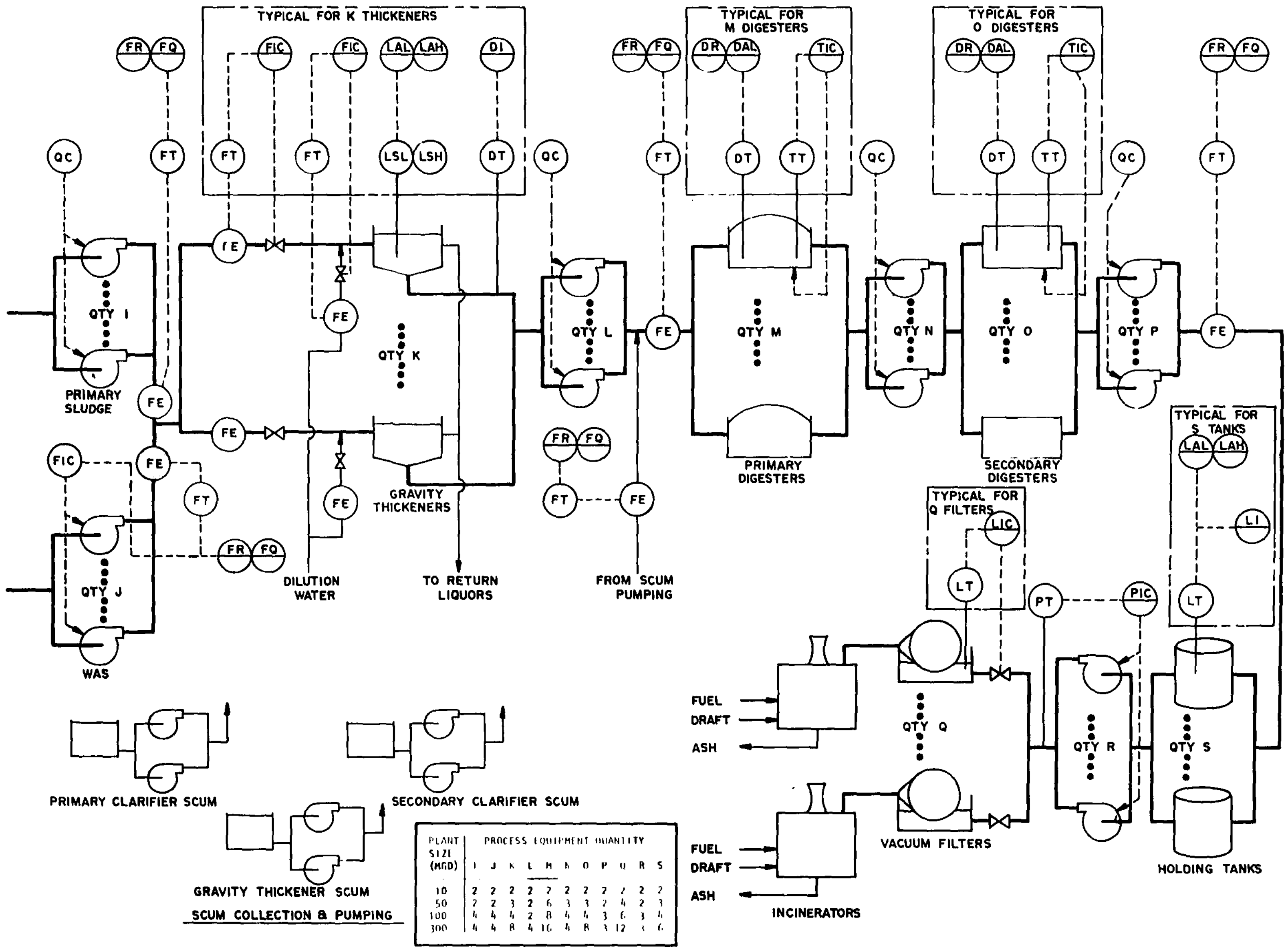


Figure 5-4. Solids train P&ID - 5 mgd.



PLANT SIZE (MGD)	PROCESS EQUIPMENT QUANTITY							
	I	J	K	L	M	N	O	P
10	3	2	4	4	3	3	2	2
50	4	2	4	6	3	3	3	2
100	4	3	8	16	4	4	4	4
300	4	6	16	32	4	4	4	4

Figure 5-5. Liquid train P&ID - 10 to 300 mgd.



PLANT SIZE (MGD)	PROCESS EQUIPMENT QUANTITY										
	I	J	K	L	M	N	O	P	Q	R	S
10	2	2	2	2	2	2	2	2	2	2	2
50	2	2	3	2	6	3	3	2	4	2	3
100	4	4	4	2	8	4	4	3	6	3	4
300	4	4	8	4	16	4	8	3	12	3	6

Figure 5-6. Solids train P&ID - 10 to 300 mgd.

Primary Clarifier

Flow to multiple clarifiers is dynamically divided by a flow splitting control scheme (see Hydraulic Flow Control, Section 3). Unequal flow balance is available to compensate for variations in performance among the clarifiers. Sludge withdrawal is based on blanket level and sludge density with timer overrides.

Aeration

Multiple, variable flow compressors maintain a constant pressure on a common discharge header. Flow control valves regulate the air flow to each tank based on dissolved oxygen. Density compensated RAS flow is ratioed to influent flow.

Secondary Clarifier

Flow to multiple clarifiers is dynamically divided by a flow splitting control scheme. Unequal flow balance is available to compensate for hydraulic inequalities. Sludge withdrawal is based on sludge blanket level and sludge density or timer overrides.

Chlorination

Chlorine application is ratio controlled based on the treatment plant influent flow to the contact chamber influent with chlorine residual feed-back control.

RAS Pumping

RAS pumping is ratio controlled based on the influent flow to the treatment plants. Multiple, variable speed return activated sludge pumps are controlled based on the flow demand in a common discharge header. Sludge wet well level controls are provided to override on high and low level.

WAS Pumping

Multiple, variable speed waste activated sludge pumps are flow ratio controlled based on a manual flow control setpoint. Sludge wet well level control overrides on high and low level.

Return Liquors Pumping

Multiple, variable speed lift pumps are controlled by the return liquors wet well level. Pump speed ramps up or down and pumps are sequenced on or off in response to the variable load.

Gravity Thickening

Flow to multiple gravity thickeners is dynamically divided by a flow splitting control scheme. Unequal flow balance is available to compensate for performance inequalities. Underflow withdrawal is based on blanket level and sludge density with timer overrides. Dilution water is flow ratioed to gravity thickener influent flow.

Anaerobic Digesters

Primary and secondary digester feed and withdrawal are controlled by timers and density sensors. The digester temperature is controlled. Digester gas flow and composition are related to the process performance, but are not incorporated into the process control.

Drying Bed Pumping

Drying bed feed pumps transfer digested sludge on a timed basis.

Sludge Holding

Fill and withdrawal to holding tanks is controlled by sequence logic and high/low limit relays.

Vacuum Filtration

Sludge is withdrawn from the holding tanks by variable speed pumps discharging to a common header. Pump speed is a function of header pressure. Sludge is transferred to the individual vacuum filters based on vat level. Chemical addition (lime and ferric) is ratioed to the density compensated sludge flow to each filter.

Incineration and Flue Gas Scrubbing

Fuel and combustion air flows are based on load and temperature. The secondary combustion air flow into the incinerator is controlled by an oxygen measurement in the flue gas. Induced draft is controlled to maintain a slight negative pressure in the incinerator. Scrubber water, chemical addition and blow down is controlled by differential pressure and sequence timers.

CONTROL SYSTEM CONFIGURATIONS

For the purpose of a cost effective analysis demonstration, three commonly used control system configurations are applied to five activated sludge process wastewater treatment plant sizes ranging from 5 to 300 mgd (220 to 13000 dm^3/s). Using terminology defined in Section 4, the configurations are: 1) conventional (distributed analog) control; 2) central analog control; and 3) central digital control. Figure 5-7 illustrates an example of the control panel configurations used in the three types of systems analyzed and defines three levels of equipment locations (field, local and central).

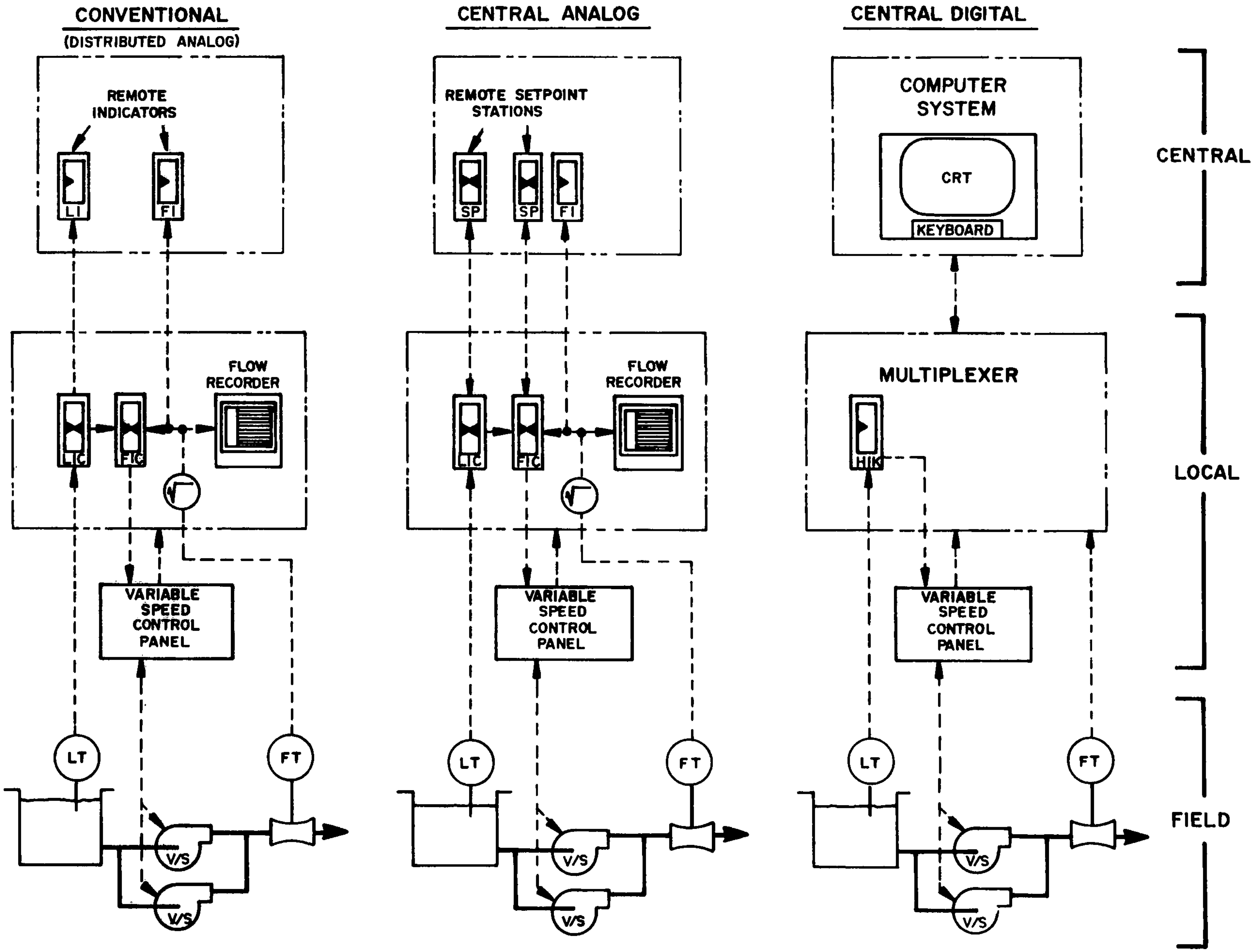


Figure 5-7. Control system panel comparison.

Field Mounted Equipment

Field mounted equipment includes instrumentation, final control elements such as valves and pumps, motors, motor controls, field control (maintenance) panels, and the associated wiring between this equipment and the local control panel or multiplexer. Instrumentation includes items such as flow meters, flow transmitters, pressure transmitters, level transmitters and analytical sensors (e.g. DO probes, etc.). The same field mounted equipment is utilized regardless of the alternate control system employed. Pneumatic instrumentation is not considered in this comparative analysis since it is not normally used with digital control.

Primary elements such as flow tubes are installed for measurement of the desired variables. The accompanying transmitters are mounted as near as possible to the primary devices and maintenance panel. The transmitter signals are wired to the local control panel or multiplexer. Signal conditioning devices, primarily square root extractors for flow signal linearization, are mounted in the local panel.

Final element positioners such as motors, pneumatic or hydraulic systems are used to control the variable final control element. The pneumatic and hydraulic positioners require field conversion of the modulating control signals transmitted to these devices. A means of manual operation for each final element is provided at that element for maintenance and emergency control purposes.

Motors are controlled through motor control centers (MCC) which include disconnects, starters and related circuits. Manual controls for the motors are installed at the motor control center, at the motor, or at both locations to aid maintenance and startup operations. Related control circuits consist of variable speed drives, start/stop functions and motor protection equipment including vibration monitors, interlocks and sequence logic.

Field maintenance panels are utilized in all three alternate control systems. For the smaller plants, the maintenance equipment will be located at the device. For the larger plants, the maintenance controls will be located at panels having control for a number of related pieces of equipment.

Conventional Control System (Distributed Analog)

The conventional control system is a localized manual/analog system common at small wastewater treatment plants or at individual unit processes in large treatment plants. The basis of this control is to divide the treatment plant into major subsystems, generally along unit process boundaries. Divided into multiple operating centers in this way, the plant can be staffed by operators experienced in selected areas. Each unit process has one or more control panels with all the necessary controllers, recorders, information and status indicators, switches, etc. required to operate the process. The panel is usually located in the vicinity of the equipment to be controlled at smaller plants and in area control rooms at larger plants. Verbal and written communication between operators is required for process coordination and maintenance. The communication is often inadequate which causes diversified and, at times, conflicting process decisions.

The analog control equipment includes indicators for process variables and final control elements. The controllers have switches for selecting automatic or manual mode, setpoint adjustments, manual final element adjustments plus bias, gain and rate adjustments. Internally mounted components include signal conditioners, arithmetic modules, integrators, timers, sequencers and relays.

Motor control on these panels is usually limited to start/stop pushbuttons. Most of the interlocking relays and the magnetic starters are housed in a separate motor control center. Rotating and mechanical equipment is monitored for operational status, alarm and shutdown conditions. These conditions are indicated on the panel by lights, meters and annunciator panels.

A minimal number of process parameters, status and alarm signals from each control panel are wired to a central monitor panel. The information displayed is limited to a few critical process parameters, an alarm indicator for each process, and alarm and status indications for selected equipment. The central monitor panel does not have any control provisions.

Central Analog Control System

A central analog system controls all operations from one central location. In practice, this is only practical at small plants because much of the local control panel equipment consists of internally mounted components (relays, timers, etc.) which would require excessive wiring to centralize. This is a popular approach in other industries where separation distances are smaller but is a rare occurrence at wastewater treatment plants larger than 50 mgd. In general practice, most of the information and control capabilities available from the panel mounted devices on the local panel are made available at the central location; the local panel remains essentially the same as in a conventional control system. The analog controllers are located in the local panels and connections are made to remote setpoint stations in the central control panel. (As an alternative, the controlling equipment may be located in the central control room and the local panels used for backup operation only.) Additional controllers and panel instrumentation for cascade, feedforward and closed-loop interprocess control can be incorporated. Some switches, alarm annunciators, panel lights and meters are duplicated on both local and central panels. Most of the process recorders remain in the field since much of the recorded data is necessary only for upset and process failure analysis. The local mounting of recorders reduces the complexity of the central analog panel.

A subtle yet important difference exists between the conventional and central analog control approaches. The large increase in duplicate instrumentation and control is evident in central analog control, but the advantages of centralizing plant control must be considered. Under a conventional control approach, process decisions are made by local operators distributed throughout the plant. The decisions made by these operators are based on the information available to each individual operator. The operators have limited communication with each other which may lead to situations where conflicting process control decisions may be made. The centralized control approach improves information availability so that a operations supervisor can coordinate actions that may affect several processes. Process data from the entire plant is available to the plant engineer at a central location and allows all control decisions to be made and implemented from the plant central control room.

Central Digital Control System

Central digital process control can be implemented using centralized hardware or distributed hardware, depending upon the location and number of computers. In either configuration, operators are stationed at a central location and their interface with the control system is basically the same. Digital control using distributed hardware will not be considered in this analysis, however. The computer control system configuration chosen for the various plant sizes are shown in Figure 5-8.

The digital control systems in this analysis make use of multiplexers to reduce the wiring required to the central location. The cost of a multiplexer can be offset and possible additional savings realized due to the elimination of the voluminous amount of interconnecting wiring that would otherwise be required. Multiplexers are equipped with circuitry for interfacing the central computer to the field equipment. Analog and discrete inputs from field equipment are converted to digital signals and are transmitted to the computer. Similarly, digital signals from the computer representing modulating outputs or discrete control outputs are received by the multiplexer and are converted from digital form to a form acceptable to the field devices. The four input/output classifications are as follows:

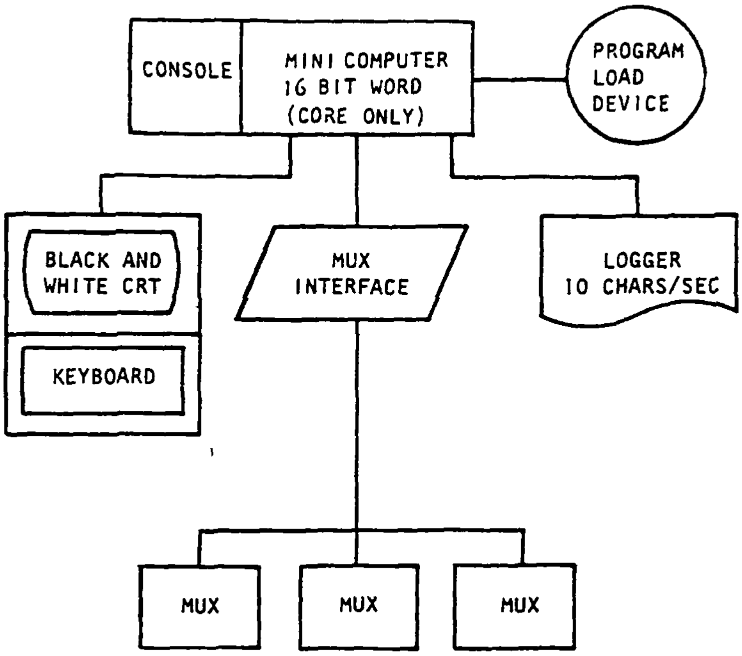
Analog Input (AI)--Analog inputs consist of signals wired to the multiplexer representing process variables such as level, flow or pressure. The input signals could be in the form of variable current, voltage, resistance, pulse rate or pulse width.

Modulating Output (MO)--Modulating outputs include positional type analog outputs and incremental (velocity type) outputs. In either case they are used to control the operation of devices such as control valves or variable speed pumps.

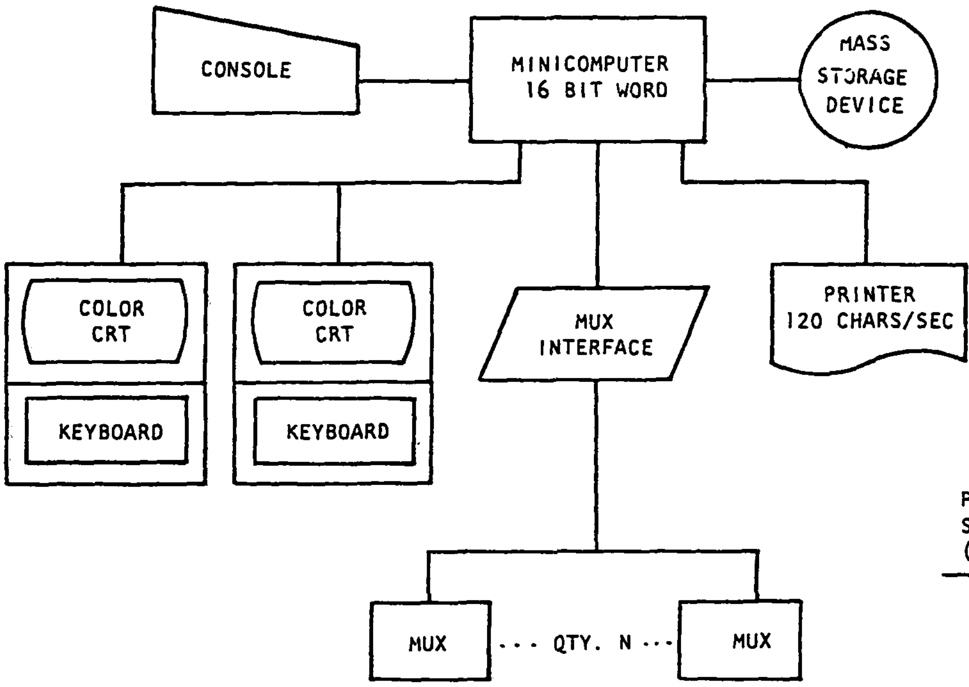
Digital Input (DI)--Digital inputs are in the form of an open or closed electrical contact wired to the multiplexer. The inputs represent status, device position or alarm conditions.

Control Outputs (CO)--Control outputs are used for operating two-state control devices such as motors (start/stop control) or valves (full open/close control). These outputs are in the form of relay contact outputs from the multiplexer.

a) Hardware configuration - 5 mgd



b) Hardware configuration - 10 to 300 mgd



PLANT SIZE (MGD)	QTY. OF MUX'S (N)
10	7
50	8
100	11
300	14

Figure 5-8. General central digital system configuration.

Locally mounted multiplexers can accommodate large quantities of the above type signals. Communication with the central computer is via a high speed data channel which requires only a few wires.

Analog controllers and other instrumentation found in analog control panels are replaced by computer control programming (software). All modulating outputs from the computer are interfaced to field equipment through manual loading stations.

In place of the large central panels used in conventional and central analog control, one or more cathode ray tube (CRT) monitors and keyboards are used. The CRT displays are generated by the computer and can include dynamic process graphic diagrams as well as simulations of controllers, indicators, annunciators, recorders or any other panel mounted device. Information pertinent to any subprocess, process or group of processes can be displayed on demand. The operator can manipulate the process via the keyboard as if a portion of a central analog control panel were before him. The digital control system retains all the advantages of central analog process automation without incurring the costs of a large hardware installation. A digital control system also offers additional features and advantages which were discussed in Section 4. It should be emphasized that for the purpose of an equal comparison, only those control strategies performed by the conventional and central analog alternate control systems for each of the individual processes are implemented by the digital control system to closely model the analog control approach.

The 5 mgd (220 dm^3/s) plant configuration includes a small minicomputer with core resident software. Report generation includes event and alarm logging, daily reports and monthly summaries. Process optimization and Management Information System (MIS) functions are not included.

The 10, 50, 100 and 300 (440, 2200, 4400 and 13000 dm^3/s) plants incorporate disk memory based operating systems. The disk system allows additional reporting functions including maintenance scheduling, trending, greater historical data storage and recovery. Dynamic process graphic diagrams are available for display on a color CRT operator's console.

A low speed logger is provided for the 5 mgd plant. These loggers typically print at a rate of 30 to 130 characters per second. A high speed printer is provided for the larger plants to accommodate the larger report volume requirements. These printers typically print at rates of 400 to 600 characters per second.

ASSUMPTIONS USED IN EQUIPMENT & WIRING COST COMPARISON

To compare the three control alternatives on an equal basis, the following assumptions have been made:

Field Mounted Sensors and Control Elements

These equipment items are utilized regardless of the control system chosen because the same variables must be sensed and controlled. Consequently capital and recurring cost estimates for these devices are not included in this analysis.

Maintenance Panels

Periodic inspection, calibration and maintenance will be necessary for all components of the process control system including sensors and control devices. Operators and technicians should have a means of manual control from a local maintenance panel. For the smaller plants, these panels are adjacent to each device. For the larger plants, these panels are in convenient areas grouping a number of devices on a single maintenance panel. These maintenance panels also serve as a backup control panel in the event that a failure disables any portion of the control system. Cost and reliability considerations dictate that these maintenance/backup panels be as simple and straightforward as possible. The panel should, however, contain sufficient equipment to perform selected critical tasks. Since these panels are common to all three alternative control systems, they are not included in the cost estimates.

Level of Control

The three alternate control systems are configured as nearly identical in control executions as possible. Conventional control requires operators to implement the strategies. Analog and digital automation have the potential of reducing operational labor, but require higher capital investment and cost more to maintain. The computer control system detailed in this cost comparison is not truly representative of a typical installation because it simply emulates an analog control system. Because it is difficult to quantify the capabilities and flexibilities of a computer based system, in most cases they are ignored. In cases where they could be quantified, the savings are shown in the material and energy savings analysis.

EQUIPMENT COSTS

Table A-1 in the Appendix of this section lists the material cost, installation cost and total unit cost for the analog instrumentation and equipment used in the conventional and centralized analog control approaches. Cost estimates represent second quarter 1978 averages. It has been assumed that the control panels are preassembled, wired and tested at the factory, and that external wiring connections are made on screw type terminal strips.

The control equipment quantities and costs for conventional analog control in 5 mgd to 300 mgd plants are summarized in Appendix Tables A-2 through A-6. These schedules indicate the instrumentation and control requirements, excluding field mounted equipment, for each unit process within the example treatment plants.

Similarly, quantities and costs for central analog control are summarized in the Appendix in Tables A-7 through A-11.

Each unit process to be controlled by a central digital control system is evaluated in terms of the input/ output signals required for monitoring and control. The computer input/ output (I/O) for each plant size is summarized in the Appendix in Tables A-12 through A-16. Equipment costs listed in the Appendix in Tables A-17 through A-21 for the five digital computer control systems are based on past experience, manufacturing costs and the I/O point counts. As stated earlier, the costs are based on a digital computer system emulation of an analog control system. For this reason, the total cost estimates, particularly the memory size and software man-hour estimates, are not as high as would be expected if complex advanced algorithms and management information processing were involved. This is particularly true for plant sizes 50, 100 and 300 mgd (220, 440 and 13000 dm^3/s).

The control equipment costs for each alternative control system are plotted as a function of plant size in Figure 5-9. The control costs do not include the field mounted sensors, final control elements and the maintenance panels because they are common to each alternative control system. As a check on the reasonability of these control costs, the total estimated capital costs for the five plant sizes were calculated using the EPA executive costing program.(6) Three percentages (.1%, 1%, and 10%) of the total plant costs were calculated and plotted in Figure 5-9 for comparison.

Control wiring, which may add a significant amount to the installed cost of the control equipment, is treated separately in the next section and is not included in the above comparison.

CONTROL WIRING COSTS

The cost of control wiring is individually analyzed for the three alternative control systems and the five plant sizes. The analysis starts with calculation of the cost per pair foot of discrete, analog and digital wiring.

Wiring cost calculations are based on Building Cost Data 1977 (7). The costs per pair foot are derived by summing material, installation, and overhead and profit (O&P) costs. Termination costs are $1.76 per pair. Three types of wiring are considered:

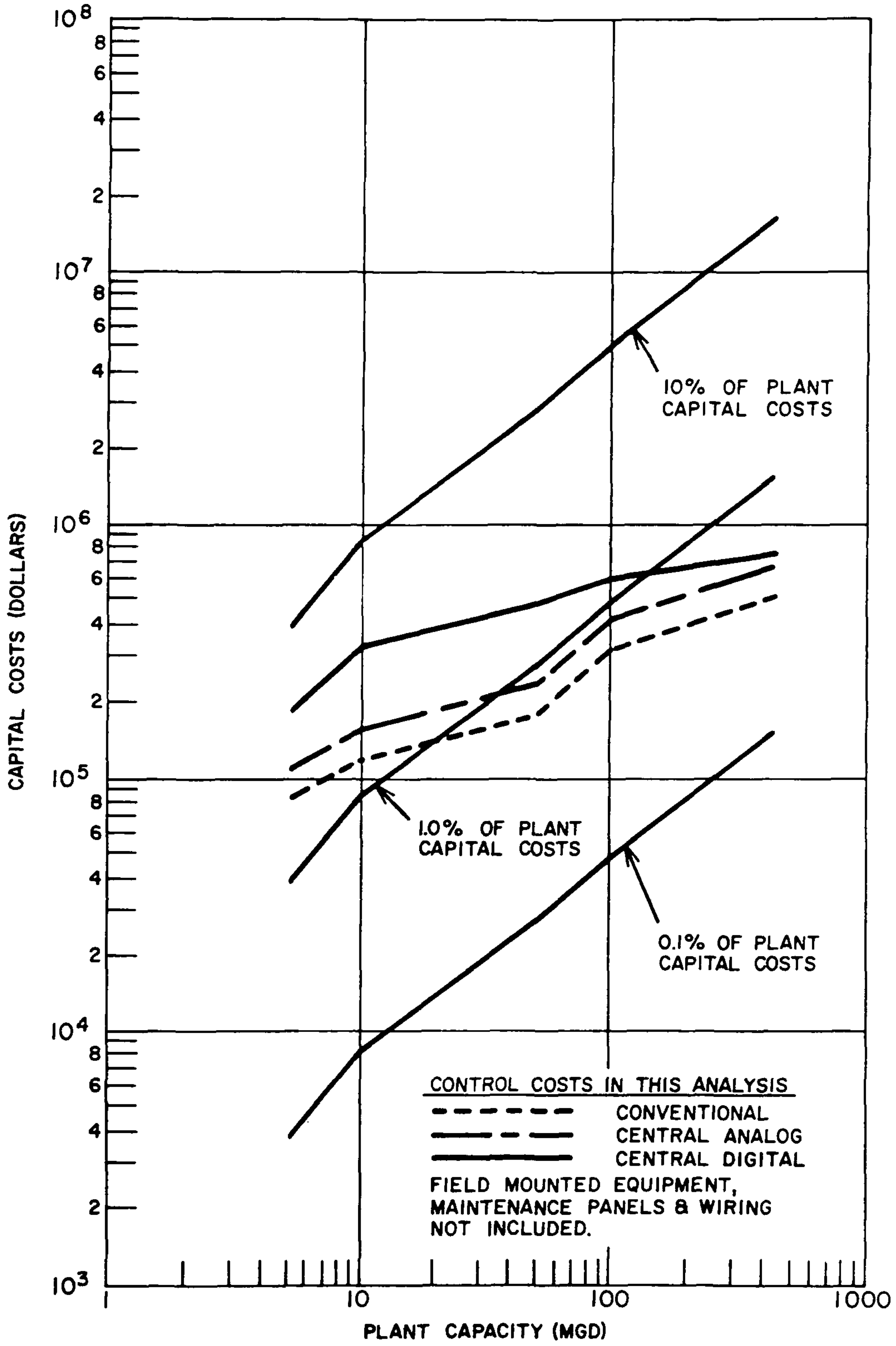


Figure 5-9. Alternative control system costs.

Discrete Signal Wiring

This is typically wiring from output relays to field control relays, magnetic starters and solenoids or wiring from status and alarm contacts from field equipment. Two #12 AWG stranded conductors constitute one pair. Seven pair are installed per 1½" rigid conduit.

Discrete	Material	Installation	O & P	Total
(2) #12	2(.039)	+ 2(.063)	+ 2(.0285)	= .2610 $/Pr. Ft.
7 Pr./1½ Conduit	1/7(1.35)	+ 1/7(2.00)	+ 1/7(.95)	= .6143 $/Pr. Ft.
				.8753 $/Pr. Ft.

Analog Signal Wiring

This wiring is typically for 4-20 ma or 1-5 volt signals. Two #14 AWG stranded conductors with an overall plastic jacket constitutes one pair. Seven pair are installed per 1½" rigid conduit.

Analog	Material	Installation	O & P	Total
#14 Pr	.2100	+ .09	+ .05	= .3500 $/Pr. Ft.
7 Pr./1½ Conduit	1/7(1.35)	+ 1/7(2.00)	+ 1/7(.95)	= .6143 $/Pr. Ft.
				.9643 $/Pr. Ft.

A single composite cost for the discrete and analog signal wiring was developed to simplify the analysis. A distribution of 47% discrete wiring and 53% analog wiring was chosen. This yields a composite pair cost of $0.92/Pr. Ft.

Digital Signal Wiring

High speed, low level data link is used to connect the multiplexers and the computer. Two #14 AWG stranded conductors with an overall plastic jacket constitutes one pair. Two pair are installed per 3/4" rigid conduit.

Digital	Material	Installation	O & P	Total
#14 Pr.	.2100	+ .09	+ .05	= .3500 $/Pr. Ft.
2 Pr./3/4 Conduit	1/2(.62)	+ 1/2(1.58)	+ 1/2(.65)	= 1.4250 $/Pr. Ft.
				1.7750 $/Pr. Ft.

Wiring requirements are developed from the schedules of equipment mounted in the centralized monitor panel or the central control room for the conventional and central analog control systems respectively. The wiring for field mounted equipment that is independent of the choice of the control configuration (level transmitters, flow transmitters, etc.) is not included in the wire count. The wiring analysis for a digital control system requires a schedule of multiplexer locations to determine the pair requirements.

The wiring distances are developed from a model of each treatment plant. The process centers maintain the same relative position on a square plant site. The area of the plant site varies in a simple relationship to capacity. The land area (exclusive of expansion space) per mgd capcity was estimated from several actual plants. An average value of 50,000 square feet for each mgd was derived.

Comparative wiring costs for the three alternate control systems in each plant size are shown in the Appendix in Tables A-22 through A-26 for conventional control. Tables A-27 through A-31 are for central analog and Tables A-32 through A-36 are for digital control. The digital multiplexer assignments are shown in Table A-37.

Control equipment costs developed previously and wiring costs for the alternate control systems are summarized in Table 5-1 for comparison purposes. It should be noted that these are initial or nonrecurrent costs. Wiring costs for conventional control are minimal because very little information is brought back to a central location as discussed earlier. Wiring costs for central analog control are high due to the fact that more information and control signal wires are routed to the central location. Substantial savings in wiring costs are achieved in digital systems because wiring is reduced by the use of multiplexers. These savings are partially reduced by the cost of the multiplexers.

MANPOWER ANALYSIS

The primary objective of process centralization and automation is to reduce the dependency on operational labor. The decreased operational dependency is attained by adopting an "operation by exception" philosophy where events out of the ordinary are detected by the control system and annunciated to an operator for action, thus reducing or eliminating labor required for routine monitoring of equipment and manual data logging.

The potential annual cost savings due to centralization are significant. The cost of labor for operations and maintenance of a typical wastewater treatment facility normally approaches one-half of the total operating budget. If a capital investment for centralized control is annualized over twenty years at 7% interest and compared to the annual salary of an operator ($15,000 per year), it can be shown that over $150,000 in capital cost can be amortized and still not equal the annual cost of one operator.

TABLE 5-1 CONTROL EQUIPMENT AND WIRING CAPITAL COST SUMMARY

	Plant Capacity - MGD (dm^3/s)				
	5 (220)	10 (440)	50 (2200)	100 (4400)	300 (13000)
CONVENTIONAL					
Equipment*	$85,612	$130,583	$189,100	$297,942	$ 532,266
Wiring+	10,021	24,320	69,606	164,058	574,749
Total	$95,633	$154,903	$258,706	$462,000	$1,107,015
CENTRAL ANALOG					
Equipment*	$113,585	$170,602	$244,116	$ 389,269	$ 688,470
Wiring+	52,041	105,446	317,267	739,211	2,202,833
Total	$165,626	$267,066	$561,383	$1,128,480	$2,891,303
CENTRAL DIGITAL					
Equipment*	$191,040	$352,690	$482,860	$597,520	$762,865
Wiring+	8,565	14,349	28,900	72,662	150,815
Total	$199,605	$367,039	$511,760	$670,182	$913,680

* Does not include field mounted sensors, final control elements and maintenance panels

\+ Does not include wiring between field equipment and local control panels or multiplexers

The analysis compares the operational labor requirements of conventional (distributed analog) control systems with two centralized systems--analog and digital. Maintenance requirements of the two centralized alternatives are then analyzed to determine the impact of added instrumentation associated with centralization. In this way, a comparison can be made in terms of total labor cost for operation and maintenance.

Data for estimating manpower requirements at conventional treatment plants has been collected by Patterson and Banker (8) and Burke (9). The data provides a means for estimating staffing requirements for a variety of conventional wastewater treatment plants on an average basis. Since the data is not adjusted for local conditions or changing design requirements, it cannot be considered applicable for specific treatment plant estimates. The United States Environmental Protection Agency (USEPA) has analyzed this data and has developed a staffing model. The model is incorporated in a computer program which accepts definitions of unit processes and plant sizes and calculates man-hours of operational labor and maintenance labor for each associated unit process. The purpose is to provide average estimates for proper plant staffing for planning studies assuming a conventional control system approach. Manpower in an actual conventionally controlled plant may be more or less than these estimates. However, more staff may mean overstaffing and a higher potential for manpower savings and less staff may be an indication of improper operations. The EPA program forms the basis for conventional control operation and maintenance staffing estimates in this analysis.

Operational Manpower Requirements

The estimated operational manpower requirements for the five plant sizes are shown in Table 5-2. This data is based on the conventional control systems analyzed by Patterson and Banker and from the USEPA program. These estimated man-hours are for operations only and do not include administrative time, laboratory time or manual labor time. The operations man-hour estimates are then divided by 1,800 man-hours per year per person to account for weekends, holidays and sick leave. At 1,800 man-hours per year, 4.9 people are required (8760/1800) for each position that must be manned on a 24-hour basis seven days a week. Although there were many staffing options observed in the field, this analysis assumes that five operational groups are required to operate a facility.

To demonstrate potential operational labor reductions that may be achieved by centralization, the tasks associated with three operator positions will be evaluated. The task list examples provided in Tables 5-3, 5-4 and 5-5 are for secondary treatment and were obtained during the field visits. The approximate completion times for each task are estimated for centralized control based on the fact that the control system frees the operator from much of the routine equipment monitoring and manual data logging that would otherwise be required. The tasks and times were provided by the Metropolitan Waste Control Commission during field visits.

TABLE 5-2. OPERATIONS ANNUAL MANHOURS-CONVENTIONAL CONTROL

	5 MGD ($220\ dm^3/s$)	10 MGD ($440\ dm^3/s$)	50 MGD ($2200\ dm^3/s$)	100 MGD ($4400\ dm^3/s$)	300 MGD ($1300\ dm^3/s$)
Influent Pumping	500	700	2,000	3,000	5,000
Preliminary Treatment	1,400	2,100	5,000	15,000	30,000
Primary Treatment & Sludge	1,600	2,450	5,000	8,000	16,000
Aeration	2,000	3,000	6,500	10,000	20,000
Secondary Clarification	850	1,300	3,300	5,200	10,000
Chlorination	1,000	1,500	3,500	5,000	10,000
RAS	300	500	1,800	2,500	5,000
WAS	300	500	850	1,000	2,000
Gravity Thickening	350	500	1,200	1,600	3,200
Digestion	1,500	2,000	10,000	14,000	28,600
Sludge Holding	0	700	1,700	2,100	4,200
Vacuum Filters	0	3,000	10,000	14,000	28,000
Drying Beds	750	0	0	0	0
Incineration	0	2,500	7,500	11,000	22,000
Reaeration	0	0	0	0	0
Miscellaneous	400	800	800	800	900
Total Manhours Per Year	10,950	21,550	59,150	93,200	184,900
People Required (1800 MH = 1 Man)	6	12	33	52	102

TABLE 5-3. PROCESS OPERATOR TASKS

Task	Estimated Time to Complete (min/shift)	
	Conventional Control	Centralized Control
Check compressor equipment (motor, bearing, vibration)	30	0
Foam & solids carryover check	30	30
Clarifier drives and other equipment checks	30	0
Pump and motor check (bearing, temperature, vibration)	60	0
Valve, alarm & status change logging	60	30
RAS withdrawal control (4 times per shift)	60	60
RAS distribution control	60	60
Air flow control	60	30
WAS control	60	30
Miscellaneous	30	30
Total Time	480	300

TABLE 5-4. OPERATING ATTENDANT II TASKS

Task	Estimated Time to Complete (min/shift)	
	Conventional Control	Centralized Control
Tank stickings collector operation	120	120
Outside cleaning (shovel)	30	30
Device checks	60	0
D.O. logging	30	0
Air supply logging	30	0
Mixed liquor flow logging	45	0
Centrifuge tests, settling tests, logging	60	60
Waste & return flow checking & logging	15	0
Miscellaneous (device checks, alarms, operator communications)	45	45
Total Time	480	255

TABLE 5-5. OPERATING ATTENDANT I TASKS

Task	Estimated Time to Complete (min/shift)	
	Conventional Control	Centralized Control
Settling tests (30 min.)	120	120
Centrifuge tests	60	60
Sampler line flushing	60	60
Sink Cleaning	30	30
D.O. probe flushing	60	60
Composite sample pickup and distribution	30	30
Pump cleaning	60	60
Relamping (average)	30	30
Floor and drain cleaning	60	60
Total Time	480	480

Table 5-3 indicates that centralization can reduce the time required for typical operational functions performed by process operators by about 37%. Table 5-4 indicates that typical operating attendant II control functions and operating time are reduced by approximately 46%. Table 5-5 shows that the operational tasks for a typical operating attendant I will not be reduced or affected by centralization. Checking of devices (preventive maintenance), sampling, testing and cleaning all continue to be necessary. Centralization saves operational man-hours predominantly in the process operator and operating attendant II categories. Operation by exception, made possible by the use of centralized control, reduces the total number of people needed to make control decisions and log data.

The average man-hour savings are greater than 25% in terms of actual operational functions and time in the examples cited. A simple average reduction in operational labor cannot be assigned on an arbitrary basis across the board. The actual number of operators assigned to a facility must be based on an analysis of the unit processes, equipment, monitoring and control point quantities and other complexities. In an attempt to estimate potential operator staff reductions for centralized control, conventional control staffing for the example treatment plants will first be reviewed. The analysis will then briefly describe how the same facilities could be staffed with centralized, automated systems. All of the data is presented in Table 5-6. The process assignments are in general accordance with actual assignments observed at the plants visited.

TABLE 5-6. OPERATIONAL MANPOWER ASSIGNMENTS

PLANT SIZE MGD - (dm^3/s)	CONVENTIONAL CONTROL OPERATOR STATION	MANPOWER ASSIGNMENTS	TOTAL MANPOWER (DAY SHIFT)	TOTAL OPERATIONAL STAFF	COMMENTS	CENTRAL/AUTOMATED CONTROL OPERATOR STATION	MANPOWER ASSIGNMENTS	TOTAL MANPOWER (DAY SHIFT)	TOTAL OPERATIONAL STAFF	COMMENTS
5 (220)	PLANT OPERATOR	1 - days	2	6	Day shift only.	PLANT OPERATOR	1 - days	4	4	Only day shift attended. Telemetry provides alarms, control system records events on off-hours.
	OPERATING ATTENDANT	5 groups of 1			All shifts.	DAY SHIFT ATTENDANTS	3 - days			
10 (440)	OPERATIONS SUPVR./ LIQUID TRAIN	5 groups of 1	4	12	Secondary operator serves as group supervisor.	OPERATIONS SUPVR.	5 groups of 1	2	10	Control room
	SOLIDS TRAIN	5 groups of 1				OPERATING ATTENDANTS	5 groups of 1			Field
	DAY SHIFT ATTENDANTS	2								
50 (2200)	OPERATIONS SUPVR.	5 groups of 1	9	33	Three field operator stations.	OPERATIONS SUPVR.	5 groups of 1	8	24	Control room
	PRELIM/PRIM/SEC	5 groups of 1				LIQUID TRAIN	5 groups of 1			Field
	DIGESTION/DEWATERING	5 groups of 2				SOLIDS TRAIN	5 groups of 2			Field
	INCINERATION	5 groups of 2				DAY SHIFT ATTENDANTS	4			Field
	DAY SHIFT ATTENDANTS	3								
100 (4400)	OPERATIONS SUPVR.	5 groups of 1	16	52	Five field operator stations.	OPERATIONS SUPVR.	5 groups of 1	16	40	Control room
	PRELIMINARY/PRIMARY	5 groups of 1				LIQUID TRAIN	5 groups of 2			Control room/field
	BLOWERS	5 groups of 1				SOLIDS TRAIN	5 groups of 3			Control room/field
	SECONDARY	5 groups of 1				DAY SHIFT ATTENDANTS	10			
	DIGESTION/DEWATERING	5 groups of 3								
	INCINERATION	5 groups of 2								
	DAY SHIFT ATTENDANTS	7								
300 (13000)	OPERATIONS SUPVR.	5 groups of 1	26	102	Seven field operator stations.	OPERATIONS SURVR.	5 groups of 1	23	75	Control room
	PRELIMINARY	5 groups of 2				LIQUID TRAIN	5 groups of 1			Control room/field
	PRIMARY	5 groups of 2				SOLIDS TRAIN	5 groups of 1			Control room/field
	BLOWERS	5 groups of 2				BLOWERS	5 groups of 1			Field
	SECONDARY	5 groups of 2				RAS/WAS	5 groups of 1			Field
	DIGESTION	5 groups of 3				DIGESTION	5 groups of 2			Field
	VACUUM FILTRATION	5 groups of 3				VACUUM FILTRATION	5 groups of 3			Field
	INCINERATION	5 groups of 4				INCINERATION	5 groups of 3			Field
	DAY SHIFT ATTENDANTS	7				DAY SHIFT ATTENDANTS	10			

5.0 MGD (220 dm^3/s) Plant--

A conventionally controlled plant is typically supported by either one full time operator attendant for each shift and a plant operator for days only or two shifts of three operators with one of the operating people on the day shift acting as plant supervisor. The total operational staffing requirement is six. If this plant were centralized, the plant would be manned only on the day shift (week days) by a plant operator and three attendants. A staff of four would be required and two operator positions could be saved.

10.0 MGD (440 dm^3/s) Plant--

With conventional control, this plant requires full time operation of the liquid train by the operations supervisor and one full time operator in the solids train. Two additional day shift support attendants are typically provided for daylight operational support. Total operational staffing requirements are twelve men. With a centralized system, an operations supervi- sor and one operating attendant would operate the plant. This would require a total staff of ten, thus saving two operator positions.

50.0 MGD (2200 dm^3/s) Plant--

A conventional control system for this size plant requires a full time operations supervisor located in the control room. There are typically three area control centers in the plant: preliminary/primary/secondary, digestion/dewatering and incineration. One operator per shift controls preliminary, primary and secondary. There are typically two operators in the digestion/dewatering area and two operators in the incineration area. Three day shift operating attendants are required to support the operational staff.

A centralized system would require a shift supervisor and three operators per shift. In addition, four day shift support attendants would be required. Nine operating positions would be saved.

100 MGD (4400 dm^3/s) Plant--

A conventional control system for this plant requires an operations supervisor in the control room and full time operators at the five control centers. The control centers are preliminary/primary treatment, blowers, secondary, digesters/dewatering and incineration. Each area is manned by one operator on each shift with the exception of digestion/dewatering which requires three operators per shift and incineration, requiring two operators per shift. Seven day shift operating attendants are needed to support the operational staff.

Centralization of this plant would require an operations supervisor and two assistant operators (liquid and solids train supervisors) in the control room. The two assistant operators would work in the field part of the time. The liquid train operator supervises one attendant. The solids train operator supervises two operating attendants. Ten additional operating attendants support the operating staff on the day shift. Centralization would reduce the operational staff requirements by twelve positions.

300 MGD (13000 dm^3/s) Plant--

A conventional control system for this size plant requires an operations supervisor on each shift. There are seven operator stations, each manned twenty-four hours per day. Each of these stations requires more than one person on each shift because of the quantities of equipment. The secondary process requires two people per shift as would the blowers, preliminary, and primary treatment areas. Dewatering and digestion each require three operators per shift, and incineration requires four operators per shift. In addition the day shift would be staffed with at least seven support operating attendants.

Centralization of this size plant would require a shift supervisor and two operators (liquid and solids train supervisors) in the main control room. The two operators would also work in the field part of the time. In addition, there are operators at each of five stations in the field. Blowers are manned by a single operator per shift. The RAS/WAS system would be manned by a single operator per shift. The digesters would typically require two operators per shift. The vacuum filters and incinerators would each require three operating attendants per shift. In addition, the day shift would have a support staff of at least ten operating attendants for cleaning and preventive maintenance. Centralization would reduce the operational staffing requirements by twenty-seven positions.

Summary of Operational Staffing--

Table 5-7 below illustrates that on the average, centralization can reduce the total operational manpower requirements by about 25%.

TABLE 5-7. OPERATOR STAFFING COMPARISON-CONVENTIONAL vs CENTRALIZED CONTROL

Plant Size mgd (dm^3/s)	Conventional System Staffing	Centralized System Staffing
5 (220)	6	4
10 (440)	12	10
50 (2200)	33	24
100 (4400)	52	40
300 (13000)	102	75

Control System Maintenance Manpower

This analysis will determine the amount of additional maintenance that will be required for the centralized control systems in comparison to conventional control. It will be shown that for the example configurations chosen, the additional maintenance requirements for the central analog system are minimal and that there is no change in the total number of maintenance people required for the central digital system.

The analysis is based on the maintenance requirements associated with the components used in the centralized control systems. Table 5-8 shows the maintenance requirements for various control components as tabulated in a recent EPA publication (10).

TABLE 5-8. MAINTENANCE REQUIREMENTS PER COMPONENT

Component	Maintenance (hours/year)
Annunciators	2
PID Controllers, Ratio and Setpoint Stations	8
Signal Converters	10
Recorders	8
Control Switches	2

The central analog control system examined in this analysis requires a large number of additional items such as setpoint stations, switches and alarm annunciators that are not utilized in a conventional control system (see Table 5-9). Based on this increase in components, the additional manpower required to maintain a central analog control system can be derived. The component quantities are translated to maintenance manhours using Table 5-8 and the number of additional maintenance people required is determined by dividing total man-hours by 1800. The results of this analysis show that the increase in maintenance manpower is, at most, one additional person over the requirements of conventional control.

TABLE 5-9. CENTRAL ANALOG MAINTENANCE REQUIREMENTS-COMPARISON WITH CONVENTIONAL CONTROL

Component	Maint. MH per Unit	Plant Capacity MGD (dm^3/s) 5 (220)		10 (440)		50 (2200)		100 (4400)		300 (13000)	
		Qty.	Hrs.	Qty.	Hrs.	Qty.	Hrs.	Qty.	Hrs.	Qty.	Hrs.
Setpoint Station	8	+21	+168	+32	+256	+47	+376	+77	+616	+143	+1144
Alarm Annunciator	2	+10	+ 20	+18	+ 36	+29	+ 58	+49	+ 98	+ 96	+ 192
Control Switch	2	+20	+ 40	+24	+ 48	+27	+ 54	+39	+ 78	+ 46	+ 92
Increased Maintenance Manhours per Year			+228		+340		+488		+792		+1428
Additional People Required (1800 MH = 1 Man)			1		1		1		1		1

The central digital control system examined in this analysis requires fewer components compared to the equivalent conventional control system (see Table 5-10). The major components that are eliminated include recorders and PID controllers. Other minor components such as signal conditioners, totalizers and timers are also eliminated but these are not significant and will not be considered in this analysis. The decrease in components is used to derive the reduction in manpower requirements in a manner similar to that discussed under central analog control.

A digital control system has additional maintenance requirements associated with the computer, peripheral equipment and the multiplexers. It is difficult to accurately estimate the maintenance requirement for computer equipment because an exact component makeup cannot be determined. Furthermore, generally applied and accepted maintenance values for the various components are not available at this time. Experience has shown that the most significant maintenance items are the multiplexer components used for input/output signals at the local level. An estimate of one hour per input/output point per year will be used to derive the maintenance requirements for the multiplexers and the computer system equipment.

As indicated in Table 5-10, the reduction in maintenance due to component decrease is almost entirely offset by the increased maintenance requirements of the computer system equipment; there is no significant change in the maintenance manpower requirements for the digital system as compared to conventional control.

TABLE 5-10. CENTRAL DIGITAL CONTROL MAINTENANCE REQUIREMENTS - COMPARISON WITH CONVENTIONAL CONTROL

Component	Maint. MH per Unit	Plant Capacity MGD (dm^3/s) 5 (220)		10 (440)		50 (2200)		100 (4400)		300 (13000)	
		Qty.	Hrs.	Qty.	Hrs.	Qty.	Hrs.	Qty.	Hrs.	Qty.	Hrs.
Recorder	8	-16	-128	-21	-168	-33	-264	-47	-376	-85	-680
PID Controller	8	-20	-160	-31	-248	-46	-368	-76	-608	-142	-1136
Multiplexer I/O	1/PT		+173		+276		+361		+599		+1036
Maintenance Manhours per Year Saved			115		140		271		385		780
People Saved (1800 MH = 1 Man)			0		0		0		0		0

Summary of Operation and Maintenance Manpower Costs

To estimate the total maintenance costs for the alternate control systems, a base line cost must be established for conventional control. Patterson and Banker's man-hour estimates for a conventionally controlled treatment plant are listed in Table 5-11 and are used to determine the base line maintenance estimates. These numbers are translated to the number of people required through division by 1800 as explained earlier. These staffing requirements are then adjusted for central analog and central digital control according to the results of the maintenance manpower analysis.

TABLE 5-11. MAINTENANCE MANPOWER-CONVENTIONAL CONTROL

	5 MGD (220 dm^3/s)	10 MGD (440 dm^3/s)	50 MGD (2200 dm^3/s)	100 MGD (4400 dm^3/s)	300 MGD (13000 dm^3/s)
Influent Pumping	600	621	1,500	2,046	2,046
Preliminary Treatment	500	947	3,000	5,433	10,000
Primary Treatment & Sludge	600	1,212	2,800	4,062	8,000
Aeration/ Reaeration	900	1,718	3,300	6,755	14,000
Secondary Clarification	350	684	1,500	2,981	6,000
Chlorination	150	288	1,500	2,971	6,000
RAS	420	537	800	1,765	3,500
WAS	420	300	500	1,000	2,000
Gravity Thickening	175	248	450	892	1,700
Digestion	750	1,150	4,500	8,827	17,000
Sludge Holding	230	342	700	1,261	2,500
Vacuum Filters	0	494	1,300	2,590	5,000
Drying Beds	298	0	0	0	0
Incineration	0	1,112	2,800	5,472	10,000
Total Manhours Per Year	5,393	9,653	24,650	46,055	87,746
People Required (1800 MH = 1 Man)	3	5	14	26	49

An average labor cost of $15,000 has been selected for both operations and maintenance personnel based on a direct labor cost of $6.00 per hour and an additional indirect labor cost of 20%. Since a portion of the staff at a digitally controlled plant must have specialized knowledge relating to the control system and will typically require higher than average pay, a labor cost estimate of $15,500 was selected for the digital control systems. Table 5-12 summarizes the operation and maintenance requirements (staffing and associated labor costs) for the five plant sizes.

TABLE 5-12. ANNUAL OPERATIONS & MAINTENANCE MANPOWER COSTS

	Plant Capacity MGD (dm^3/s)									
	5 (220)		10 (440)		50 (2200)		100 (4400)		300 (13000)	
	Men	Cost	Men	Cost	Men	Cost	Men	Cost	Men	Cost
CONVENTIONAL										
Operations	6	$ 90,000	12	$180,000	33	$495,000	52	$780,000	102	$1,530,000
Maintenance	3	45,000	5	75,000	14	210,000	26	390,000	49	735,000
Total		$135,000		$255,000		$705,000		$1,170,000		$2,265,000
CENTRAL ANALOG										
Operations	4	$ 60,000	10	$150,000	24	$360,000	40	$600,000	75	$1,125,000
Maintenance	4	60,000	6	90,000	15	225,000	27	405,000	50	750,000
Total		$120,000		$240,000		$585,000		$1,005,000		$1,875,000
CENTRAL DIGITAL										
Operations	4	$ 62,000	10	$155,000	24	$372,000	40	$620,000	75	$1,162,500
Maintenance	3	46,500	5	77,500	14	217,000	26	403,000	49	759,000
Total		$108,000		$232,500		$589,000		$1,023,000		$1,922,000

MATERIAL AND ENERGY COST

Energy and chemical costs represent approximately thirty percent of wastewater treatment plants' annual operating cost (8). The consumables of most concern in a cost analysis are fuel, electrical energy and chemicals. Most of the potential cost savings result from the use of automated load following control techniques. Power demand control has not been demonstrated in this industry, but has shown large savings in other industries. Power factor correction can save on cost of power, but is not often utilized.

Load Following Savings

Load following involves the definition of a process model in terms of a mathematical formula. This formula can be as simple as a proportional adjustment relative to the load (e.g. hydraulic load following) or can be as complicated as a logarithmic relationship describing a pH titration curve. Using the model, the required chemical feed is calculated for actual process needs. These feedforward control models should be accompanied by feedback to compensate for errors between the actual process load and the load predicted from the mathematical model. This combination of feedforward and feedback control minimizes chemical costs and optimizes the process operation.

In Figure 5-10 (adapted from reference 10) the use of two types of load following is compared with constant rate chemical feed to show how load following can reduce the materials used for chemical feed.

The concept of load following, when applied to dissolved oxygen control, saves energy by minimizing aeration in a manner similar to that shown for chemical feed. Feedforward control is based on organics (mass loading) to be metabolized. The mass of organics is translated to a required air flow, and the measured dissolved oxygen provides feedback trim. Dissolved oxygen control has been shown to yield a significant reduction in energy use when advanced control strategies are applied.

Conventional control systems typically control chemical feed on an open-loop basis. This means that an operator periodically sets a chemical feed dose rate controller and that setting is maintained. Dissolved oxygen control is also conventionally implemented on an open-loop basis. The operator increases or decreases air flow rates based on visual observations, dissolved oxygen readings or laboratory data. Accurate load following cannot be achieved in these instances because changes in loads are usually unpredictable. Frequent manual adjustment would be required to compensate for these changes. The implementation of load following generally requires feedforward and feedback controls that are typically included in centralized control systems.

In estimating the average savings obtainable through the use of load following control, demonstrated experiences can be the only guide. In a study on dissolved oxygen control of activated sludge processes (11), involving twelve treatment plants, an analysis of the percent improvement in air supplied per unit quantity of BOD removed indicates an average air and

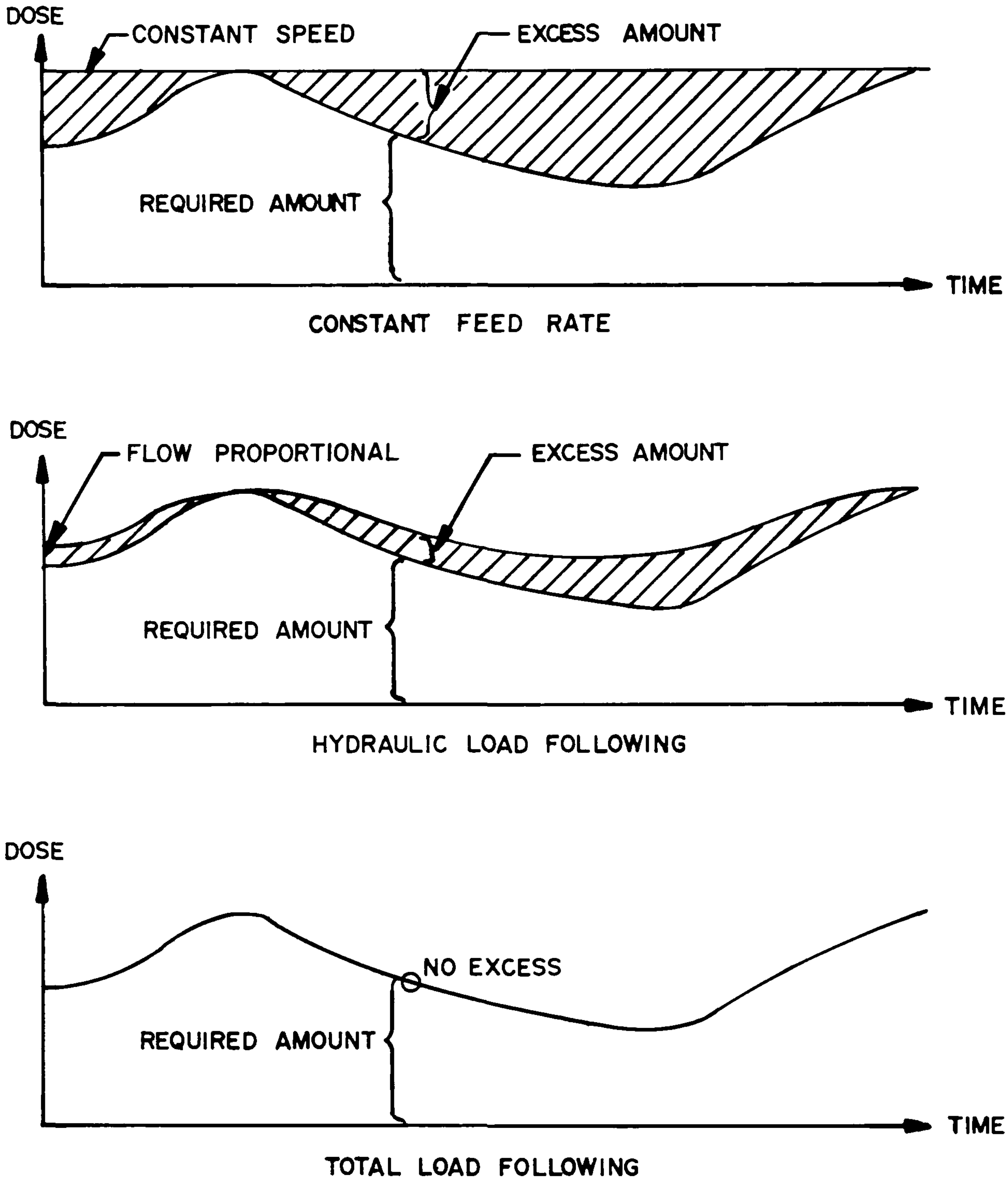


Figure 5-10. Chemical feed control methods.

power savings of twenty percent. This savings can be realized using centrifugal blowers with adjustable inlet vane or suction throttling constant pressure control. The study analyzed plant sizes from 1 mgd to 100 mgd. Since blower power consumption in a treatment plant is at least fifty percent of the total plant power consumption, load following savings of ten percent of total plant power consumption will be used for power cost reduction due to dissolved oxygen control.

An automated chlorine disinfection system can significantly reduce chemical needs (12). Load following chemical feed has been shown to reduce both chemical usage and fuel consumption (13). Chemical savings (chlorine) greater than six percent have been demonstrated with use of simple load following via compound loop chlorination (14)(15).

Cost for alum addition were calculated for a periodically adjusted constant feed rate, hydraulic load following and total (mass) load following at at a 10 mgd plant. The hydraulic load following provided an alum savings of 5% and the total load following provided an alum savings of 15% over the constant feed rate. Similar cost comparisons have been made for methanol addition for denitrification and for breakpoint chlorination.(16) Since smaller plants have a more widely varying diurnal load variation, the anticipated savings might be greater (15% for alum for a 10 mgd plant) for a small plant then for a large plant. However, equipment to follow these diurnal variation (turndown ratios, multiple feeders) is more likely to be found in larger plants then in small plants. Consequently, for the purposes of this analysis, a 5% savings in chemical costs using centralized analog control will be applied to all plant sizes. Since more complex process models may be programmed in the digital computer to implement total mass load following, a 8% saving in chemical costs using centralized digital control will be applied to all plant sizes.

Power Demand Control Savings

Power company tariffs usually consider two factors in billing rates: amount of energy consumed and maximum power demand. The basic charge is for energy used, whereas, the power demand charges can be viewed as penalties or surcharges on the basic rate. The power companies monitor power demand during intervals of fifteen or thirty minutes. The Cincinnati Gas and Electric Company (CG&E) defines power demand as "...the kilowatts derived from the company's demand meter for the fifteen minute period of customer's greatest use during the month" (17). Power demand billing techniques vary throughout the country. CG&E bill on a specified percentage (50%) of the highest reading during a six month period. Some other power companies bill the power demand charges on the highest demand reading during each month. They may also be a "summer ratchet," where the demand reading during the winter months cannot be less than a specified percentage of the peak summer demand. Therefore, there are significant economic justifications for power demand control.

The total power load can be divided into two classes, base loads and selected loads. The base load is lighting, small appliances and major loads which are extremely critical to system operation. Selected loads can either be reduced in power level or shed entirely for a short time as required to control demand peaks.

The basic concept of power demand control involves shedding a block of loads or preventing startups from occurring to prevent demand from exceeding a setpoint; deferring consumption of that block of energy to a period when the remainder of the electrical load is lower. In this way, peaks are lowered, but energy consumption is not reduced. Figure 5-11 illustrates this concept. A 500 KW reduction in the power demand peak is obtained by deferring heavy energy use to a period of lower demand. This amount of power would otherwise be used to calculate a demand charge determined by the monthly demand peak multiplied by a rate which can be as high as $1.50/KW/month. Therefore, keeping the power demand below the assigned peak demand can result in significant savings.

Power demand control cannot be implemented in a conventional or central analog control system because the complexity of the necessary control logic requires the capabilities of a digital computer. Industrial groups have implemented power demand control techniques using computers. Applications have been reported (18, 19) presenting successful installations where power costs were reduced by more than ten percent by reducing demand charges. Numerous industrial installations can also be cited where savings like these have been demonstrated. As a result of these findings, a reduction of five percent will be used as an estimate of the average power cost savings that can be achieved through the implementation of power demand control with digital systems. The potential savings in a particular wastewater treatment plant will depend upon the plant's operational flexibility (ability to defer or shed electrical loads such as blowers without significantly affecting overall plant performance).

<u>Determining Plant Energy and Material Costs for Conventionally Controlled Plants</u>

The material and energy cost estimates in 1971 for conventionally controlled plants are based on data provided by the EPA.(20) Material costs were updated to June 1978 using a factor calculated from the wholesale price index for industrial commodities.

$$\frac{WPI(1978)}{WPI(1971)} = \frac{208.5}{112.2} = 1.86$$

Electrical energy costs were updated in a similar way to June 1978 based on the consumer price index for electricity.

$$\frac{CPIE(1978)}{CPIE(1971)} = \frac{209.6}{109.8} = 1.91$$

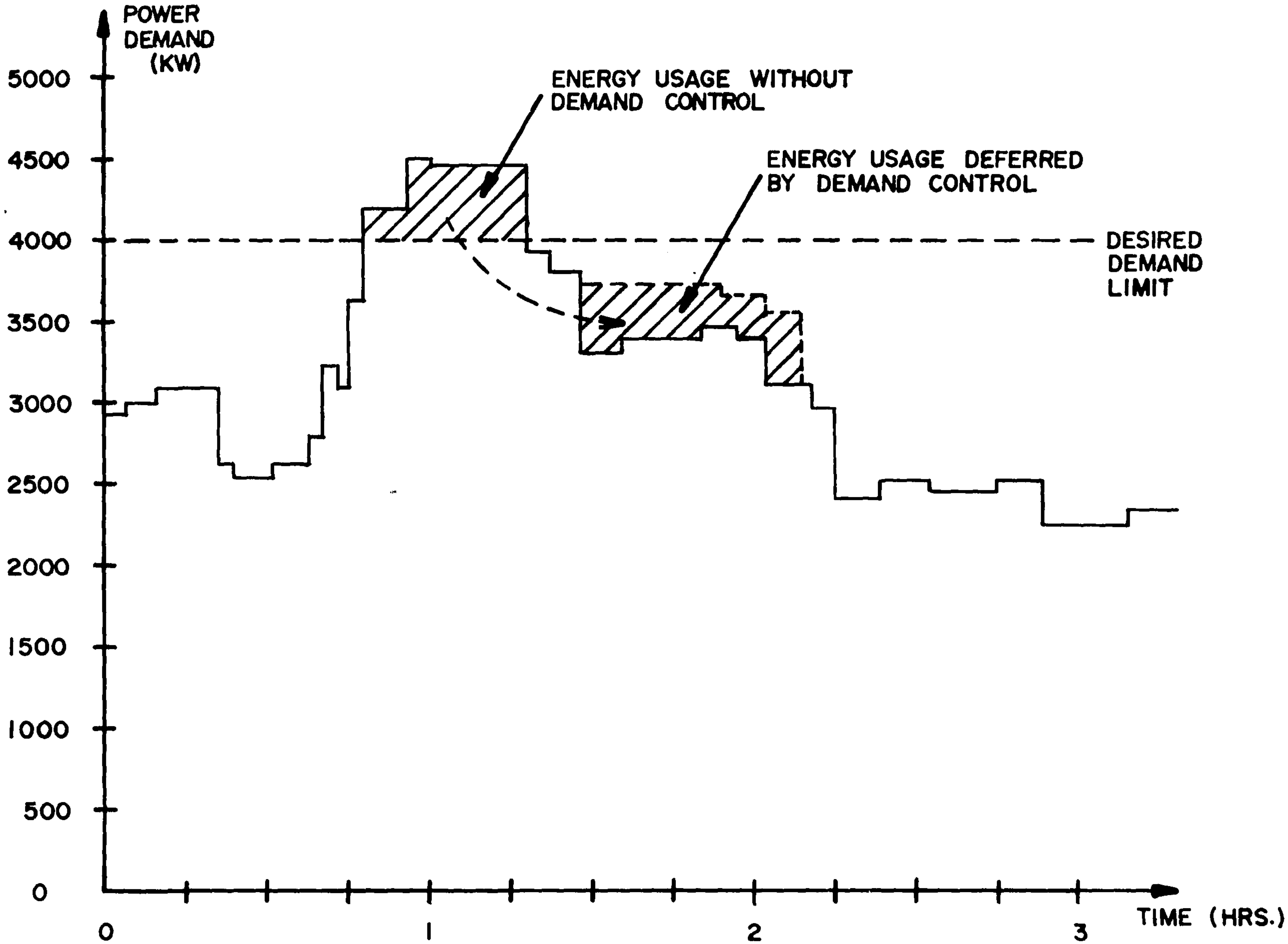


Figure 5-11. Power demand control.

The base data and transitions are shown as follows:

	Material Cost 1971	Correction Factor	Material Cost 1978
1 MGD (44 dm^3/s)	$ 32,442	1.86	$ 60,000
10 MGD (440 dm^3/s)	129,700	1.86	241,000
100 MGD (4400 dm^3/s)	720,260	1.86	1,340,000

	Energy Cost 1971	Correction Factor	Energy Cost 1978
1 MGD (44 dm^3/s)	$ 10,530	1.91	$ 20,000
10 MGD (440 dm^3/s)	62,300	1.91	119,000
100 MGD (4400 dm^3/s)	498,260	1.91	952,000

The updated data is plotted in Figure 5-12. Cost data for 5, 50 and 300 mgd plant sizes are interpolated and extrapolated from a straight line approximation and shown in Table 5-13.

Summary of Material and Energy Costs

An energy and material cost analysis is important because these costs represent almost one-third of the cost of operating a treatment plant. With consideration of the limited supply of conventional energy sources, conservation becomes an environmental as well as economic concern. Using the percentage savings in material and power costs previously discussed, Table 5-13 indicates that significant savings can be gained from automation. Conservative estimates of the savings to be expected have been indicated. Greater savings than those indicated have been demonstrated in the field for power and chemical feed at wastewater treatment plants. Greater savings than those estimated for power demand control have also been demonstrated in the field for industrial installations. The case histories referenced illustrate that currently available technology can achieve these savings. While the percentage savings selected for this demonstration cost analysis are consistent with wastewater and industrial experience, a specific analysis should be carried out for an actual process flow sheet taking into account equipment design and operational flexibility.

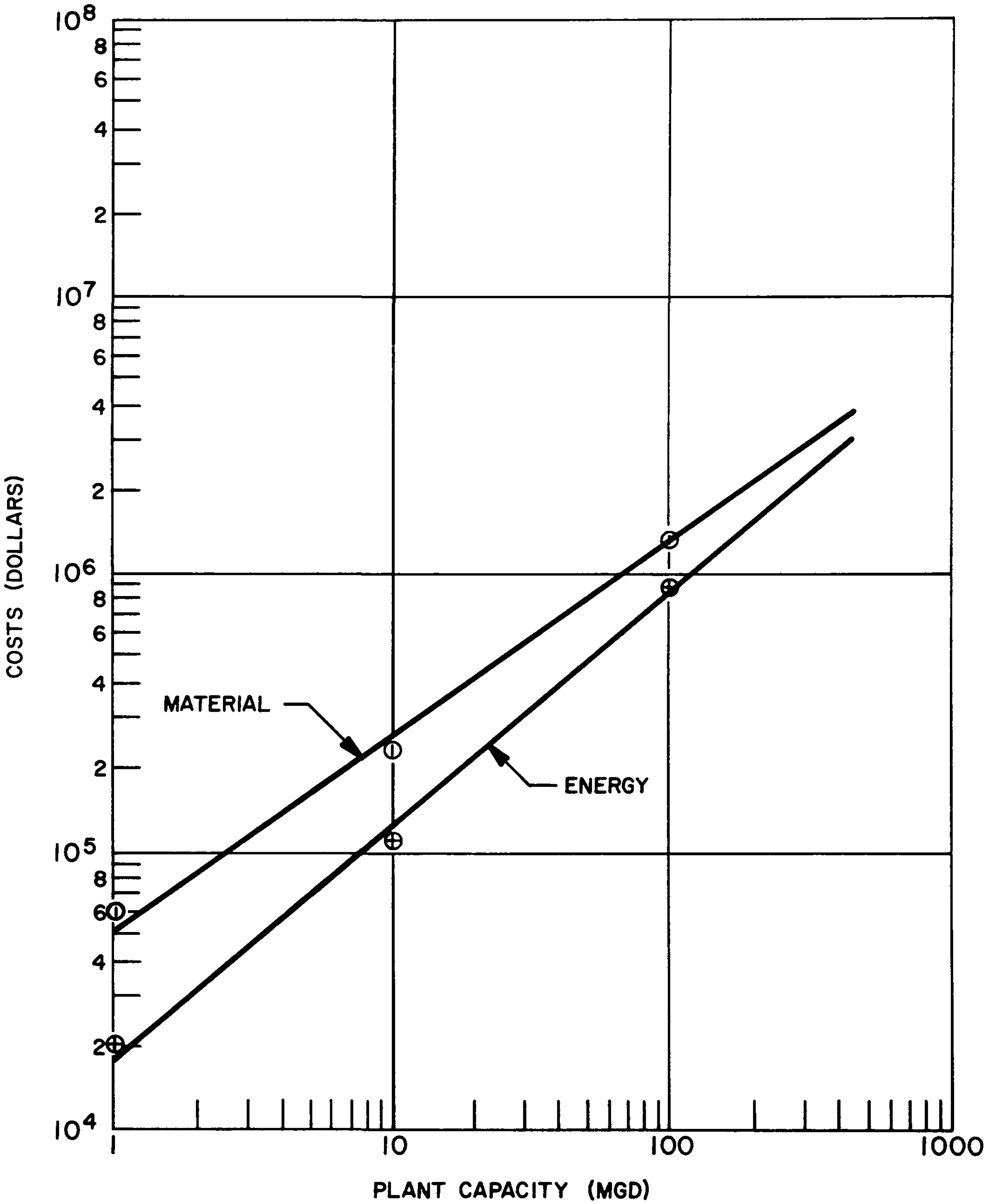


Figure 5-12. Material and energy costs, June 1978, for conventional control.

TABLE 5-13. ANNUAL MATERIAL AND ENERGY COSTS

	Plant Capacity MGD (dm³/s)				
	5 (220)	10 (440)	50 (2200)	100 (4400)	300 (13000)
CONVENTIONAL					
Materials	$160,000	$260,000	$780,000	$1,300,000	$2,800,000
Energy	70,000	130,000	500,000	900,000	2,300,000
CENTRAL ANALOG					
Materials[1]	$152,000	$247,000	$741,000	$1,235,000	$2,660,000
Energy[2]	63,000	117,000	450,000	810,000	2,070,000
CENTRAL DIGITAL					
Materials[3]	$147,000	$239,000	$718,000	$1,196,000	$2,576,000
Energy[2,4]	59,500	110,500	425,000	765,000	1,955,000

1. 5% savings due to hydraulic load following control
2. 10% savings due to DO load following control
3. 8% savings due to mass load following control
4. 5% savings due to power demand control

COST EFFECTIVE ANALYSIS SUMMARY

The economics of wastewater treatment plant automation have been analyzed in terms of capital investment in control instrumentation, operation and maintenance labor costs, and material and energy costs. The present worth of the equipment, labor, materials and energy costs is presented in Table 5-14. The present worth method conforms to the cost effective analysis guidelines in the Sewage Treatment Construction Grants Manual (7-23-79), using a 20 year planning period at seven percent annual interest with an useful life of 15 years for the control equipment. The uniform series present worth factor is 10.954 for the annual operations and maintenance costs in Table 5-12 and the annual material and energy costs in Table 5-13. Only the control equipment, not the wiring, is assumed to be replaced at the original cost after the 15 years of useful life.

TABLE 5-14. PRESENT WORTH ANALYSIS

(All costs are in units of $1000)

Present Worth[1,2]	Plant Capacity MGD (dm^3/s) 5 (220)	10 (440)	50 (2200)	100 (4400)	300 (13000)
CONVENTIONAL					
Capital[3]	96	155	259	462	1,107
Replacement[4,5]	31	47	69	108	193
Operations[6]	954	1,907	5,244	8,263	16,209
Maintenance	477	795	2,225	4,132	7,787
Material	1,695	2,754	8,263	13,772	29,663
Energy	742	1,377	5,297	9,535	24,366
Total	3,995	7,035	21,357	36,272	79,325
CENTRAL ANALOG					
Capital[3]	166	267	561	1,129	2,891
Replacement[4,5]	41	62	89	141	250
Operations[6]	636	1,589	3,814	6,356	11,918
Maintenance	636	954	2,384	4,291	7,946
Material	1,610	2,617	7,850	13,084	28,180
Energy	667	1,240	4,767	8,581	21,930
Total	3,756	6,729	19,465	33,582	73,115
CENTRAL DIGITAL					
Capital[3]	200	367	512	670	914
Replacement[4,5]	69	128	175	217	277
Operations[6]	657	1,642	3,941	6,568	12,316
Maintenance	493	821	2,299	4,269	8,047
Materials	1,557	2,532	7,606	12,670	27,290
Energy	630	1,171	4,503	8,104	20,711
Total	3,606	6,661	19,036	32,498	69,555

1. Present Worth is based upon a 20-year period at a 7% annual rate of return.
2. Estimated cost June 1978. In accordance with EPA methodology, no escalation is assumed for annual operating costs or replacement costs.
3. Field mounted sensors, final control elements, maintenance panels, and wiring between field equipment and local control panels (or multiplexers) not included, because they are common to the alternatives.
4. Fifteen years useful life for control equipment (excluding wiring)
5. No salvage value assumed for replacement control system after 20 years, because of high technical obsolescence and customized design.
6. Does not include administrative, laboratory or manual labor time.

According to the guideline, the component costs should be calculted on the basis of the market prices prevailing at the time of the cost-effective analysis. A single payment present worth factor of .3624 is used to obtain the present worth of the replacement equipment. The actual future replacement decision will depend upon many factors, such as failure rates, availability of spare parts and maintenance costs.

The present worth analysis shows that central analog control is cost effective compared to conventional control and that centralized digital control is cost effective compared to centralized analog control and conventional (distributed analog) control for the five plant sizes. While the economic benefits of automation for these generalized treatment schemes have been illustrated through this cost-effective analysis, the cost information in this section should not be used for application to other specific analysis. Actual processes, process equipment, plant influent, staffing, electrical contracts and other local conditions must be fully considered in the cost-effective analysis.

Table 5-15 is included to show the relative cost differentials on an annual cost basis to provide a different viewpoint on the economics of centralization. A capital recovery factor of 0.944 (7%, 20 years) was applied to the present worth figures in Table 5-14 to obtain the annual costs. The annual costs for centralized analog control and centralized digital control were then subtracted from the annual costs for conventional control to obtain Table 5-15.

Automation has the potential of achieving many desirable objectives; the most important of these is a reduction in operational labor, chemicals and power costs. As operational labor is reduced, more effort can be concentrated on maintenance. The establishment of comprehensive preventive maintenance programs will greatly aid in achieving continuous effective use of instrumentation and control equipment and assure more consistent effluent quality from wastewater treatment plants.

TABLE 5-15. DIFFERENCE BETWEEN CENTRALIZED CONTROL AND CONVENTIONAL CONTROL ANNUAL COST ANALYSIS

	Plant Capacity - MGD (dm^3/s)				
	5 (220)	10 (440)	50 (2200)	100 (4400)	300 (13000)
CENTRAL ANALOG					
Capital	$+ 6,600	$+ 11,500	$+ 28,600	$+ 62,900	$+168,000
Replacement	+ 1,000	+ 1,300	+ 1,900	+ 2,900	+ 5,400
Operations	- 30,000	- 30,000	-135,000	-180,000	-405,000
Maintenance	+ 15,000	+ 15,000	+ 15,000	+ 15,000	+ 15,000
Material	- 8,000	- 13,000	- 39,000	- 65,000	-140,000
Energy	- 7,000	- 13,000	- 50,000	- 90,000	-230,000
Total	$- 22,400	$- 28,200	$-178,500	$-254,200	$-586,200
CENTRAL DIGITAL					
Capital	$+ 9,800	$+ 20,000	$+ 23,900	$+ 19,000	$- 18,000
Replacement	+ 3,600	+ 7,600	+ 10,000	+ 10,200	+ 7,900
Operations	- 28,000	- 25,000	-123,000	-160,000	-368,000
Maintenance	+ 1,000	+ 2,500	+ 7,000	+ 13,000	+ 24,500
Material	- 13,000	- 21,000	- 62,000	-104,000	-224,000
Energy	- 10,500	- 20,000	- 75,000	-135,000	-345,000
Total	$- 37,100	$- 35,900	$-219,000	$-356,800	$-922,800

SECTION 5
REFERENCES

1. Nelson, J. K. and B. B. Mishra, Management-The Key to Success With Computers. Presented at the ISA Philadelphia, PA, October 15-19, 1978 Conference, October 18, 1978.

2. Flanagan, M. J., Full Automation Goal of Water Reclamation Plant, Water and Wastewater Engineering. December, 1975.

3. Roesler, J. F., A. Manning and R. Timmons, A Cost/Benefit Analysis for Automation of Wastewater Treatment Plants. Presented at the IAWPR Workshop on Instrumentation and Control, May, 1977.

4. Standards for Waste Treatment Works. New York State Dept. of Environmental Conservation, 1970.

5. Metcalf & Eddy, Inc., Wastewater Engineering. McGraw-Hill Book Company, 1972.

6. Male, J. W. and S. P. Graef, editors of Applications of Computer Programs in the Preliminary Design of Wastewater Treatment Facilities. Short course proceedings, August 15-19, 1977.

7. Building Construction Cost Data 1977, 35th Annual Edition of Means Cost Index.

8. Patterson, W. L. and R. F. Banker, Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities. Environmental Protection Technology Series, 17090 DAN 09/71, October, 1971.

9. Burke, G. W., Jr., Estimating Personnel Needs for Wastewater Treatment Plants. Journal Water Pollution Control Federation 48, 241, 1976.

10. Molvar, A. E., Selected Applications of Instrumentation and Automation in Wastewater Treatment Facilities. Environmental Protection Technology Series, EPA 600/2-76-276, December, 1976.

11. Flanagan, M.J. and B.D. Bracker, Design Procedures for Dissolved Oxygen Control of Activated Sludge Processes. Environmental Protection Technology Series, EPA-600/2-77-032, June 1977.

12. Molvar, A. E., J. F. Roesler, R. H. Wise and R. H. Babcock, Instrumentation and Automation Experiences in Wastewater Treatment Facilities. Environmental Protection Technology Series, EPA-600/2-76-198, October, 1976.

13. Covery, John J., Joseph F. Roesler and Robert H. Wise, Automation and Control of Physical-Chemical Treatment for Municipal Wastewater. Applications of New Concepts of Physical-Chemical Wastewater Treatment Symposium, September 18-22, 1972.

14. Manning, A. W., Direct Digital Control at the Iowa City Water Treatment Plant, Journal of American Water Works Association. Volume 69, Number 6, June, 1977.

15. Kron, C., Direct Digital Control of the Iowa City Water Treatment Plant. Presented at the National AWWA Conference, June, 1975.

16. Roesler, J.F., Evaluation of the Effectiveness of Automation, Research Needs for Automation of Wastewater Treatment Systems, Clemson University, Clemson, SC, September 23-25, 1974.

17. Cincinnati Gas and Electric Company, Rate General Service, PUCO No. 16, September, 1976.

18. Thibodeau, G. J., Peak Power Demand Savings Through Computer Control of Production Electric Furnaces. Digital Equipment Corporation, April, 1977.

19. Crowell, W. H., Power Demand Control for Lowering Operating Costs. Proceedings of the ISA Annual Conference, October, 1974.

20. Smith, R., A Comparison Between Recently Computed Cost for Conventional Plants and Previous Estimates. Memo to John J. Convery, July 6, 1972.

SECTION 5
APPENDIX

COST EFFECTIVE ANALYSIS TABLES

TABLE A-1. UNIT PRICING

Instrument or Device	Material	Installation	Installed Unit Cost
Recorder	$ 700	$ 40/PEN	$ 740
Ratio Station	585	50	635
PID Controller	1,150	50	1,200
Setpoint Station	750	40	790
Panel Indicator	240	40	280
Totalizer	800	40	840
Signal Conditioner	555	30	585
Annunciator	25/PT	30/PT	55/PT
Control Switch	130	100	230
Timer	100	30	130
Panel Section	800	200	1,000

TABLE A-2

EQUIPMENT ANALYSIS

CONVENTIONAL ANALOG

5 MGD

	RECORDERS	RATIO STATIONS	PID CONTROL	PANEL INDICATORS	TOTAL-IZERS	SIGNAL CONDITION	ALARM ANNUN	CONTROL SWITCHES	TIMERS/ CLOCKS ETC	CNTL PNL SECTION	REMOTE S.P. STA
INFLUENT PUMPING	1		1	2	1	2	2	2		1	
PRELIM TREATMENT				2			2	2	2		
PRIMARY TREATMENT			2	4			4			1	
AERATION	1		3	4			2			1	
SECONDARY CLARIFIER	1		3	5	1		4			1	
CHLORINATION		1						2			
RAS PUMPING	1		1	1	1	2	2	2			
WAS PUMPING	1		1	1	1	2		2			
GRAVITY THICKENING	2		4	2			4			2	
DIGESTION	6		4	6	2		4	4	4	2	
DRYING BEDS	1			1	1			2	2	1	
MISCELLANEOUS	2		1	2	2	2	2	4	2	1	
INSTRUMENT TOTAL	16	1	20	30	9	8	26	20	10	10	
UNIT COST	740	635	1,200	280	840	585	55	230	130	1,000	790
TOTAL COST	11,840	635	24,000	8,400	7,560	4,680	1,430	4,600	1,300	10,000	
PLANT COST											74,445
ENGINEERING (.15)											11,167
SYSTEM TOTAL											85,612
EPA CONSTRUCTION COST ESTIMATE											3,930,619
I/C COST AS A PERCENT OF CONSTRUCTION											2.2

TABLE A-3

EQUIPMENT ANALYSIS

CONVENTIONAL ANALOG

10 MGD

	RECORDERS	RATIO STATIONS	PID CONTROL	PANEL INDICATORS	TOTAL-IZERS	SIGNAL CONDITION	ALARM ANNUN	CONTROL SWITCHES	TIMERS/ CLOCKS ETC	CNTL PNL SECTION	REMOTE S.P. STA
INFLUENT PUMPING	1		1	2	1	3	2	3		1	
PRELIM TREATMENT				3			3	2	2	2	
PRIMARY TREATMENT			4	8			8			2	
AERATION	2		5	7			3			2	
SECONDARY CLARIFIER	1		5	9	1		8			2	
CHLORINATION		4						2			
RAS PUMPING	2		3	2	2	2	2	2			
WAS PUMPING	1		1	1	1	2		2			
GRAVITY THICKENING	2		4	2			4			2	
DIGESTION	6		4	6	2		4	4	4	2	
SLUDGE HOLDING	1			5	1		4	2	2	1	
VACUUM FILTER	3		3	3		2		2		2	
INCINERATION				10			4			1	
MISCELLANEOUS	2		1	2	2	4	2	5	3	1	
INSTRUMENT TOTAL	21	1	31	60	10	13	44	24	11	18	
UNIT COST	740	635	1,200	280	840	585	55	230	130	1,000	790
TOTAL COST	15,540	635	37,200	16,800	8,400	7,605	2,420	5,520	1,430	18,000	
PLANT COST											113,550
ENGINEERING (.15)											17,033
SYSTEM TOTAL											130,583
EPA CONSTRUCTION COST ESTIMATE											8,476,227
I/C COST AS A PERCENT OF CONSTRUCTION											1.5

TABLE A-4

EQUIPMENT ANALYSIS

CONVENTIONAL ANALOG

50 MGD

	RECORDERS	RATIO STATIONS	PID CONTROL	PANEL INDICATORS	TOTAL-IZERS	SIGNAL CONDITION	ALARM ANNUN	CONTROL SWITCHES	TIMERS/ CLOCKS ETC	CNTL PNL SECTION	REMOTE S.P. STA
INFLUENT PUMPING	1		1	2	1	4	2	4		1	
PRELIM TREATMENT				3			3	2	2	2	
PRIMARY TREATMENT			4	8			8			2	
AERATION	4		7	11			3			2	
SECONDARY CLARIFIER	1		7	13	1		12			3	
CHLORINATION		1						2			
RAS PUMPING	4		5	4	4	3	2	3		1	
WAS PUMPING	1		1	1	1	2		2		1	
GRAVITY THICKENING	3		6	3			6			3	
DIGESTION	11		9	11	2		9	5	5	6	
SLUDGE HOLDING	1			7	1		6	2	2	1	
VACUUM FILTER	5		5	5		2		2		3	
INCINERATION				20			8			2	
MISCELLANEOUS	2		1	2	2	4	2	5	3	2	
INSTRUMENT TOTAL	33	1	46	90	12	15	61	27	12	29	
UNIT COST	740	635	1,200	280	840	585	55	230	130	1,000	790
TOTAL COST	24,420	635	55,200	25,200	10,080	8,775	3,355	6,210	1,560	29,000	

PLANT COST	164,435
ENGINEERING (.15)	24,665
SYSTEM TOTAL	189,100
EPA CONSTRUCTION COST ESTIMATE	28,319,122
I/C COST AS A PERCENT OF CONSTRUCTION	0.7

TABLE A-5

EQUIPMENT ANALYSIS

CONVENTIONAL ANALOG

100 MGD

	RECORDERS	RATIO STATIONS	PID CONTROL	PANEL INDICATORS	TOTAL-IZERS	SIGNAL CONDITION	ALARM ANNUN	CONTROL SWITCHES	TIMERS/ CLOCKS ETC	CNTL PNL SECTION	REMOTE S.P. STA
INFLUENT PUMPING	1		1	2	1	4	2	4		2	
PRELIM TREATMENT				3			3	3	3	2	
PRIMARY TREATMENT			8	16			16			4	
AERATION	8		12	20			4			4	
SECONDARY CLARIFIER	1		17	33	1		32			8	
CHLORINATION		[illegible]						4			
RAS PUMPING	8		9	8	8	4	2	4		2	
WAS PUMPING	1		1	1	1	4	4	4		1	
GRAVITY THICKENING	4		8	4			8			4	
DIGESTION	14		12	14	2		12	6	6	12	
SLUDGE HOLDING	1			9	1		8	3	3	1	
VACUUM FILTER	7		7	7		3		3		3	
INCINERATION				30			12			3	
MISCELLANEOUS	2		1	2	2	5	2	8	4	3	
INSTRUMENT TOTAL	47	1	76	149	16	20	105	39	16	49	
UNIT COST	740	635	1,200	280	840	585	55	230	130	1,000	790
TOTAL COST	34,780	635	91,200	41,720	13,440	11,700	5,775	8,970	2,080	49,000	
PLANT COST											259,080
ENGINEERING (.15)											38,862
SYSTEM TOTAL											297,942
EPA CONSTRUCTION COST ESTIMATE											50,670,676
I/C COST AS A PERCENT OF CONSTRUCTION											0.6

TABLE A-6

EQUIPMENT ANALYSIS

CONVENTIONAL ANALOG

300 MGD

	RECORDERS	RATIO STATIONS	PID CONTROL	PANEL INDICATORS	TOTAL-IZERS	SIGNAL CONDITION	ALARM ANNUN	CONTROL SWITCHES	TIMERS/ CLOCKS ETC	CNTL PNL SECTION	REMOTE S.P. STA
INFLUENT PUMPING	1		1	2	1	4	2	4		2	
PRELIM TREATMENT				3			3	6	6	3	
PRIMARY TREATMENT			16	32			32			8	
AERATION	16		20	36			4			8	
SECONDARY CLARIFIER	1		33	65	1		64			16	
CHLORINATION		1						6			
RAS PUMPING	16		17	16	16	4	2	4		6	
WAS PUMPING	1		1	1	1	4		4		2	
GRAVITY THICKENING	8		16	8			16			8	
DIGESTION	26		24	26	2		24	8	8	24	
SLUDGE HOLDING	1			13	1		12	3	3	2	
VACUUM FILTER	13		13	13		3		3		5	
INCINERATION				60			24			6	
MISCELLANEOUS	2		1	2	2	5	2	8	4	6	
INSTRUMENT TOTAL	85	1	142	277	24	20	185	46	21	56	
UNIT COST	740	635	1,200	280	840	585	55	230	130	1,000	790
TOTAL COST	62,900	635	170,400	77,560	20,160	11,700	10,175	10,580	2,730	96,000	
PLANT COST											462,840
ENGINEERING (.15)											69,426
SYSTEM TOTAL											532,266
EPA CONSTRUCTION COST ESTIMATE											133,767,672
I/C COST AS A PERCENT OF CONSTRUCTION											0.4

EQUIPMENT ANALYSIS

TABLE A-7

CENTRAL ANALOG

5 MGD

	RECORDERS	RATIO STATIONS	PID CONTROL	PANEL INDICATORS	TOTAL-IZERS	SIGNAL CONDITION	ALARM ANNUN	CONTROL SWITCHES	TIMERS/ CLOCKS ETC	CNTL PNL SECTION	REMOTE S.P. STA
INFLUENT PUMPING	1		1	1	1	2	2	4		1	1
PRELIM TREATMENT				4			2	4	2		
PRIMARY TREATMENT			2	4			4			1	2
AERATION	1		3	6			2			1	3
SECONDARY CLARIFIER	1		3	4	1		4			1	3
CHLORINATION		1				1		4			1
RAS PUMPING	1		1		1	2	2	4			1
WAS PUMPING	1		1		1	2		4			1
GRAVITY THICKENING	2		4	2			4			2	4
DIGESTION	6		4	6	2		4	8	4	2	4
DRYING BEDS	1			1	1			4	2	1	
MISCELLANEOUS	2		1	2	2	2	12	8	2	3	1
INSTRUMENT TOTAL	16	1	20	30	9	9	36	40	10	12	21
UNIT COST	740	635	1,200	280	840	565	55	230	130	1,000	790
TOTAL COST	11,840	635	24,000	8,400	7,560	5,265	1,980	9,200	1,300	12,000	16,590
PLANT COST											98,770
ENGINEERING (.15)											14,815
SYSTEM TOTAL											113,585
EPA CONSTRUCTION COST ESTIMATE											3,930,619
I/C COST AS A PERCENT OF CONSTRUCTION											2.9

TABLE A-8

EQUIPMENT ANALYSIS

CENTRAL ANALOG

10 MGD

	RECORDERS	RATIO STATIONS	PID CONTROL	PANEL INDICATORS	TOTAL-IZERS	SIGNAL CONDITION	ALARM ANNUN	CONTROL SWITCHES	TIMERS/ CLOCKS ETC	CNTL PNL SECTION	REMOTE S.P. STA
INFLUENT PUMPING	1		1	1	1	3	2	6		1	1
PRELIM TREATMENT				6			3	4	2	2	
PRIMARY TREATMENT			4	8			8			2	4
AERATION	2		5	10			3			2	5
SECONDARY CLARIFIER	1		5	8	1		8			2	5
CHLORINATION		1				1		4			1
RAS PUMPING	2		3		2	2	2	4			3
WAS PUMPING	1		1		1	2		4			1
GRAVITY THICKENING	2		4	2			4			2	4
DIGESTION	6		4	6	2		4	8	4	2	4
SLUDGE HOLDING	1			5	1		4	4	2	1	
VACUUM FILTER	3		3			2		4		2	3
INCINERATION				10			4			1	
MISCELLANEOUS	2		1	2	2	4	20	10	3	4	1
INSTRUMENT TOTAL	21	1	31	58	10	14	62	48	11	21	32
UNIT COST	740	635	1,200	280	840	585	55	230	130	1,000	790
TOTAL COST	15,540	635	37,200	16,240	8,400	8,190	3,410	11,040	1,430	21,000	25,280
PLANT COST											148,365
ENGINEERING (.15)											22,255
SYSTEM TOTAL											170,620
EPA CONSTRUCTION COST ESTIMATE											8,476,227
I/C COST AS A PERCENT OF CONSTRUCTION											2.0

TABLE A-9

EQUIPMENT ANALYSIS

CENTRAL ANALOG

50 MGD

	RECORDERS	RATIO STATIONS	PID CONTROL	PANEL INDICATORS	TOTAL-IZERS	SIGNAL CONDITION	ALARM ANNUN	CONTROL SWITCHES	TIMERS/ CLOCKS ETC	CNTL PNL SECTION	REMOTE S.P. STA
INFLUENT PUMPING	1		1	1	1	4	2	8		1	1
PRELIM TREATMENT				6			3	4	2	2	
PRIMARY TREATMENT			4	8			8			2	4
AERATION	4		7	14			3			2	7
SECONDARY CLARIFIER	1		7	12	1		12			3	7
CHLORINATION		1				1		4			1
RAS PUMPING	4		5		4	3	2	6		1	5
WAS PUMPING	1		1		1	2		4		1	1
GRAVITY THICKENING	3		6	3			6			3	6
DIGESTION	11		9	11	2		9	10	5	6	9
SLUDGE HOLDING	1			7	1		6	4	2	1	
VACUUM FILTER	5		5			2		4		3	5
INCINERATION				20			8			2	
MISCELLANEOUS	2		1	2	2	4	31	10	3	6	1
INSTRUMENT TOTAL	33	1	46	84	12	16	90	54	12	33	47
UNIT COST	740	635	1,200	280	840	585	55	230	130	1,000	790
TOTAL COST	24,420	635	55,200	23,520	10,080	9,360	4,950	12,420	1,560	33,000	37,130
PLANT COST											212,275
ENGINEERING (.15)											31,841
SYSTEM TOTAL											244,116
EPA CONSTRUCTION COST ESTIMATE											28,319,122
I/C COST AS A PERCENT OF CONSTRUCTION											0.9

264

TABLE A-10

EQUIPMENT ANALYSIS

CENTRAL ANALOG

100 MGD

	RECORDERS	RATIO STATIONS	PID CONTROL	PANEL INDICATORS	TOTAL-IZERS	SIGNAL CONDITION	ALARM ANNUN	CONTROL SWITCHES	TIMERS/ CLOCKS ETC	CNTL PNL SECTION	REMOTE S.P. STA
INFLUENT PUMPING	1		1	1	1	4	2	8		2	1
PRELIM TREATMENT				6			3	6	3	2	
PRIMARY TREATMENT			8	16			16			4	8
AERATION	8		12	24			4			4	12
SECONDARY CLARIFIER	1		17	32	1		32			8	17
CHLORINATION		1						8			1
RAS PUMPING	8		9		8	4	2	8		2	9
WAS PUMPING	1		1		1	4		8		1	1
GRAVITY THICKENING	4		8	4			8			4	8
DIGESTION	14		12	14	2		12	12	6	12	12
SLUDGE HOLDING	1			9	1		8	6	3	1	
VACUUM FILTER	7		7			3		6		3	7
INCINERATION				30			12			3	
MISCELLANEOUS	2		1	2	2	5	51	16	4	13	1
INSTRUMENT TOTAL	47	1	76	138	16	20	150	78	16	55	77
UNIT COST	740	635	1,200	280	840	585	55	230	130	1,000	790
TOTAL COST	34,780	635	91,200	38,640	13,440	11,700	8,250	17,940	2,080	59,000	60,830
PLANT COST											338,495
ENGINEERING (.15)											50,774
SYSTEM TOTAL											389,269
EPA CONSTRUCTION COST ESTIMATE											50,670,676
I/C COST AS A PERCENT OF CONSTRUCTION											0.8

265

EQUIPMENT ANALYSIS

TABLE A-11

CENTRAL ANALOG

300 MGD

	RECORDERS	RATIO STATIONS	PID CONTROL	PANEL INDICATORS	TOTAL-IZERS	SIGNAL CONDITION	ALARM ANNUN	CONTROL SWITCHES	TIMERS/ CLOCKS ETC	CNTL PNL SECTION	REMOTE S.P. STA
INFLUENT PUMPING	1		1	1	1	4	2	8		2	1
PRELIM TREATMENT				6			3	12	6	3	
PRIMARY TREATMENT			16	32			32			8	16
AERATION	16		20	40			4			8	20
SECONDARY CLARIFIER	1		33	64	1		64			16	33
CHLORINATION		1						12			1
RAS PUMPING	16		17		16	4	2	8		6	17
WAS PUMPING	1		1		1	4		8		2	1
GRAVITY THICKENING	8		16	8			16			8	16
DIGESTION	26		24	26	2		24	16	8	24	24
SLUDGE HOLDING	1			13	1		12	6	3	2	
VACUUM FILTER	13		13			3		6		5	13
INCINERATION				60			24			6	
MISCELLANEOUS	2		1	2	2	5	98	16	4	20	1
INSTRUMENT TOTAL	85	1	142	252	24	20	281	92	21	110	143
UNIT COST	740	635	1,200	280	840	585	55	230	130	1,000	790
TOTAL COST	62,900	635	170,400	70,560	20,160	11,700	15,455	21,160	2,730	110,000	112,970
PLANT COST											598,670
ENGINEERING (.15)											89,800
SYSTEM TOTAL											688,470
EPA CONSTRUCTION COST ESTIMATE											133,767,672
I/C COST AS A PERCENT OF CONSTRUCTION											0.7

TABLE A-12 — INPUT/OUTPUT ANALYSIS — CENTRAL DIGITAL CONTROL — 5 MGD

UNIT PROCESS	ANALOG INPUT	MODULATING OUTPUT	DISCRETE INPUT	CONTROL OUTPUT
INFLUENT PUMPING	4	1	2	2
PRELIMINARY TREATMENT	2		2	2
PRIMARY TREATMENT	6	2	8	2
AERATION	7	3	1	2
SECONDARY CLARIFIER	8	3	9	4
CHLORINATION	1	1		
RAS PUMPING	5	2	5	2
WAS PUMPING	4	1	2	2
GRAVITY THICKENING	10	4	10	
DIGESTION	10	4	6	10
DRYING BEDS	1			
MISCELLANEOUS	6	1	8	8
COLUMN TOTALS	64	22	53	34
ANALOG / DISCRETE		86		87
PLANT TOTAL				173

INPUT/OUTPUT ANALYSIS

TABLE A-13 CENTRAL DIGITAL CONTROL 10 MGD

UNIT PROCESS	ANALOG INPUT	MODULATING OUTPUT	DISCRETE INPUT	CONTROL OUTPUT
INFLUENT PUMPING	5	1	3	3
PRELIMINARY TREATMENT	3		2	2
PRIMARY TREATMENT	12	4	16	4
AERATION	12	5	2	3
SECONDARY CLARIFIER	14	5	17	8
CHLORINATION	1	1		
RAS PUMPING	7	3	6	2
WAS PUMPING	4	1	2	2
GRAVITY THICKENING	10	4	10	
DIGESTION	10	4	6	10
SLUDGE HOLDING	3			
VACUUM FILTER	8	3	4	4
INCINERATION	5		4	
MISCELLANEOUS	8	1	16	16
COLUMN TOTALS	102	32	88	54
ANALOG / DISCRETE		134		142
PLANT TOTAL				276

INPUT/OUTPUT ANALYSIS

TABLE A-14 — CENTRAL DIGITAL CONTROL — 50 MGD

UNIT PROCESS	ANALOG INPUT	MODULATING OUTPUT	DISCRETE INPUT	CONTROL OUTPUT
INFLUENT PUMPING	6	1	4	4
PRELIMINARY TREATMENT	3		2	2
PRIMARY TREATMENT	12	4	16	4
AERATION	18	7	4	3
SECONDARY CLARIFIER	20	7	19	6
CHLORINATION	1	1		
RAS PUMPING	12	5	9	3
WAS PUMPING	4	1	2	2
GRAVITY THICKENING	15	6	14	
DIGESTION	20	9	7	16
SLUDGE HOLDING	4			
VACUUM FILTER	12	5	6	6
INCINERATION	10		8	
MISCELLANEOUS	8	1	16	16
COLUMN TOTALS	145	47	107	62
ANALOG / DISCRETE		192		169
PLANT TOTAL				361

TABLE A-15 — INPUT/OUTPUT ANALYSIS — 100 MGD

CENTRAL DIGITAL CONTROL

UNIT PROCESS	ANALOG INPUT	MODULATING OUTPUT	DISCRETE INPUT	CONTROL OUTPUT
INFLUENT PUMPING	6	1	4	4
PRELIMINARY TREATMENT	3		3	3
PRIMARY TREATMENT	24	8	32	8
AERATION	32	12	8	4
SECONDARY CLARIFIER	50	17	49	16
CHLORINATION	1	1		
RAS PUMPING	21	9	14	4
WAS PUMPING	6	1	4	4
GRAVITY THICKENING	20	8	20	
DIGESTION	26	12	9	21
SLUDGE HOLDING	5			
VACUUM FILTER	17	7	9	9
INCINERATION	15		12	
MISCELLANEOUS	9	1	25	25
COLUMN TOTALS	235	77	189	98
ANALOG / DISCRETE		312		287
PLANT TOTAL				599

INPUT/OUTPUT ANALYSIS

TABLE A-16 — CENTRAL DIGITAL CONTROL — 300 MGD

UNIT PROCESS	ANALOG INPUT	MODULATING OUTPUT	DISCRETE INPUT	CONTROL OUTPUT
INFLUENT PUMPING	6	1	4	4
PRELIMINARY TREATMENT	3		6	6
PRIMARY TREATMENT	48	16	64	16
AERATION	56	20	16	4
SECONDARY CLARIFIER	98	33	97	32
CHLORINATION	1	1		
RAS PUMPING	37	17	22	4
WAS PUMPING	6	1	4	4
GRAVITY THICKENING	40	16	40	
DIGESTION	50	24	11	35
SLUDGE HOLDING	7			
VACUUM FILTER	29	13	15	15
INCINERATION	30		24	
MISCELLANEOUS	9	1	25	25
COLUMN TOTALS	420	143	328	145
ANALOG / DISCRETE		563		473
PLANT TOTAL				1,036

TABLE A-17 5 MGD (220 dm^3/s) EQUIPMENT COST, DIGITAL

	Quantity	Unit Cost	Total Cost
HARDWARE			
Central Processor	1	$ 14,000	$ 14,000
Memory	32K 16-Bit Words	2,500/4K	20,000
Program Console	1	5,500	5,500
Program Load Device	1	4,000	4,000
Printer	1	3,000	3,000
Operator Console	1	2,500	2,500
Multiplexer Interface	1	1,000	1,000
Multiplexer	6	3,100	18,600
AI	64	200	12,800
MO	22	450	9,900
DI	53	80	4,240
CO	34	175	5,950
HARDWARE SUBTOTAL			$ 101.490
SOFTWARE			
Development/Integration	550 MH	$45/MH	$ 24,750
Process Control	800 MH	$45/MH	$ 36,000
ENGINEERING	640 MH	$45/MH	$ 28,800
SYSTEM TOTAL			$ 191,040

TABLE A-18 10 MGD (440 dm^3/s) EQUIPMENT COST, DIGITAL

	Quantity	Unit Cost	Total Cost
HARDWARE			
Central Processor	1	$ 14,000	$ 14,000
Memory	32K 16-Bit Words	2,500/4K	20,000
Program Console	1	5,500	5,500
Disk (Fixed Head)	1	20,000	20,000
Program Load Device	1	14,000	14,000
Printer	1	6,000	6,000
Operator Console (Dual)	1	32,000	32,000
Multiplexer Interface	1	1,000	1,000
Multiplexer	7	3,100	21,700
AI	102	200	20,400
MO	32	450	14,400
DI	88	80	7,040
CO	54	175	9,450
HARDWARE SUBTOTAL			$ 185,490
SOFTWARE			
Development/Integration	1,040 MH	$50/MH	$ 52,000
Process Control	1,600 MH	$45/MH	$ 72,000
ENGINEERING	960 MH	$45/MH	$ 43,200
SYSTEM TOTAL			$ 352,690

TABLE A-19 50 MGD (2200 dm^3/s) EQUIPMENT COST, DIGITAL

	Quantity	Unit Cost	Total Cost
HARDWARE			
Central Processor	1	$ 14,000	$ 14,000
Memory	48K 16-Bit Words	2,500/4K	30,000
Program Console	1	5,500	5,500
Disk (Fixed Head)	1	20,000	20,000
Program Load Device	1	14,000	14,000
Printer	1	6,000	6,000
Operator Console (Dual)	1	32,000	32,000
Multiplexer Interface	1	1,000	1,000
Multiplexer	8	3,100	24,800
AI	145	200	29,000
MO	47	450	21,150
DI	107	80	8,560
CO	62	175	10,850
HARDWARE SUBTOTAL			$ 216,860
SOFTWARE			
Development/Integration	1,600 MH	$50/MH	$ 80,000
Process Control	2,800 MH	$45/MH	$ 126,000
ENGINEERING	1,200 MH	$50/MH	$ 60,000
SYSTEM TOTAL			$ 482,860

TABLE A-20 100 MGD (4400 dm^3/s) EQUIPMENT COST, DIGITAL

	Quantity	Unit Cost	Total Cost
HARDWARE			
Central Processor	1	$ 14,000	$ 14,000
Memory	60K 16-Bit Words	2,500/4K	37,500
Program Console	1	5,500	5,500
Disk (Fixed Head)	1	20,000	20,000
Program Load Device	1	14,000	14,000
Printer	1	6,000	6,000
Operator Console (Dual)	1	32,000	32,000
Multiplexer Interface	1	1,000	1,000
Multiplexer	11	3,100	34,100
AI	235	200	47,000
MO	77	450	34,650
DI	189	80	15,120
CO	98	175	17,150
HARDWARE SUBTOTAL			$ 278,020
SOFTWARE			
Development/Integration	2,000 MH	$50/MH	$ 100,000
Process Control	3,100 MH	$45/MH	$ 139,500
ENGINEERING	1,600 MH	$50/MH	$ 80,000
SYSTEM TOTAL			$ 597,520

TABLE A-21 300 MGD (13000 dm^3/s) EQUIPMENT COST, DIGITAL

	Quantity	Unit Cost	Total Cost
HARDWARE			
Central Processor	1	$ 14,000	$ 14,000
Memory	72K 16-Bit Words	2,500/4K	45,000
Program Console	1	5,500	5,500
Disk (Fixed Head)	1	20,000	20,000
Program Load Device	1	14,000	14,000
Printer	1	6,000	6,000
Operator Console (Dual)	1	32,000	32,000
Multiplexer Interface	1	1,000	1,000
Multiplexer	14	3,100	43,400
AI	420	200	84,000
MO	143	450	64,350
DI	328	80	26,240
CO	145	175	25,375
HARDWARE SUBTOTAL			$ 380,865
SOFTWARE			
Development/Integration	2,400 MH	$50/MH	$ 120,000
Process Control	3,600 MH	$45/MH	$ 162,000
ENGINEERING	2,000 MH	$50/MH	$ 100,000
SYSTEM TOTAL			$ 762,865

WIRE ANALYSIS

TABLE A-22 — CONVENTIONAL ANALOG — 5 MGD

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	100	2	200
PRIMARY TREATMENT	200	2	400
AERATION	350	1	350
SECONDARY CLARIFIER	650	3	1,950
RAS PUMPING	650	2	1,300
WAS PUMPING	650	1	650
GRAVITY THICKENING	600	2	1,200
DIGESTION	500	6	3,000
DRYING BEDS	500	1	500
MISCELLANEOUS	650	2	1,300
TOTAL		22	10,850
WIRE	.92/ PR-FT		9,982
TERMINATION	1.76 / PR		39
TOTAL COST			10,021

WIRE ANALYSIS

TABLE A-23 — 10 MGD

CONVENTIONAL ANALOG

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	150	2	300
PRIMARY TREATMENT	300	4	1,200
AERATION	550	2	1,100
SECONDARY CLARIFIER	950	5	4,750
RAS PUMPING	950	4	3,800
WAS PUMPING	950	1	950
GRAVITY THICKENING	800	2	1,600
DIGESTION	600	6	3,600
SLUDGE HOLDING	600	3	1,800
VACUUM FILTER	670	3	2,010
INCINERATION	670	5	3,350
MISCELLANEOUS	950	2	1,900
TOTAL		39	26,360
WIRE	.92 / PR-FT		24,251
TERMINATION	1.76 / PR		69
TOTAL COST			24,320

TABLE A-24 — WIRE ANALYSIS — CONVENTIONAL ANALOG — 50 MGD

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	300	2	600
PRIMARY TREATMENT	700	4	2,800
AERATION	1,200	4	4,800
SECONDARY CLARIFIER	2,100	7	14,700
RAS PUMPING	2,100	4	8,400
WAS PUMPING	2,100	1	2,100
GRAVITY THICKENING	1,850	3	5,550
DIGESTION	1,510	11	16,610
SLUDGE HOLDING	1,510	4	6,040
VACUUM FILTER	650	5	3,250
INCINERATION	650	10	6,500
MISCELLANEOUS	2,100	2	4,200
TOTAL		57	75,550
WIRE .92 / PR-FT			69,506
TERMINATION 1.76 / PR			100
TOTAL COST			69,606

WIRE ANALYSIS

TABLE A-25 — CONVENTIONAL ANALOG — 100 MGD

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	400	2	800
PRIMARY TREATMENT	1,000	8	8,000
AERATION	1,650	8	13,200
SECONDARY CLARIFIER	3,000	17	51,000
RAS PUMPING	3,000	8	24,000
WAS PUMPING	3,000	1	3,000
GRAVITY THICKENING	2,600	4	10,400
DIGESTION	2,150	14	30,100
SLUDGE HOLDING	2,150	5	10,750
VACUUM FILTER	950	7	6,650
INCINERATION	950	15	14,250
MISCELLANEOUS	3,000	2	6,000
TOTAL		91	178,150
WIRE	.92 / PR-FT		163,898
TERMINATION	1.76 / PR		160
TOTAL COST			164,058

WIRE ANALYSIS

TABLE A-26 — CONVENTIONAL ANALOG — 300 MGD

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	700	2	1,400
PRIMARY TREATMENT	1,700	16	27,200
AERATION	2,900	16	46,400
SECONDARY CLARIFIER	5,200	33	171,600
RAS PUMPING	5,200	16	83,200
WAS PUMPING	5,200	1	5,200
GRAVITY THICKENING	4,500	8	36,000
DIGESTION	3,700	26	96,200
SLUDGE HOLDING	3,700	7	25,900
VACUUM FILTER	1,650	13	21,450
INCINERATION	1,650	30	49,500
MISCELLANEOUS	5,200	2	10,400
TOTAL		170	574,450
WIRE	1.03 / PR-FT		574,450
TERMINATION	1.76 / PR		299
TOTAL COST			574,749

WIRE ANALYSIS

TABLE A-27 — CENTRAL ANALOG — 5 MGD

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	100	7	700
PRELIMINARY TREATMENT	100	6	600
PRIMARY TREATMENT	200	6	1,200
AERATION	350	9	3,150
SECONDARY CLARIFIER	650	8	5,200
CHLORINATION	650	6	3,900
RAS PUMPING	650	6	3,900
WAS PUMPING	650	6	3,900
GRAVITY THICKENING	600	10	6,000
DIGESTION	500	22	11,000
DRYING BEDS	500	5	2,500
MISCELLANEOUS	650	22	14,300
TOTAL		113	56,350
WIRE	.92 / PR-FT		51,842
TERMINATION	1.76 / PR		199
TOTAL COST			52,041

WIRE ANALYSIS

TABLE A-28 CENTRAL ANALOG 10 MGD

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	150	9	1,350
PRELIMINARY TREATMENT	150	7	1,050
PRIMARY TREATMENT	300	12	3,600
AERATION	550	15	8,250
SECONDARY CLARIFIER	950	14	13,300
CHLORINATION	950	6	5,700
RAS PUMPING	950	10	9,500
WAS PUMPING	950	6	5,700
GRAVITY THICKENING	800	10	8,000
DIGESTION	600	22	13,200
SLUDGE HOLDING	600	7	4,200
VACUUM FILTER	670	10	6,700
INCINERATION	670	5	3,350
MISCELLANEOUS	950	32	30,400
TOTAL		165	114,300
WIRE .92 / PR-FT			105,156
TERMINATION 1.76 / PR			290
TOTAL COST			105,446

WIRE ANALYSIS

TABLE A-29 — CENTRAL ANALOG — 50 MGD

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	300	11	3,300
PRELIMINARY TREATMENT	300	7	2,100
PRIMARY TREATMENT	700	12	8,400
AERATION	1,200	21	25,200
SECONDARY CLARIFIER	2,100	20	42,000
CHLORINATION	2,100	6	12,600
RAS PUMPING	2,100	16	33,600
WAS PUMPING	2,100	6	12,600
GRAVITY THICKENING	1,850	15	27,750
DIGESTION	1,510	39	58,890
SLUDGE HOLDING	1,510	8	12,080
VACUUM FILTER	650	14	9,100
INCINERATION	650	10	6,500
MISCELLANEOUS	2,100	43	90,300
TOTAL		228	344,420
WIRE	.92/ PR-FT		316,866
TERMINATION	1.76 / PR		401
TOTAL COST			317,267

WIRE ANALYSIS

TABLE A-30 — CENTRAL ANALOG — 100 MGD

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	400	11	4,400
PRELIMINARY TREATMENT	400	9	3,600
PRIMARY TREATMENT	1,000	24	24,000
AERATION	1,650	36	59,400
SECONDARY CLARIFIER	3,000	50	150,000
CHLORINATION	3,000	10	30,000
RAS PUMPING	3,000	26	78,000
WAS PUMPING	3,000	10	30,000
GRAVITY THICKENING	2,600	20	52,000
DIGESTION	2,150	50	107,500
SLUDGE HOLDING	2,150	11	23,650
VACUUM FILTER	950	20	19,000
INCINERATION	950	15	14,250
MISCELLANEOUS	3,000	69	207,000
TOTAL		361	802,800
WIRE	.92 / PR-FT		738,576
TERMINATION	1.76 / PR		635
TOTAL COST			739,211

WIRE ANALYSIS

TABLE A-31 300 MGD

CENTRAL ANALOG

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	700	11	7,700
PRELIMINARY TREATMENT	700	15	10,500
PRIMARY TREATMENT	1,700	48	81,600
AERATION	2,900	60	174,000
SECONDARY CLARIFIER	5,200	98	509,600
CHLORINATION	5,200	14	72,800
RAS PUMPING	5,200	42	218,400
WAS PUMPING	5,200	10	52,000
GRAVITY THICKENING	4,500	40	180,000
DIGESTION	3,700	90	333,000
SLUDGE HOLDING	3,700	13	48,100
VACUUM FILTER	1,650	32	52,800
INCINERATION	1,650	30	49,500
MISCELLANEOUS	5,200	116	603,200
TOTAL		619	2,393,200
WIRE .92 / PR-FT			2,201,744
TERMINATION 1.76 / PR			1,089
TOTAL COST			2,202,833

WIRE ANALYSIS

TABLE A-32 5 MGD

CENTRAL DIGITAL CONTROL

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	100	2	200
PRIMARY TREATMENT	200	2	400
AERATION	350	2	700
SECONDARY CLARIFIER	650	2	1,300
GRAVITY THICKENING	600	2	1,200
DIGESTION	500	2	1,000
TOTAL		12	4,800
WIRE 1.78 / PR-FT			8,544
TERMINATION 1.76 / PR			21
TOTAL COST			8,565

WIRE ANALYSIS

TABLE A-33 — 10 MGD

CENTRAL DIGITAL CONTROL

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	150	2	300
PRIMARY TREATMENT	300	2	600
AERATION	550	2	1,100
SECONDARY CLARIFIER	950	2	1,900
GRAVITY THICKENING	800	2	1,600
DIGESTION	600	2	1,200
VACUUM FILTER	670	2	1,340
TOTAL		14	8,040
WIRE	1.78 / PR-FT		14,311
TERMINATION	1.76 / PR		24
TOTAL COST			14,349

WIRE ANALYSIS

TABLE A-34 — 50 MGD

CENTRAL DIGITAL CONTROL

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	300	2	600
PRIMARY TREATMENT	700	4	2,800
AERATION	1,200	4	4,800
GRAVITY THICKENING	1,850	2	3,700
DIGESTION	1,510	2	3,020
VACUUM FILTER	650	2	1,300
TOTAL		16	16,220
WIRE 1.78 / PR-FT			28,872
TERMINATION 1.76 / PR			28
TOTAL COST			28,900.

WIRE ANALYSIS

TABLE A-35 — CENTRAL DIGITAL CONTROL — 100 MGD

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	400	2	800
PRIMARY TREATMENT	1,000	4	4,000
AERATION	1,650	4	6,600
SECONDARY CLARIFIER	3,000	4	12,000
CHLORINATION	3,000	2	6,000
GRAVITY THICKENING	2,600	2	5,200
DIGESTION	2,150	2	4,300
VACUUM FILTER	950	2	1,900
TOTAL		22	40,800
WIRE	1,78/ PR-FT		72,624
TERMINATION	1.76 / PR		38
TOTAL COST			72,662

WIRE ANALYSIS

TABLE A-36 — 300 MGD

CENTRAL DIGITAL CONTROL

UNIT PROCESS	FEET	PAIR	PAIR-FT
INFLUENT PUMPING	700	2	1,400
PRIMARY TREATMENT	1,700	4	6,800
AERATION	2,900	4	11,600
SECONDARY CLARIFIER	5,200	4	20,800
CHLORINATION	5,200	2	10,400
GRAVITY THICKENING	4,500	2	9,000
DIGESTION	3,700	2	7,400
SLUDGE HOLDING	3,700	2	7,400
VACUUM FILTER	1,650	2	3,300
INCINERATION	1,650	4	6,600
TOTAL		28	84,700
WIRE	1.78 / PR-FT		150,766
TERMINATION	1.76 / PR		49
TOTAL COST			150,815

TABLE A-37. MULTIPLEXER ASSIGNMENTS

Plant Size	Quantity	Multiplexer Location
5 MGD (220 dm^3/s)	6	Influent Pumping Primary Treatment Aeration Secondary Clarifier Gravity Thickening Digestion
10 MGD (440 dm^3/s)	7	Influent Pumping Primary Treatment Aeration Secondary Clarifier Gravity Thickening Digestion Vacuum Filter
50 MGD (2200 dm^3/s)	8	Influent Pumping 2 - Primary Treatment 2 - Aeration Gravity Thickening Digestion Vacuum Filter
100 MGD (4400 dm^3/s)	11	Influent Pumping 2 - Primary Treatment 2 - Aeration 2 - Secondary Clarifier Chlorination Gravity Thickening Digestion Vacuum Filter
300 MGD (13000 dm^3/s)	14	Influent Pumping 2 - Primary Treatment 2 - Aeration 2 - Secondary Clarifier Chlorination Gravity Thickening Digestion Sludge Holding Vacuum Filter 2 - Incineration

SECTION 6

AVAILABLE INSTRUMENTATION

INTRODUCTION

A wastewater treatment plant is faced with a difficult task of treating an influent stream of continually changing quality and quantity while required to consistently maintain effluent standards. Also, ever increasing costs of energy, labor and materials make the problem more challenging. However, the judicious application of instrumentation to monitor key process parameters and present the information for operational decision making can aid in achieving the desired goals.

This section provides a procedure which can be followed for the selection of an instrument, a discussion of maintenance requirements for long-term operation and a summary of commonly used instrumentation in wastewater facilities with recommendations for application. By following the procedures in this section, data can be compiled to aid in making a final decision to use an instrument.

GUIDE FOR INSTRUMENT SELECTION

This discussion offers a guideline for users of instrumentation to aid in the selection and application of an instrument. By examining the need for measurement of a process parameter, determining the various methods for accomplishing the desired measurement and establishing a procedure for making a final selection, the probability of achieving a successful installation is greatly increased.

The general guide consists of a series of questions which, if individually addressed and answered or determined inappropriate for the case under review, can lead to best conclusions. Also, there is a discussion of frequently used terminology which will aid in interpreting instrument specification sheets published by manufacturers. By using the information provided, there is an orderly procedure which can be followed for the evaluation and selection of equipment to provide reliable measurement of a parameter.

MEASUREMENT CONSIDERATIONS

Objectives

The first consideration in the design of any measurement system should include a statement of the objective. Typical examples of wastewater analysis and control are:

- Establishing a material balance.
- Control sludge wasting rate.
- Detecting LEL (lower explosive gas level) in closed tanks or wet wells.
- Control wet well level.
- Control of chemical feed addition.
- Monitoring final effluent quality.

After the general objective is stated, the next step will be to analyze measurement systems which will accomplish the stated objective. Parameters required for the analysis depend on the actual process information desired. The following major points or questions should be considered in determining the type of measurement system required.

Measurement For Control & Optimizing of the Resources

What instrument accuracy is needed? Accuracy will depend on the process requirement. For example, precise level measurement for interceptor storage control is more critical than an application for wet well level measurement where the primary concern is to prevent flooding the wet well or running the pumps dry.

Is the measurement required for relieving operating personnel of monotonous and nonchallenging tasks?

Can the process control tolerate momentary or extended periods of interruption? If momentary interruptions can create process upsets, signal locking should be specified with the instrument. A signal locking arrangement will store the last measurement whenever the signal is disturbed or stopped for a period of time. Will the process be interrupted often? If so, will fouling of the sensor occur? Provide necessary cleaning devices if such interruptions are expected to affect performance.

Measurement For Safety

The reliability of the instrument should be the major consideration here. Fail-safe arrangement should be considered where the process is critical or involves personnel safety.

Measurement For Process Monitoring

In this case, accuracy, repeatability and reliability requirements may not be as stringent as they are in the first two considerations. The reason for monitoring the parameter should provide background on the accuracy requirements. Measurement used for billing purposes or NPDES compliance reporting requires better accuracy and reliability than the measurement used for maintenance or trending purposes.

Instrument Location

The next step in the measurement system design is to determine a point of measurement in the process. Process characteristics largely determine the optimum location of the point of measurement, however, the feasibility of making the measurement at a specific point and accessibility may dictate the location.

There are three general areas in which instruments can be located for process monitoring and control. These include on the input to the process, on the output of the process or in the process. Influent and effluent measurements of a unit process normally require sensor mounting on closed conduits, wet wells or an open channel. Obtaining a measurement in a process involves installation of a sensor in an open or closed tank.

Limitations

Once a location for the measurement element is determined, the next step will be to evaluate constraints which may exist where the measurement is to be made. This section lists a number of limitations under which a selected instrument may have to work. Each limitation should be carefully reviewed considering the characteristics and performance data of the available instruments.

Physical--

Evaluate the point of measurement to determine if physical restrictions exist. Is the location accessible for maintenance? Is pipe size adequate? Are up and down stream pipe characteristics conducive to representative measurements? Is there adequate space for installation? These are only a few of the physical characteristics that have to be examined before making a final instrument selection.

Environmental--

Temperature - If the instrument has to work under extreme temperature conditions, means should be provided to protect the instrument against freezing, condensation and high temperatures.

Vibration - If an instrument is located on or near rotating or reciprocating equipment, accuracy and/or long term reliability may be affected by the vibration.

Humidity - This should be checked against the instrument specification and specifically where sample gas or air lines are required, proper protection should be provided against collection of condensibles in the lines.

Corrosive Gases - If corrosive gases are expected in the instrument environment, proper protection should be provided for the instrument in its enclosure.

Cleaning - If steam or chemical cleaning is expected, verify that the sensor material would withstand the cleaning; or if not, that proper protection is provided.

Process Material Characteristics--

The process material characteristics should be reviewed to check their compatibility with the performance and the life of the instrument.

Foreign Materials - Undesirable materials like grease, scum, entrained solids and chemicals can have detrimental effects on instruments exposed to them. Each type of available instrument's performance should be checked in similar environment.

Suspended Solids, pH - Value of suspended solids and/or pH of the process material will affect the performance of certain instruments.

Temperature and Pressure - The sensors' performance will be affected with respect to accuracy and the life of the sensor by extreme temperature and pressure. These should be considered separately from the outside environment consideration.

Rangeability--

This characteristic of the instrument will indicate its suitability for the present requirement as well as future expansions. The selected instrument should be able to measure the process parameter over the range anticipated and if required, should be able to expand or suppress the range if the parameter's range is expected to change in the future. The performance of the instrument should remain within its specified limits in the total range.

Technology--

A large variety of sensors and transducers are available for measuring each of the most commonly encountered parameters in the wastewater treatment field. These sensors are designed based either on different scientific principles or different techniques using the same principle.

Each instrument considered should be evaluated against the requirement for the measurement. A less sophisticated, field proven instrument may be more desirable than a new instrument claiming improved performance.

Available Measurement Methods

After a measurement parameter and the location for the measurement are determined, the next step is to locate an instrument to measure the parameter. Out of the multitude of instruments available, one needs to select the most suitable instrument for the application. This section provides an organized approach to obtain the information about available measurement methods and potential suppliers of the instruments.

Literature Search--

Information related to instrumentation applications, theory and suppliers is published in several different forms. The applicable publications are discussed here.

Trade Journals--

1. Instruments & Control Systems, a monthly publication, published by Chilton Co., Randor, PA.

2. Control Engineering, a monthly publication of Technical Publishing Co., Chicago, IL.

3. Instrumentation Technology, a monthly publication of Instrument Society of America, Pittsburgh, PA.

4. Waste & Sewage Works, a monthly publication of Scranton Gillette Co., Chicago, IL.

Equipment Guides--

1. Visual Search Micro Films (VSMF) a service provided by Information Handling Services of Englewood, Colorado

2. Chemical Engineering Equipment Buyers' Guide, McGraw Hill Publication, New York, NY.

3. Chilton's Control Equipment Master, Chilton Book Co., Randor, PA.

4. Environmental Yearbook and Products Reference Guide, Technical Publishing Co., Greenwich, CT.

5. Pollution Equipment News Buyers' Guide, a Rimbach Publication, Pittsburgh, PA.

Reference Books--These reference books will provide detailed information about different kinds of instruments available in the market. These references sometimes provide comparison of different types of instruments available to measure a parameter. Examples of these references are:

1. Chemical Engineer's Handbook, John H. Perry, McGraw Hill Book Co., New York, NY.

2. Liptak's Environmental Engineers' Handbook, B. G. Liptak, Chilton Book Co., Randor, PA.

3. Process Instruments & Controls Handbook, D. M. Considine, McGraw Hill Book Co., New York, NY.

Manufacturer's Representative--

Representatives of the instrument manufacturer can also provide the information needed about the instrument evaluation for the application. He may be able to help you evaluate the application with respect to the instrument he is representing. If an applicable instrument is not made by the firm he/she represents, he/she may guide you to another manufacturer who can supply the required instrument. Both factory and local sales representatives can provide useful technical information and literature.

UNDERSTANDING INSTRUMENT SPECIFICATIONS

It is essential that the individual evaluating instrumentation alternatives understand instrument specifications so that comparisons can be done on a common base. The following discussion explains commonly used terms found in manufacturers instrument specifications.

The instrument specifications published by suppliers are organized in numerous ways. For the sake of clarity, the following description is organized in major sections and subsections similar to that used in many specifications.

General Features

This part of a specification describes the general use and capabilities of the instrument. These highlights can provide information relative to the kind of environment in which the instrument can be used, the intended service, rangeability, maintenance requirements and the kind of flexibility the instrument offers. Many times it is possible to determine from this information whether the instrument is worth considering for the requirements of the measurement system.

Detailed Design Specifications

If the general specification meets the general requirements of the intended application, it is then necessary to study the detailed specifications of the instrument.

Material--

The material of construction for each part of the instrument in contact with the process should be described. If not, the supplier should be consulted to check the material compatibility with the process media and environment. Ascertain the instrument enclosure material also meets the requirements of the environment in which it will be working.

Connection Size--

If the sensor or sensor enclosure is required to be physically connected with the other process equipment or parts, size (including thread specification if threaded connections are used) and the type of connector should be specified. Always try to specify and obtain standard size connectors.

Mounting--

The kind of mounting available for sensor assembly and the signal converter should be specified. The sensor could be in-line, pipe, duct, tank mounted, or may require specially designed mounting. The signal converter enclosure could be portable, surface, pedestal or panel mounted type.

Utilities--

This part of the specification should indicate necessary utilities like electric power, air, steam or chemicals that may be required for either instrument operation or calibration. Rate of consumption, pressure, voltage, temperature or concentration should be specified.

Performance Specifications

Performance evaluation rates high on the list of items considered in selecting an instrument. Each item affecting the performance should be considered against the requirements of the total system. Major items that affect the accuracy are repeatability, linearity, static and dynamic errors and dead band. These are figures published by the instrument manufacturers and will hold only in ideal operating conditions and if the system is maintained according to the manufacturer's recommendations.

Accuracy--

It is defined as the limit, usually expressed as a percentage of full scale range, span or measured value, not exceeded by errors when the instrument is used under certain reference conditions. Verify the actual absolute error across the range of measurement and the conditions under which the accuracy would hold. Caution: Specific component accuracy is not to be confused with loop accuracy where component accuracy may be compounded.

Repeatability--

Repeatability is defined as the ability of an instrument to come back to the same value of measurement at different times. It is normally specified in terms of maximum error between two values of the same measurement made at different times, but under the same operating conditions. It is expressed in terms of percent of the full scale value of the measurement.

Linearity--

It is the closeness to which a curve formed of measurement points approximates a straight line. It is specified in terms of maximum deviation between an average curve and a straight line.

Drift--

Drift is defined as a change in the output for the same input and operating conditions over a specified period of time. It is normally expressed in terms of maximum change in output across the measured range in percent of full scale value. The drift could be caused by sensor deterioration or signal converter output variation.

Sensitivity--

The sensitivity of a measuring instrument is the minimum change in value of the measured variable the instrument can sense and provide a useful output. Also, the minimum value which instrument can provide a useful signal within accuracy of specs.

Dead Band--

The largest range through which the variable being measured can change without the change being sensed by the instrument.

Limitations

All instruments have restrictions which must be considered in order to assure reliable performance within the specified accuracy of the instrument. These must be examined closely to determine if they may affect an instrument's ability to perform as required.

Rangeability--

This indicates the practical measured range over which an instrument will perform within the specified accuracy and other performance criteria. It is normally expressed as a ratio of maximum to minimum measured value. At times different sizes of the same instrument may be necessary to cover the range over which an instrument is expected to operate. Other instruments are designed to operate over multiple ranges which are switch selectable. Also, options are available with some instruments for expanding and suppressing the range.

Environment--

This specifies the range of parameters like temperature, pressure, humidity or any other special environment parameters within which the instrument can operate and provide results within the specified performance. Verify these limits for both the sensor assembly and the signal converter.

Physical--

This is concerned with restrictions which should be observed for proper installation. Restrictions on direction, location or orientation of the sensor in the process, maximum distance allowed between the sensor and the signal converter and need for special accessories for mounting are discussed here.

Options

Instruments are designed to be suitable for as many applications as is practical. However, options are frequently offered to enable customization of an instrument for a user's specific purpose. It may enhance the reliability, provide more flexibility, wider range, better control or may make it suitable for harsher environment.

Maintainability--

Options like ultrasonic cleaning, a corporation stop for in-line installation, plug-in modules and local on/off control are offered for the purpose of improving the maintainability and ease of calibration.

Output Signal--

Special types and levels of signals are offered to meet different interface requirements. If the line has intermittent flow or is often shut down, the zero signal option should be purchased.

Controls--

Local controls and indication are provided for ease of calibration.

Future Expansion--

Span elevation or suppression provisions or a range selector are provided to accommodate future expansion of the capability of the instrument.

Instrument Protection--

Diaphragm seal for pressure transmitter, intrinsically safe equipment, or enclosures for hazardous locations provides safety of the equipment. Heat trace or steam trace lines are offered for sample lines for protecting the lines in colder and/or humid environments.

Instrument Design For Safety--

If the instrument is expected to work in a hazardous area, provide explosion proof or intrinsically safe equipment. Check if there is any other optional equipment available for safety reasons.

Material--

Special material of construction for the sensor and other wetted parts or special protection well are offered for harsher (or corrosive) process media applications. Check if enclosure material also is compatible with the environment.

Installation--

Special mounting assemblies or fixtures to facilitate the ease of installation.

FINAL INSTRUMENT SELECTION

In evaluating different instruments, in addition to their design and performance specifications there are other factors that should be considered. This section identifies many of these factors and discusses the importance of each for consideration in arriving at the most suitable instrument for the desired measurement system.

Performance of the Instrument

Performance parameters desired of the measurement system usually are not subject to compromise. Determine the performance needs of the process and select the instrument which will deliver the required accuracy, maintainability and reliability. Selection of instruments with a greater performance than is necessary will make the instrument costs excessive.

Accuracy--

Accuracy should be considered with respect to the process requirement. Inaccuracy because of only static error is not critical to automatic control. In order to enhance protection or the reliability of the sensor, a lower degree of accuracy may be acceptable. Accuracy figures in terms of a percent of measurement rather than a percent of maximum span will provide a better picture of the measurement system.

Sensitivity--

Sensitivity is not very critical in most of the applications in the wastewater treatment process, except in the laboratory analysis. Sacrificing sensitivity of the sensor in favor of better protection and reliability is usually valid.

Repeatability--

This is important in automatic control of a process and the designer should strive to obtain the best available.

Drift--

This is important as it affects repeatability for automatic control systems. If a high rate of drift is unavoidable, automatic recalibration of the system at regular intervals should be specified. Signal locking should be specified for continuous control if automatic recalibration is specified.

Warranty--

The engineer must consider the length of warranty period and items and work covered in the contract. It should provide for replacement of all worn and defective parts detected during the warranty period. If it is a new equipment item, check the availability of the instrument for trial period use on the actual process.

Acceptance Testing--

The basis for evaluation of an instrument has to be stated in order for a supplier to determine if his equipment can achieve the desired performance. Who will conduct the test, where the test will be conducted, the duration over which performance must be maintained and the action to be taken in a pass or fail situation must all be clearly stated.

Maintainability

This is the weakest link in the total measurement system; but if properly considered and prepared for, it can insure the long-term successful operation of the system.

Uniformity and Consistency--

Specifying instruments that are of the same make or model as that of the existing instruments offers several advantages. The inventory of spare parts and spare units is greatly reduced. It reduces the need for training maintenance persons and operators for a variety of brands of instruments. There is less possibility of error in calibration or operation.

Maintenance Record--
Determine the need for maintenance for the instrument. It may not be available in the catalogs or the instruction manual. Insist on obtaining the information on the performance record with respect to maintenance requirement. This should include custodial and preventive maintenance requirements, and frequency of failure.

Required Skill Level for Maintenance--
Make sure properly trained personnel will be available to maintain the instrument.

Easy Access for Maintenance--
Discuss the accessibility of the instrument parts that need maintenance. Can it be serviced in its installed position? Does it provide any built-in aids for maintaining the instrument?

On-Line Servicing--
If it can be serviced on line, is it equipped with signal locking provision for continuous operation of the control loop? Is the signal converter equipped with an indicator and necessary controls for on-line calibration?

Spare Parts and Serviceability--
Are the spare parts and service people available in the area where the instrument will be used? Check the time within which a service person can be available for service. Will the spare parts be available for the instrument for its expected life span?

Safety - Instrument and Personnel

Does the instrument need venting or purging for safe operation? Check the classification of the area of the instrument location and ascertain the available instrument is designed for use in the area. Does the instrument design meet all the OSHA requirements and any other prevailing local and insurance company safety codes? Does the instrument require protection against lightning? If the instrument system is used for measuring a safety (of personnel and equipment) level of the environment in a room or an area, a redundant sensor or measurement system should be provided.

Installation Consideration--
The following points should be considered with respect to installation of the instrument on the process.

Location--
Compare the space available and location of the measurement point with the size of sensor assembly available.

Alignment Restriction--
Check if there is any alignment requirement for the instrument and see if that would create any problem.

Distance Between the Sensor and the Signal Transmitter--
Check that the distance permissible between the sensor and the transmitter meets the installation requirements.

Utility Requirement--
Check requirements for electrical power, air, steam and water for the instrument. Are they available in the area? Do they meet the voltage, pressure or temperature requirements? Is there any special grounding requirement?

Weather Protection--
If the instrument is located outdoors, check availability of weatherproof enclosure for the instrument and junction box for the electrical connections. Proper protection and/or auxiliary heating system should be provided for cold weather protection.

Costs

Cost of the instrument is one of the major criteria in selecting the instrument. One should, however, consider the total cost of the instrument over its life span rather than just initial cost of the instrument. For comparison, the total annual cost of each instrument should be used. The total cost of the instrument should include consideration of the following:

- Purchase price
- Installation (labor, parts and materials)
- Spare/Replacement parts
- Operation (include utilities and expendable materials)
- Maintenance labor

Evaluation of Supplier

Obtain first hand, written statements from the supplier about the operation, maintenance and reliability of the instrument.

Qualifications of the Supplier

This can be obtained by surveying the users of the supplier's instrument and/or visiting and observing different installations. A user survey would reveal both good and bad points of the instrument and supplier's operation and reliability.

IMPORTANCE OF INSTRUMENTATION MAINTENANCE

Instrumentation forms the foundation or base of any control system. If automation is to succeed, the sensors must be kept in working condition. When properly maintained, instrumentation can provide information to centralize operation decision making in a remote facility. To accomplish this requires implementation of an effective maintenance program to insure the availability of reliable process information.

The Maintenance Commitment

Wastewater streams characteristically contain high concentrations of grease, scum and suspended solids; all of which can interfere with the performance of an instrument. Since wastewater in contact with precise equipment can cause fouling in a short period, instrumentation has often been turned off and labeled unworkable when it failed to operate without attention for extended periods of time. For this reason, instruments have developed a poor reputation in the wastewater industry. To overcome these problems requires a conscious commitment on the part of the instrument specifier, manufacturer and user.

An instrument specifier has a responsibility to select equipment which is satisfactory for the application and provides information which is necessary for safety or process operation. The specifier and user must maintain communications relative to the frequency of maintenance required for each instrument and the availability of personnel to perform the maintenance. Also, the specifier must provide provisions for maintenance in the installation details.

Instrument manufacturers are responsible for maintaining an available supply of expendable and replacement spare parts and for furnishing useful instruction materials so a user can maintain the equipment. In addition, it is also a manufacturer's responsibility not to exaggerate claims of performance and to be realistic in frequency and time to perform periodic maintenance.

The user, having agreed to use the instrumentation, is responsible for making available a trained staff capable of performing all required maintenance and with sufficient manpower so the tasks can be performed when required. This is the key to successful instrument application. Therefore, the user must commit to clean, calibrate and/or repair the instrumentation as required. The importance of this commitment increases with increasing levels of automation. Although automation can minimize the labor required for operations, there is a corresponding shift to maintenance to insure the instruments are reporting reliable information for making operation decisions.

Levels of Maintenance

Instrumentation failures can be obvious as when the signal suddenly drives to its maximum or minimum value due to a component breakdown. Other failures cause gradual degradation of the instrument's performance either resulting from fouling of the sensor or changes in calibration because of age or environmental conditions. The second class of failures is difficult to detect since the loss of accuracy and sensitivity is too subtle to be picked up in normal operations. An effective maintenance program will be capable of detecting and responding to both classes of failures. To accomplish this, maintenance can be classified as follows:

- Custodial
- Periodic Calibration
- Repair

Each is independently definable, typically performed by different personnel, and each is equally important to overall system performance.

Custodial maintenance can be defined as the routine cleaning and/or observation of an instrument to assure validity of the information. An instrument which is in contact with the material being measured will tend to become coated. Therefore, routine cleaning must be performed. Optical instruments are a good example of this type of maintenance. One can wait for an optical instrument to degrade enough to show an obvious failure, but long before, the instrument has been providing an incorrect reading.

Keeping instruments clean and checking for reasonableness and variability solves about half the problems. In wastewater treatment plants, the ambient temperatures constantly change on a seasonal and daily basis. The sensor will start to be coated and the transmitter will drift with time. Periodic calibration must be performed to ensure successful operation.

The third category of maintenance is identified as repair/replace. It is not uncommon for a sensor and/or a transmitter "or some supporting component" to fail. The instrument is there for a reason. Therefore, when the instrument fails, its repair and/or replacement is the highest priority. This requires spare parts, spare instruments and the technical expertise to perform the work. Again, repair maintenance is crucial to the system communication and security.

Maintenance Organization

Organizing an instrument maintenance program is important and a team responsible for maintenance must be formed. This team should be comprised of personnel from operations, laboratory and electrical/mechanical trades. The staff operators should perform the cleaning and reasonability checks. They should be assigned specific and detailed tasks to be performed regularly on every instrument.

The periodic calibration should be performed under this organization by a chemist or analytical technician. In most instances, periodic calibration can be accomplished by a chemist without the assistance of an electrical/mechanical maintenance person. This should be one of the objectives in the specification of the instrument. The person responsible to calibrate a sensor and possibly a transmitter should not be required to rewire or have to disassemble a device. There are definitely times when this is not possible. However, for the most part, a chemist should be able to handle the calibration.

Repair maintenance would normally be accomplished by the electrical/mechanical maintenance technician. Spare parts is the key here. Failure of a transmitter or sensor can normally be diagnosed at a workbench while the failed unit has been replaced by a spare.

It is very important that the management of this team develop the cooperation and constructive attitude which is necessary. Feelings of not knowing one's responsibilities or work tasks or feelings of not being comfortable in performing certain maintenance functions must be avoided. Training and hands-on supervised instruction is important. This must be an on-going task.

Once the team is organized, the next crucial item is establishing a routine; a discipline. Each member of the team should be given specific tasks to be accomplished on a daily, weekly or monthly basis. A schedule should be developed for each instrument type. As a start, custodial or reasonability type maintenance should be performed every day until operating experience determines what frequency is actually required. Periodic calibration should be specified for each type of instrument. As examples, a chlorine residual analyzer should be calibrated daily or a magnetic flow meter should be calibrated monthly. The same approach is used for other types of instruments. Care must be taken to consider the application when establishing a maintenance schedule. As an example, in an intermittently pumped primary sludge line the magnetic flow meter electrodes become coated very rapidly. Continuous or portable ultrasonic cleaning along with frequent routine calibration is necessary here.

Documentation of the three levels of preventive maintenance must be provided. Records must be kept and verified. This will allow development of a more directly applicable schedule because history will show what the actual requirements are. The documentation should include operator initials along with comments and observations. A form should be developed which is practical and useable.

Communication with operations during the performance of the routine maintenance is crucial. When an instrument is specified, the rule was that it was necessary for reporting, process control or safety. Therefore, that sensor is important and cannot be arbitrarily inactivated. The shift operators who are performing operator maintenance and the chemists and technicians who are performing repair/replace maintenance must first receive authorization from central operations. The management organization of an instrument maintenance program requires daily communication with operations. They must be in the loop and they must authorize actions or tasks which are scheduled.

The job of management and of the preventive maintenance team is to establish and maintain an "attitude" of thinking preventive instrument maintenance as opposed to crisis maintenance. The fact is that the performance of their duties is crucial to the central operation of the plant. A desire to keep instruments and sensors operational must be nurtured. A pride in their work must be developed. The team should be aware of the challenge to have all instrumentation functioning.

Implementation of an Instrument Preventive Maintenance Program

If the organization of the maintenance team is structured properly and an air of cooperation established, then implementation of the program should be fairly smooth. Again, the key is direction and management. One person must be in charge and given full responsibility for all three types of instrument maintenance. Proper operation of the sensors and transmitters is that person's responsibility.

The goals and objectives of the preventive maintenance program should be made crystal clear to all the team members. They are:

- Maintain and verify the validity of sensor measurements.
- Minimize sensor downtime.
- Have 100% of system instrumentation operational 95% of the time.
- Establish close working relationships and cooperation between team disciplines.
- Establish a team spirit in carrying out the goals and objectives set forth above.

Maintaining the discipline required for an instrument preventive maintenance program requires that routine tasks be performed, that they be verified by management and that they be discussed periodically. Communication must be clear. The tasks must be specific and well documented on a "work order" form. The daily work orders should call out tasks for each shift operator, each analytical technician and each electrical/mechanical technician. The work order answers questions like what, who, where, when and how to perform the tasks which are his responsibility. Successful implementation is dependent on communication. In order to develop a pride and desire to perform the repetitive tasks outlined, management should illustrate the importance of these tasks by reviewing them regularly. The team must be aware that someone is reviewing their work and taking action as a result of their findings.

AMMONIA ANALYZER

OPERATING PRINCIPLE: Electrochemical transducers (ion selective electrodes) generate a millivolt potential when immersed in a conducting solution containing free ions to which the electrodes are responsive.

Primary Element: Gas sensing electrodes which sense ammonia/ammonium present in the sample solution.
Transmitter: Measures the potential generated between the electrodes.

GENERAL SPECIFICATIONS: The system includes a sample filtering system, sample conditioning (pH adjustment) equipment, a temperature controller, reagent storage and supply equipment, electrodes and the analyzer.

Analyzer: This will measure the millivolt potential between the electrodes, control the pH of the sample, control reagent flow and automatically recalibrate the instrument at regular intervals and display the amount of drift. The analyzer also controls the sample temperature at which the system is calibrated.
Accuracy: $\pm$ 10% of actual concentration of ammonia.
Repeatability: $\pm$ 5% of span.
Response: Maximum 10 minutes to a step change in ammonia concentration.
Rangeability: 0.1 to 3 ppm to 1 to 50 ppm.

INSTALLATION: The analyzer is normally located indoors.

Electrical: 115 VAC, 150 VA for the analyzer and heater.
Mechanical: If the process stream being monitored is not pressurized, a pumping system will be required to deliver a sample flow of a constant pressure and rate. If the process stream is adequately pressurized, pressure and flow regulation equipment will be required in the sample line.

APPLICATION: May be used on raw sewage or primary effluent to provide early warning of high ammonia concentration in plant influent; however, raw sewage application is not recommended because of the need for a clean sample. Also used on final effluent for monitoring NPDES compliance.

Environment: Sample temperature operating range between 32 and 120°F (0 and 50°C) and ambient temperature 32 to 105°F (0 to 40°C). Humidity - 10 to 100% relative humidity.

MAINTENANCE: Analyzers in use today have not demonstrated a high reliability.

Custodial: Daily check sample system to insure proper operation. Weekly check calibration and operation of the analyzer and clean the filter and electrodes.
Preventive: Monthly check filter, check sample tubing, reagent solutions and standardization solution. Every other month, replenish reagent and standardization solution, replace electrodes and service the temperature control system.
Frequency of Failure: Estimated 3 to 4 times per month.

- ACCESSORIES/OPTIONS: Output-- ma, volts or output relay contacts. Recorder. Auxiliary strainer.

CHLORINE RESIDUAL ANALYZER

OPERATING PRINCIPLE: Chlorine being a strong oxidizing agent, depolarizes one of the two electrodes in an amperometric cell. This results in an electric current in proportion to the concentration of oxidizing agent.

Primary Element: Two dissimilar metal electrodes that form the amperometric cell act as a primary element. Located in the analyzer chamber.
Analyzer: A filtered and pretreated sample water (pH is adjusted) enters the cell area where it reacts with a reagent like potassium iodine. Oxidation of the reagents results in a separation of iodine. This quantity is measured by measuring the current through electrodes.

GENERAL SPECIFICATIONS: Electrodes used could be gold, copper or other noble metals. A continuous cleaning system should be provided for the electrodes.

Rangeability: 0 to 1 through 0 to 20 mg/1 with several intermediate ranges.
Accuracy: ± 2% of actual value.
Sensitivity: 0.01 mg/1.
Response Time: 10 seconds from the time the sample enters the analyzer.

All chemicals for pretreatment and electrolysis should be provided with the equipment. Quantities provided should last at least 60 days. The chemicals supplied should have at least 60 days shelf life or the plant chemist can order them as required per manufacturer's specifications.

INSTALLATION: The analyzer is enclosed in a free-standing enclosure. A water sample is drawn from the main stream and delivered to the analyzer at rate and pressure recommended by the manufacturer. A self-cleaning system is used to filter the sample before it reaches the analyzer. All wetted material should be corrosion resistant.

Electrical: 115 VAC for instruments and pumps, 150 VA approximately.

APPLICATION: Applicable in chlorination process and measuring chlorine level in the final effluent. Fouling of the copper electrode affects the performance of the electrodes. Electrodes seem to lose sensitivity when operating near residual chlorine concentration of close to zero.

Environment: 32 to 120^{o}F (0 to 50^{o}C) when furnished with automatic temperature compensation.

MAINTENANCE:

Custodial: Daily visual checks for leakage, clogged lines and calibration. Refill the chemicals required every 60 days.
Preventive: Servicing pumps. Replace filter and tubing every 30 days. Clean electrodes every 30 days.
Frequency of Failure: Estimated 6 to 10 times a year.

ACCESSORIES/OPTIONS: Titration equipment for calibration. Sample lines. Heat trace lines. Sample pumps. Continuous motor driven filter. Recorder. Output-- ma or volts or output relay contacts.

DENSITY ANALYZER - NUCLEAR

OPERATING PRINCIPLE: Gamma radiation is absorbed as it passes through material. The absorption increases proportionately with the increase in density of the material.

Primary Element: It consists of a source of Gamma radiation and a radiation detector mounted on a process pipe or vessel in diametrically opposite location. The radiations received by the radiation detector are measured.
Transmitter: The remotely located transmitter measures the changes in radiations received and converts it to appropriate output units.

GENERAL SPECIFICATIONS: Two types of primary elements are available, one for radial mounting for pipes up to 36" in diameter and for pipe with "Z" configuration with distance between the source and detector up to 36".

Rangeability: 0 to 15% density.
Accuracy: ± 1% (average) of span in 5 to 15% range.
Linearity: ± 1% of span.

INSTALLATION: A technician licensed by the Nuclear Regulatory Commission (NRC) is required for the installation. The instrument is available with special mounting for pipe or tank mounting. A glass spool is recommended with pipe installation. Installation on a vertical run is preferred, but the sensors should be mounted in horizontal plane. The location of the measuring point should be selected to minimize entrained air bubbles. Provide isolation valves, water taps and drain connection on each side of the meter for calibration.

Electrical: Need 115 VAC for detector and the transmitter. Signal cable between the transmitter and the primary element should be installed in a conduit. Provide an output contact to indicate zero flow when there is no flow.

APPLICATION: Best suited where density range is 5 to 15% total solids and fouling of the sensor is a problem. Entrained air bubbles in the liquid will significantly affect the performance. A license from AEC is required to acquire the sensor and for installation and maintenance of the Gamma source.

Environment: Gauge heads and instruments-- -20 to 140°F (-30 to 60°C) and 0 to 90% RH. Gauge heads available in NEMA 4 enclosures.

MAINTENANCE: Requires a licensed technician. Check calibration every 30 days. If feasible, zero every 30 days. The Gamma source will need replacement every two years. Should perform a "wipe" test every six months on the source enclosure.

Frequency of Failure: Estimated 2 to 3 times a year.

ACCESSORIES/OPTIONS: Output - ma and volt output. Automatic source decay compensation. Automatic temperature compensation. Glass pipe spool for protection against fouling.

PRECAUTIONS: The sensor should be handled only by a qualified NRC licensed technician. In case of an accident, fire or explosion, or lost or stolen sensor, the user shall notify the regional NRC office.

DISSOLVED OXYGEN ANALYZER

OPERATING PRINCIPLE: Instruments for measuring dissolved oxygen (DO) are designed on different principles. Galvonic Cell - Molecular oxygen diffuses through a membrane and reacts with the lead/silver electrode system to produce a current proportional to the DO concentration. Polarographic Cell - Oxygen diffuses through a membrane; after which, the oxygen is reduced by a small reference voltage applied across two metal electrodes. This cell produces a current proportional to the DO concentration.

Primary Element: Galvonic cell uses lead/silver electrodes. Polarographic cell uses noble metal electrodes with polarized voltage across them.
Transmitter: This amplifies the sensor signal and converts it to the desired output. Most units are equipped with switch selectable ranges.

GENERAL SPECIFICATIONS:

Size: Probes are available for tank or large vessel mounting and for pipe mounting.
Rangeability: Available in different ranges from 0 to 1 through 0 to 30 mg/l.
Accuracy: Specified accuracy varies from ± 0.5% to ± 2% of span.
Drift: 0.05 to 0.5% per degree C in range 0 to 50°C.
Response Time: Average 30 seconds for 99% of the actual value. This is typical, however, it may vary depending on manufacturer.

INSTALLATION: Sensor needs to be immersed at the point of measurement. Special length probe for deep water mounting is available. With in-line applications, install the probe with a corporation stop for ease of removal for maintenance. Take care not to introduce air in transport. Maximum distance between the sensor and the transmitter varies from 250' to 1,000'.

Mechanical: A sensor is installed in a stilling well.
Electrical: Either dry battery cells or 115 VAC.

APPLICATION: Fouling because of grease, biomass or suspended solids build up is one of the biggest problems with this instrument. Provision for cleaning with each probe is frequently required.

Environment: Most of the sensors are designed for submersible operation. Ambient temperature 32 to 120°F (0 to 50°C). Temperature compensation is required.

MAINTENANCE:

Custodial: As experience deems necessary, clean the probe membrane. This can be anywhere from once per day to once per month.
Preventive: Monthly check calibration.
Frequency of Failure: Estimated 6 to 10 times a year.

ACCESSORIES/OPTIONS: Output-- ma or volt output. Multiple range with selector switch. Temperature compensation system with temperature indicator on signal converter. Remote calibration unit. Ultrasonic probe cleaning. Agitator type cleaners are available but not recommended since they often tend to accumulate hair and string and can become a maintenance problem in themselves.

FLOW - MAGNETIC

OPERATING PRINCIPLE: Faraday's Law of Induction. An electromotive force (EMF) is generated when a conductive material passes through a magnetic field. The magnitude of the EMF is proportional to the speed of the conductor through the field.

Primary Element: A conductive material tube with a magnetic coil embedded in it. Has two electrodes mounted 180° apart. The tube is normally supplied with a liner of different material to suit the process liquid.
Transmitter/Signal Converter: Measures the EMF generated in the primary element and converts to an output signal compatible with other instruments.

GENERAL SPECIFICATIONS:

Primary Element Size: Less than 1" through 96" diameter and larger sizes on custom order.
Rangeability: Velocity 3 through 30 feet/second.
Accuracy: ± 1% of rate within 10:1 flow range.

INSTALLATION:

Orientation: Orientation does not affect the performance as long as the tube is full of liquid. The most desirable is to mount it in a vertical section of pipe with upflow. A system for flow calibration of the meter should be incorporated in the equipment and piping design.
Mechanical: Upstream and downstream straight pipe runs are not as critical as in case of other types of meters, but consult the manufacturer about the affects of pipe configurations on meter performance.
Electrical: Wiring required between the primary element and the transmitter. Also needs power wiring for the transmitter. Power required is approximately 5 watts per inch of meter diameter. The magnetic coil driver circuit assembly should be located within 30 feet of the primary element.
Grounding: Provide grounding rings between the metering tube and the fluid if the liner is nonconductive or when an insulated pipeline in used. Also ground it to the plant grounding system such as a cold water pipe. The grounding of the fluid and meter must be done regardless of kind of tube used.

APPLICATION: Frequently used in applications containing high solids concentrations.

Environment: Primary element - pressure 0 to 250 psig, temperature 0 to 300°F (-20 to 150°C) with teflon lining.

MAINTENANCE:

Custodial: Recommend weekly check of transmitter calibration. Inspect inner wall and electrodes every two months if the fluid measured contains high entrained solids or grease.
Preventive: Calibration every other week. Clean the electrodes every two to three months. Check and service wiring, including grounding, every two months. Flush the metering tube whenever the flow is stopped.
Frequency of Failure: Estimated 2 to 3 times a year.

ACCESSORIES/OPTIONS: ma, voltage or pulse output. Electrode ultrasonic cleaning. Low flow cutoff. Field range adjustability. Reduced flange meter. Liner material and electrode material. Removable electrodes.

FLOW - ORIFICE PLATE

OPERATING PRINCIPLE: A fluid flowing through a known size and shape of restriction creates a pressure drop across the restriction. The pressure drop is proportional to the square of the flow.

Primary Element: This is a flat metal plate with a circular hole bored through it. The thickness varies from 1/16" through 1/4" depending upon the pipe size. The hole can be concentric, eccentric or segmented. Standards for the fabrication of orifice plates have been established by ASME.
Signal Converter: It is a differential pressure transmitter that measures the pressure drop across the orifice. Location of the pressure taps for the transmitter can be in the flanges or the pipe at distances up and downstream from plate as described by ASME standard.

GENERAL SPECIFICATIONS:

Primary Element: Need to specify maximum flow available in different types of material.
Rangeability: Can be used with 1/2" through 72" diameter pipe sizes. Velocity measured 0 to 0.2 feet per second through 0 to 18 feet per second.
Accuracy: For 3:1 flow range + 2% of full scale. Output should be obtained in a straight line relation.

INSTALLATION: For concentric orifice plate it is important that the hole of the orifice be concentric with the inside diameter of the flow pipe. Flanged type orifice assembly will make this installation easier. Upstream and downstream straight pipe lengths are more critical with the orifice plate than the venturi. If adequate straight length is not available, straightening vanes shall be provided. Arrangement should be provided to clean taps either manually or automatically. Make sure cleaning does not affect accuracy of measurement. The taps should be installed with shutoff valves for easy removal of the transmitter. Use diaphragm seals with corrosive fluids.

Electrical: Power required only for the pressure transmitter.

APPLICATION: In wastewater processes it is suitable for measuring gas flows. Use concentric orifice for flows with low concentrations of entrained solids. With high concentrations of entrained solids, use eccentric orifice with bottom of the hole flush with bottom of the pipe inside diameter. With gas flow measurement, temperature compensation should be provided.

MAINTENANCE: Checking of the orifice, the pressure taps and the calibration every 60 days. If used with fluids with entrained solids, cleaning the flow tube and orifice every 60 days.

Frequency of Failure: Estimated 2 to 3 times a year.

ACCESSORIES/OPTIONS: Straightening vanes. Pressure tap cleaning system.

FLOW - PARSHALL FLUMES

OPERATING PRINCIPLE: Open channel flow, when passing through a known convergence and constriction in the channel, will produce a hydraulic head at a specific point, upstream of the constriction. The flow is approximately proportional to the three-halves power of the head.

Primary Element: It consists of a converging upstream section, a downward sloping throat and diverging downstream section.
Transmitter: This can be any of several liquid level measuring devices with its output characterized to flow.

GENERAL SPECIFICATIONS:

Primary Element Size: Available with throat width from 3" to 40' and can measure flow up to 1500 mgd.
Accuracy: ± 5% of span.

INSTALLATION:

Mechanical: The crest of the flume must have a smooth surface. No protrusion in the flume should be permitted. If a stilling well is required for level measuring, it should be connected at a point 2/3 of the converging wall length upstream from the crest. The connecting pipe between the flume and still well should be at least 2" in diameter and be horizontal. If a still well is used, provide flushing drains and connections. If used with sludge or raw sewage, provide for continuous flushing of the well with clean water.

APPLICATION: Suitable for open channel flows and measuring raw sewage flow. Parshall flume is suitable where the head loss permitted is limited.

MAINTENANCE: Periodic checking and cleaning of the stilling well and connecting pipes.

OPTIONS/ACCESSORIES: Options are in the type of sensor used to develop the flow signal.

FLOW - SONIC

OPERATING PRINCIPLE: The meter measures the speed of sound in the upstream and downstream direction simultaneously. The resulting difference is proportional to the flow rate.

Primary Element: Two electroacoustic transducers are mounted diagonally (for pipe sizes 3" and larger) or axially (for pipe sizes 2" and smaller) in a flow tube. The transducer faces must be parallel to each other and wetted by the liquid being measured. The sensors do not protrude in the flow.
Transmitter: Measures the difference between the speed of sound waves from the sensors in the upstream and downstream flow direction and translates it to an output proportional to flow.

GENERAL SPECIFICATIONS:

Size: Available for pipe sizes from 2" to 120". Specify same pipe size for the transducer assembly as main flow pipe.
Rangeability: This depends on the pipe and type of fluid flow. Works up to Reynolds number of 100,000.
Accuracy: Accuracy depends upon the range of operating Reynolds number. At higher Reynolds number, ± 1% of reading is possible.
Repeatability: As high as 0.25% rate is possible.

INSTALLATION: Should be located a minimum of 5 pipe diameters downstream and 2 pipe diameters upstream from any deviation in straight pipe. Certain pipe configurations may require greater straight pipe runs. The transducers should be mounted in horizontal plane.

Electrical: 10 watts at 120 VAC for both the sensor and meter.

APPLICATION: For monitoring of liquid flows where air bubbles are not present and solids are not expected to exceed 4%.

Environment: Sensor-- pressure limit up to 1000 psig. Transducer-- ambient temperature -100 to 300°F (-70 to 150°C). Transmitter-- ambient temperature 20 to 140°F (-10 to 60°C).

MAINTENANCE:

Preventive: Cleaning transmitter of dust and moisture and cleaning of electrodes every 60 days by flushing with high pressure steam or water.
Custodial: Checking of calibration every 60 days.
Frequency of Failure: Estimated two to three times a year.

ACCESSORIES/OPTIONS: Output-- ma and volt signal and relay contacts. Removable sensor without stopping the process. Sensor flushing ports. Heater in the transmitter for cold weather operations. Totalizer system.

FLOW - TURBINE

OPERATING PRINCIPLE: A small turbine wheel located in the fluid flow spins on its axes at a speed proportional to the velocity of the fluid.

Primary Element: A small turbine mounted on frictionless bearing is inserted in the pipe.
Signal Converter: Measures the turbine speed by using magnetic pickup which generates magnetic pulses proportional to the turbine speed.

GENERAL SPECIFICATIONS: Each meter head and transmitter shall be in NEMA 4 enclosure. The turbine shall be all 316SS with completely sealed bearings. It shall be a completely balanced turbine.

Rangeability: 1 to 45 feet/second.
Accuracy: ± 2% of the span.
Repeatability: ± 1% of the span.

INSTALLATION: Shall be installed with means for easy removal and without shutting the process off. Shall provide a NEMA 4 junction box for electrical connections. Point of location of the turbine shall be such to sense the average velocity. Install in a straight run or with straightening vanes.

Electrical: 115 VAC, or 12 or 24 VDC.

APPLICATION: This type of instrument is normally suitable for only clean fluids flow streams. Typical application is measuring effluent flow. Turbine offers some pressure drop. Entrained solids foul the element and may deteriorate bearing's performance.

Environment: -20 to +150°F (-30 to 65°C). Pressure up to 250 psig.

MAINTENANCE:

Preventive: Quarterly check the calibration.
Frequency of Failure: Estimated once per year.

ACCESSORIES/OPTIONS: Output-- ma and volts or relay contacts. High temperature bearings. Amplifier mounted in the turbine pipe. Purged bearings.

FLOW - VENTURI TUBE

OPERATING PRINCIPLE: A fluid flowing through a tube section containing a convergence and constriction of known shape and area causes a pressure drop at the constriction area. The pressure drop is proportional to the square of the flow.

Primary Element: It is a flow tube designed in four sections; main barrel section, entrance cone, throat section and discharge cone. The main barrel section is of the same diameter as the main pipe inside diameter. The entrance section converges from the barrel diameter to the throat section. The throat section connects to the discharge section that diverges to the inside diameter of the main flow pipe. Taps are provided at the barrel section and at the throat to measure the pressure drop.
Signal Transmitter: It is a differential pressure transmitter that measures the pressure drop in the venturi. The output is a squared function of the flow in the venturi.

GENERAL SPECIFICATIONS:

Rangeability: Available in 0 to 1 feet/second through 0 to 30 feet/second and can be used with pipe sizes from 3" through 48".
Accuracy: + 1.0% of span within 3:1 range.
Repeatability: + 1.0% of span.
Output: Should be obtained in a straight line relation. It shall be designed to permit field calibration by a gauge or a manometer.

INSTALLATION: The venturi tube is available in different mounting designs; flanged mounting type, welded ends type or insert type.

Mechanical: Can be mounted in any orientation as long as the pipe remains full of liquid. An arrangement should be provided for flushing the pressure taps either continuously or intermittently to prevent them from clogging. Pressure leads to the transmitter should be installed with shutoff valves to facilitate removal of the transmitter. Accuracy of the meter can be greatly affected by the up and downstream piping. A rule of thumb is to provide a minimum straight pipe from the orifice of 5 pipe diameters upstream and 2 pipe diameters downstream.

APPLICATION: Used for measurement of liquid flows. The ratio of maximum to minimum flow anticipated for an application should not exceed 3. This is necessary because the accuracy at low flow rates is very poor.

Environment: Environmental constraints are limited to those of the differential pressure transmitter connected to the pressure taps.

MAINTENANCE:

Custodial: At a frequency determined by the application and experience, rod out or flush the pressure sensing taps.
Preventive: Quarterly calibrate the differential pressure transmitter.
Frequency of Failure: Estimated 2 to 3 times a year.

ACCESSORIES/OPTIONS: Special material of construction or linings. Pressure tap cleaning system manual or automatic. Straightening vanes.

LEVEL - BUBBLER TYPE

OPERATING PRINCIPLE: The hydrostatic pressure exerted by any fluid in an open tank is directly proportional to the height and density of the fluid above the point of measurement.

Primary Element: A constant flow of air is passed through a bubble tube inserted in the liquid.
Signal Transmitter: The change in pressure to maintain flow in the line that supplies air to the bubbler tube is measured. The change in pressure is proportional to the liquid level above the bottom (zero level) of the bubble tube.

GENERAL SPECIFICATIONS:

Primary Element: Approximately 1/2" diameter tubing mounted in a rigid stand pipe. Material of construction shall be corrosion resistant and suitable for the fluid.
Rangeability: The maximum level measurement depends on the pressure of the supply air. Up to 185' (with 80 psi air) is available.
Accuracy: + 1% of actual head.
Repeatability, Drift and Linearity: Depend on the differential pressure transmitter used.

INSTALLATION:

Mechanical: The bubble tube should be mounted in a rigid pipe a few inches longer than the maximum level measurement desired, and at least 3" above the bottom of the tank. Provide either automatic or manual purging system for cleaning the bubbler tube. The air supply should be equipped with a filter, purge rotameter and a differential pressure transmitter installed following the rotameter to sense a change in level. The purge lines to the bubbler should not be so small or long so that pressure losses in the line create errors in the measured level.

APPLICATION: Suitable for corrosive liquids, viscous liquids or liquids with entrained solids.

Environment: Same as for the differential pressure transmitter.

MAINTENANCE:

Custodial: Calibration check and check for proper operation of air supply every 30 days.
Preventive: Check air filter and calibrate every 60 days.
Frequency of Failure: Estimated 2 to 3 times a year.

ACCESSORIES/OPTIONS: Special corrosion resistant material for the stand pipe and bubbler tube.

LEVEL - CAPACITANCE TYPE

OPERATING PRINCIPLE: The capacitance of a suitable electrical capacitance sensing element varies with the depth of the material in which it is immersed. The electrical measurement of the capacitance will provide a direct reading of level once it is calibrated and correlation of the depth and the liquid surface level is determined.

Primary Element: It is composed of the probe head (outer conductor), the electrode (inner conductor) and insulation to electrically insulate the head from the electrode.
Signal Transmitter/Converter: The transmitter, when supplied with constant voltage power, will provide an output proportional to level.

GENERAL SPECIFICATIONS:

Rangeability: 0 through 60 feet depending on probe length. The kind of fluid should be specified for getting correct probe. Probes are available in rod or cable form.
Accuracy: + 1% of span.
Repeatability: ± 2% of span with constant fluid properties.

INSTALLATION:

Mechanical: Both rod and cable type probes are available with standard NPT threads and can be directly mounted in the tank top or with a bracket with a mating plug. Vertical mounting is recommended. With cable probe, minimum distance between the tank wall and the probe must be about 10% of the probe length.
Electrical: An electronic assembly is located in the probe head. Power to the head is supplied through the transmitter. The probe and the transmitter can be separated up to 1,000 feet distance.

APPLICATION: Suitable for different kinds of fluids like acids, slurries, lime when a probe of proper material is available. Fluids must be electrically conductive. Foam on the top of the liquid or bubbles in the liquid will also affect accuracy.

MAINTENANCE:

Preventive: Monthly inspect, clean and calibrate.
Frequency of Failure: Estimated 2 to 3 times a year.

ACCESSORIES/OPTIONS: Output-- ma or voltage or relay output contacts. Time delay output contacts. Deadband function over measuring range.

LEVEL - DIAPHRAGM TYPE

OPERATING PRINCIPLE: Static pressure exerted by the liquid is directly proportional to the height of the liquid above the point of measurement. A diaphragm in contact with the fluid is flexed by the pressure. The amount of movement is sensed and calibrated to level.

Primary Element/Transmitter: An integrated pressure sensing assembly with the high pressure side of the diaphragm in direct contact with the process fluid.

GENERAL SPECIFICATIONS:

Primary Element: Available with different mounting flanges with different pressure rating and flange size.
Rangeability: 0 through 750" of H_2O and -225 to +225" of H_2O.
Accuracy: ± 0.5% of span for ranges 20" through 750" of H_2O.
Repeatability: 0.1% of span.

INSTALLATION: Available with different length of extension lengths to fit different wall sizes. The diaphargm shall be mounted flush with the tank inside wall. Provide proper size vent and drain valves in the low pressure side of the primary element. If the tank is covered and not vented to atmosphere, the low pressure side has to be connected to the tank top.

Electrical: 24-48 VDC.

APPLICATION: For measurement of level in tanks constructed above ground.

Environment: Process-- -40 to 350°F (-40 to 180°C). Ambient-- 0 to 130°F (-20 to 50°C).

MAINTENANCE:

Custodial: Check the calibration, piping connection for leak and the diaphragm for fouling every 60 days.
Preventive: Calibrate and clean the diaphragm every 60 days. Check electrical connections.
Frequency of Failure: Estimated 3 to 4 times a year.

ACCESSORIES/OPTIONS: Integral range elevation and suppression adjustment. Flush or extended diaphragm. Different diaphragm material to suit the fluid characteristics. Available as a pneumatic instrument.

LEVEL - SONIC/ULTRASONIC

OPERATING PRINCIPLE: Electrical impulses emitted from a sonic transmitter are reflected back from the liquid air interface. They travel at a fixed velocity and the time required to sense the reflected signal is proportional to the surface distance from the transmitter.

Primary Element: This includes a transducer that sends and receives the sound waves. The enclosure is fitted with appropriate reflector to direct the sound waves in desired direction.
Signal Transmitter: The transmitter sends sonic signals to the primary element and detects the echo received back from the liquid surface through the primary element. Sonic transmits at frequencies between 16,000 and 20,000 Hz and ultrasonic operates above 20,000 Hz. The transmitter times the period between sending and receiving the signal and outputs a signal proportional to level.

GENERAL SPECIFICATIONS:

Primary Element: Available for different environments and to be used in different physical constraints. Shall be supplied with integrally mounted temperature sensor for temperature compensation.
Rangeability: Available from 0 through 160 feet in different intermediate ranges.
Accuracy: + 1% of the span. Better accuracies possible with controlled temperature.
Repeatability: + 0.1% of span.
Drift: Maximum 0.1% for a period of six months with temperature compensation.

INSTALLATION:

Mechanical: Follow manufacturer's recommendation for the minimum separation of the transducer and the maximum expected liquid level. The transducer can be mounted close to tank wall except where the tank side is tapered. If mounted outdoors, the path of signal travel should be protected from wind. Transducers are available with different mounting fixtures.
Electrical: Two cables required; one for the temperature probe and the other for the transducer. Power for the transmitter is 115 VAC.

APPLICATION: A noncontacting sensor for measuring liquid level. Specify special material and type of enclosure for corrosive and outdoor environment. Ultrasonic's signal strength is substantially lower than the sonic's signal; therefore, ultrasonic is used for limited range of level. Foam accumulation on a liquid surface may cause erroneous level readings.

Environment: Temperature 30 to 110°F (0 to 40°C) for transmitter, -20 to 180°F (-30 to 80°C) for sensor with temperature compensation. Pressure-- sensor ± 0.5 psi above/below atmospheric pressure. Ultrasonic is more prone to dust, humidity and wind interference than sonic units.

MAINTENANCE:

Preventive: Every other month check calibration and temperature compensation.
Frequency of Failure: Estimated 2 to 3 times a year.

ACCESSORIES/OPTIONS: Output-- ma, volts or contact closures. Signal locking. Explosion proof enclosure.

LOWER EXPLOSIVE LIMIT (LEL) DETECTOR/ANALYZER

OPERATING PRINCIPLE: Combustible gas/air mixture, diffusing through a flame arrestor, oxidizes on a catalytically treated hot sensing element. Combustible gas in the mixture burns at the element, thus raising its temperature and electrical resistance.

Primary Element: The sensor is an active low temperature catalytic element arranged in one leg of the wheatstone bridge circuit.
Analyzer: It measures the change in resistance of the primary element by balancing the wheatstone bridge circuit. The measure of the change in the resistance is converted to appropriate units for explosive gas concentration.

GENERAL SPECIFICATIONS:

Rangeability: 0 to 100% LEL. Adjustable relay output contacts normally set to operate at 25% LEL and 50% LEL.
Accuracy: + 2%.
Minimum Detection: 5% LEL.
Drift: Less than 0.5% over a period of 30 days.

INSTALLATION: Locate the sensor in a location where combustible gas or vapor is likely to concentrate. If the sensor is located remote from the point where it is desired to check for an explosive condition, a sample system will be required. Use a pump for drawing sample if the stream pressure is not high enough to provide proper flow. If required, install heat trace line to protect the sample line from freezing and condensibles. Use explosion proof conduits and junction boxes for wiring. A gas drying system may be required if the sample moisture content is high.

Electrical: 115 VAC for the analyzer.

APPLICATION: Used to detect an accumulation of combustibles and provide a warning of an impending explosive condition.

Environment: 0 to 200°F (-20 to 100°C) sensor. Moisture in the sample deteriorates the sensor performance and can cause damage necessitating replacement of the sensing element.

MAINTENANCE:

<u>Custodial</u>: If a sample system is used, weekly check and clean as required.
<u>Preventive</u>: Monthly inspect sensor and calibrate analyzer using a cylinder of known gas sample. Service sample pumps and moisture removal system if used.
<u>Frequency of Failure</u>: Estimated 3 to 4 times a year.

ACCESSORIES/OPTIONS: Sample withdrawal system normally is custom made. Explosion proof enclosures. Cylinders of gas samples containing a known type and concentration of combustible material.

OXYGEN ANALYZER

OPERATING PRINCIPLE: Different oxygen concentration in a strong nonuniform magnetic environment will exert variable forces on a nitrogen filled dumbbell suspended in the environment.

Transmitter: The transmitter converts the forces exerted on the dumbbell by measuring the resultant movement. It uses optical and electronic equipment to convert the motion to electrical signal.
Sample: Normally a sampling system is required including a sampling probe, piping, flow controller and moisture removing equipment to provide dry sample of gas to the heated analyzer. Analyzer temperature is controlled.

GENERAL SPECIFICATIONS:

Rangeability: Available in selectable ranges from 0 to 100% of oxygen. Individual range is switch selectable.
Accuracy: ± 1% of full scale.
Repeatability: ± 0.05% oxygen of full scale.
Response Time: 10 seconds after the sample reaches analyzer.

INSTALLATION: Locate the sampling probe at the measuring point. Piping between the probe and the analyzer should be protected against cold weather and also from condensibles in the pipe. Sample line length should be kept to a minimum and should be made of 316SS. A pump may be required in the sampling system if the process stream is not at an elevated pressure. Provide zero flow indication when there is no sample supplied to the analyzer.

Electrical: Need 115 VAC connection to the analyzer. Consumes about 200 watts.
Sample: The sample should be delivered at specified pressure and flow rate. Temperature of the sample flow can vary between 0 and 120°F (-20 and 50°C).

APPLICATION: Can be used in measuring oxygen in vent gases from covered oxygen aeration tanks.

Environment: Ambient temperature 32 to 120°F (0 to 50°C).
Humidity 0 to 90% RH.

MAINTENANCE:

Custodial: Daily check sample flow to analyzer.
Preventive: Monthly check calibration with pure nitrogen and clean dry instrument air. Every other month check and clean sample system and check analyzer temperature control system.
Frequency of Failure: Estimated at twice per year.

ACCESSORIES/OPTIONS: Output - ma or voltage or output relay contacts. Heat tracing for sample system.

pH ANALYZER

OPERATING PRINCIPLE: A potential is developed by an electro-chemical cell when placed in a solution. The potential varies with the hydrogen ion concentration in the solution.

Primary Element: A glass pH electrode and a standard pH electrode, both filled with electrolyte form a pH probe. These two electrodes along with a temperature sensor are assembled in a molded ceramic or plastic body. Some probes use two glass electrodes and a reference electrode. Some probes include a preamplifier to amplify the low level signal for noise immunity and for transmitting the signal for longer distance.
Transmitter: Measures the input signal from the probe and converts it to a desired output.

GENERAL SPECIFICATIONS:

Primary Element: This is available for both flow-through and immersion type configurations.
Rangeability: 0 to 14 pH.
Sensitivity: 0.001 pH.
Repeatability: $\pm$ 0.02 pH.
Nonlinearity: 0.1% of full scale.
Response Time: 1 second.

INSTALLATION:

Orientation: Should be mounted vertically with the electrodes at the bottom. Flow-through sensors are available with standard threaded fittings. A valve should be used with the sensor in flow-through application to facilitate the sensor removal for cleaning and repair. Immersion type sensor will need special brackets for mounting. Care should be taken to protect the glass electrodes.
Electrical: Need 115 VAC for the transmitter.
Mechanical: Isolate it from vibration environment whenever possible.

APPLICATION: Used for pH control of plant influents and used extensively in physical/chemical plants.

Environment: Probe-- 20 to 150^{o}F (-10 to 65^{o}C), 0 to 100 psi.
Transmitter-- automatic temperature compensation to 120^{o}F (50^{o}C).

MAINTENANCE:

Custodial: Weekly check calibration using a laboratory calibrated portable probe. Visually inspect probe signal cable for signs of damage or wear. Every other week check and clean the electrodes.
Preventive: Once per month calibrate unit with known buffer solution. Quarterly it is recommended to clean the electrodes with 100% HCL. Depending on manufacturer, recharge electrodes every six months to two years.
Frequency of Failure: Estimated 3 to 4 times per year.

ACCESSORIES/OPTIONS: Output-- ma and volt signals, output relay contacts. Digital indicator. Range expander up to 10% of the scale for better accuracy. Electrode ultrasonic cleaner.

PRESSURE TRANSMITTER - ELECTRO-MECHANICAL

OPERATING PRINCIPLE: Application of pressure on a diaphragm causes a deflection which creates a change in the values of electrical components (such as a capacitor, strain gauge, or inductor) attached to the diaphragm.

Primary Element: The diaphragms are mechanically connected with one of the electrical components. The process pressure is transmitted to either one or both sides of the diaphragm through a fluid media.
Transmitter: Measures the changes in electrical component and converts into desired pressure units.

GENERAL SPECIFICATIONS:

Rangeability: Available in several ranges from 0 to 0.5 psi through 0 to 1000 psig. Also has range down to -200" of H_2O.
Accuracy: Typical $\pm$0.5% of span (includes linearity, hysterisis and repeatability).
Deadband: 0.05% of span.
Materials: Wetted parts typically 316SS. Other materials available as an option.

INSTALLATION:

Mechanical: The transmitter should be located as close as possible to the measurement point. Slope of the pressure tap lines should be suitable for the application. Install shutoff valve and drains in all pressure leads. Applications subject to clogging should have provisions for line flushing. For vacuum applications, use a minimum number of joints or valves to reduce the possibility of leaks. Provide heat trace line if the transmitter location is exposed to freezing temperatures.
Orientation: Dependent on whether the monitored fluid is a gas, liquid or condensing vapor.
Electrical: Uses standard voltage DC power. It uses two-wire signal transmission, and voltage depends on the load resistance. Typical voltage used is 24 VDC.

APPLICATION: Used for pressure, level and differential pressure flow monitoring.

Environment: Most will operate normally in 0 to 150^{o}F (-20 to 65^{o}C) and 0 to 95% relative humidity. Check temperature effect on zero and span shift.

MAINTENANCE: Recommend calibration check every 3 months.

Frequency of Failure: Estimated 3 to 4 times a year.

ACCESSORIES/OPTIONS: Special materials for wetted parts. Valve manifold for differential pressure application. Kits for elevated and suppressed zero ranges. Diaphragm seals for applications involving corrosive, viscous or solids bearing fluids. Absolute pressure calibration. Locally mounted indicator.

PRESSURE - FORCE BALANCE

OPERATING PRINCIPLE: Applied pressures on two sides of the diaphragm is measured by applying a balancing force through mechanical linkages.

Primary Element: The diaphragm to which the monitored pressure is applied is connected to the balancing device through mechanical linkages. The magnitude of the balancing force represents the pressure value.
Transmitter/Signal Converter: Measures the balancing force through a transducer and converts it to desired output units. Converter and primary element are an integral assembly.

GENERAL SPECIFICATIONS:

Rangeability: Available in several ranges from 0 to 0.5 psi through 0 to 1000 psi and -200" of H_2O to 0" of H_2O.
Accuracy: ± 1% of span (includes linearity, hysterisis and repeatability).
Dead Band: + 0.1% of span.
Materials: Wetted parts typically 316SS. Other materials available as an option.

INSTALLATION: Same as pressure transmitter-electro-mechanical.

APPLICATION: This type of transmitter is more suitable where the transmitter is exposed to electrical noise or extreme temperature and humidity.

Environment: Ambient temperature -20 to 180°F (-30 to 80°C).

MAINTENANCE: Check for leakage in the lines every month. Recommend calibration check every 3 months. Check damping fluid and sealing fluid for loss every 3 months. Every 6 months check the linkages, the force motor and balancing force assembly for wear and proper operation.

Frequency of Failure: Estimated 3 to 4 times a year.

ACCESSORIES/OPTIONS: Same as pressure transmitter-electro-mechanical. Also available with pneumatic output.

SUSPENDED SOLIDS ANALYZER - OPTICAL

OPERATING PRINCIPLE: Scattering of a beam of light by suspended particles. The scattered light is proportional to the suspended solids.

Primary Element: It consists of a light source and photocells mounted in transparent wall sample chamber.
Transmitter/Signal Converter: This measures the amount of light received by the photocells when the sample fluid is in the chamber and compares it with the light received by the photocell through a sample of known suspended solids concentration.

GENERAL SPECIFICATIONS:

Primary Sensor: This is available in both pipe and tank mounted versions.
Rangeability: Available in different ranges up to 0-30,000 mg/l.
Accuracy: ± 2% of full scale.

The output will have to be averaged over a period of time.

INSTALLATION: For tank mounting, different lengths of probes are available with necessary mounting brackets. The sensor should be submerged at least 12". Sensor should be mounted where the fluid does not contain air bubbles. It is recommended that the sensor be mounted at 15° incline from the vertical axis. Pipe mounted sensors should be installed with a corporation stop for easy removal of sensor without shutdown of the process. Upstream pipe configurations should be examined. Care should be taken to use sample from stabilized process stream.

Electrical: 115 VAC is needed for signal converter.
Utility: Shall provide liquid sample tubes filled with liquids of known suspended solids concentration for calibration.

APPLICATION: Fouling and coating of the sensor affects the operation and maintenance of the instrument greatly. Sensor should be supplied with some kind of continuous cleaning of the sensor for any wastewater application or an arrangement should be made to wipe the optical surface periodically.

Environment: Ambient 0 to 120°F (-20 to 50°C), 0 to 90% RH.

MAINTENANCE:

Custodial: Calibration check using a known sample once per week.
Preventive: The sensor should be withdrawn, inspected and cleaned every two months. Moving parts and seals should be inspected for wear and replaced if needed every two months. The light source and the detector should be checked every two months.
Frequency of Failure: Estimated 3 to 4 times a year.

ACCESSORIES/OPTIONS: Output-- ma and volt and output relay contacts. Local readout. NEMA 4 or other special enclosure. Special length of probe. Aeration baffles.

TEMPERATURE - RESISTANCE THERMOMETER (RTD)

OPERATING PRINCIPLE: Change in electrical resistance of metal due to a change in temperature.

Primary Element: It is a resistance wire wound in form of a coil and potted in a ceramic or other type insulating material.
Transmitter/Signal Converter: This uses a wheatstone bridge type circuitry to measure the change in resistance because of the temperature change.

GENERAL SPECIFICATIONS:

Primary Element: Two widely used resistance metals are nickel and platinum. Use three lead wire RTD's.
Rangeability: 0 to 400°F or 0 to 2000°F (0 to 200°C or 0 to 1000°C), depending on materials of construction.
Accuracy: + 0.5°F or better in the range.
Reproducibility: ± 0.25°F in the range.

INSTALLATION: Install in metal thermowell. Precautions should be taken to isolate the sensor from vibration. Immersion length for the RTD will vary with application. Available in different lengths. Use copper conductor for lead wires.

Electrical: The signal converters require a DC or 120 VAC external power source.

APPLICATION: Specify thermowell material as required by the process media. Grease or other sticky substance will coat the thermowell. This will increase the system response time.

Environment: The signal converter will operate normally in 32 to 120°F (0 to 50°C) and 0 to 90% relative humidity.

MAINTENANCE:

Custodial: Check the signal converter calibration every 30 days.
Frequency of Failure: Estimated once per year.

ACCESSORIES/OPTIONS: Signal converter output-- ma or voltage. Open circuit or sensor failure detection. RTD-- materials of construction. Thermowell-- size, material, termination head and extensions.

TEMPERATURE - THERMOCOUPLE

OPERATING PRINCIPLE: Seebeck's principle of thermoelectricity.

Primary Element: It can be one of the several combinations of pairs of dissimilar metal conductors welded together at the sensing end.
Transmitter/Signal Converter: Convert the millivolt signal generated by the thermocouple junction to a high level output.

GENERAL SPECIFICATIONS:

Primary Element: Commonly used thermocouples are constructed of chromel-alumel, iron-constantan, and copper-constantan.
Rangeability: Type J - Iron-Constantan 0 to 1200°F (-20 to 650°C)
Type K - Chromel-Alumel 0 to 2300°F (-20 to 1250°C)
Type T - Copper-Constantan -300 to +200°F (-160 to 100°C)
Accuracy: ± 1% of NGE, dependent on type selected.
Response Time: 1 second to 3 minutes for step change, depending on thermocouple construction.

INSTALLATION: It is recommended that the thermocouple be installed in a thermowell. The thermocouple should be insulated with either ceramic or magnesium oxide. An immersion length of approximately ten times the diameter of the thermowell is recommended. Signal extension wires have to be of the same material used for the thermocouple.

Electrical: The signal transmitter will require an external DC or 120 VAC power source.

APPLICATION: Used primarily where remote temperature indication, recording or control is required.

Environment: The signal converter will operate normally in 32 to 140°F.

MAINTENANCE:

Custodial: Recommend calibration check of signal converter once per month when used.
Frequency of Failure: Estimated once per year.

ACCESSORIES/OPTIONS: Thermocouple construction-- exposed junction, grounded with metallic sheath or ungrounded with metallic sheath. Thermowell-- size, material, termination head and extensions. Signal converter output-- ma or voltage signal or alarm relay contacts with I/O isolation. Open circuit or sensor failure indication.

TOTAL ORGANIC CARBON ANALYZER - ON LINE

OPERATING PRINCIPLE: Combustion and infrared detection.

Analyzer: The total organic carbon analyzer consists of a sampling module, inorganic removal section, sample injection module, combustion section, CO_2 analyzer and carbon analyzer. The sampling module receives the raw sample and passes on predetermined amount to the inorganic removal chamber and overflows the sample excess. A high efficiency sparger uses air to strip inorganic carbon from the measured sample. The sample with organic carbon is injected into the combustion chamber, is oxidized and the organic carbon converted to CO_2. A CO_2 analyzer, through infrared detection technique, determines the organic carbon present in the form of CO_2 and provides a proportional output signal.

Enclosure: All the modules described in the analyzer section are enclosed in one enclosure. Normally designed for indoor application but can be obtained in NEMA 4 construction if required.

GENERAL SPECIFICATIONS: The system should be able to use a sample from pressurized or nonpressurized streams.

Rangeability: 0 to 5,000 mg/l and many intermediate ranges available.
Sensitivity: Minimum detection 1.0 mg/l.
Accuracy: $\pm$ 5% of the span.
Repeatability: $\pm$ 2% of the span.
Linearity: $\pm$ 5% of the span.
Cycle Time: 0 to 60 minutes, adjustable in 5 minute intervals.
Materials: 316SS for all wetted parts.

INSTALLATION: Enclosure is normally a free-standing unit. Provide piping, pumps, filters and valves to supply necessary sample to the analyzer. For sample size requirement, consult the manufacturer.

UTILITY REQUIREMENTS:

Electrical: 120 VAC, 60 Hz, approximately 700 watts.
Water: For cooling, 1/2 gpm at maximum 80°F (25°C).
Compressed Air: Less than 1.0 cfm at 30 psia.
Oxygen: 200 cc/minute at 40 psia, commercial grade.
Acid: 3 Normal Hydrochloric acid, 3 gallons/month.

APPLICATION: Used for monitoring of organic loading in liquid process streams. Although the analyzers use proven techniques for determining the organic carbon, they have not been widely acceptable in wastewater treatment processes due to high maintenance requirements.

MAINTENANCE:

<u>Custodial</u>: Daily calibration check and visual inspection.
<u>Preventive</u>: Weekly clean filters and service pumps. Replenish the acid and oxygen supply every month and check tubing.
<u>Frequency of Failure</u>: Estimated 1 to 4 weeks.

ACCESSORIES/OPTIONS: Output-- ma, volts or relay output contacts. Equipment failure alarm contacts. Multiple stream sampler.

SECTION 6
BIBLIOGRAPHY

Baily, S. J., Varieties of Pressure Sensing Enrich Instrument Application, Control Engineering. February, 1977.

Considine, D. M.. Process Instruments and Controls Handbook. McGraw Hill Book Company, New York, NY, 1974.

D'Amelio, Peter and C. F. Guarino, Instrument Specifications: The Operator's View, Deeds and Data.

Lawford, V. N., Differential Pressure Instruments: The Universal Measurement Tools, Instrumentation Technology. December, 1974.

Liptak, B. G., Environmental Engineers' Handbook. Chilton Book Co., Randor, PA, 1974.

Manual on Installation of Refinery Instruments and Control System, Section 1 - Flow, Section 2 - Level and Section 4 - Pressure. American Petroleum Institute, Washington, DC.

Pearson, C. R.. Things to Remember About Pressure Transmitters, Instruments and Control Systems. August, 1977.

Process Instrumentation, a reprint from Chemical Engineering. McGraw Hill Book Co.

Rogers, Alan J. and John W. Liskowitz, Wastewater Instrumentation, Theory and Application. August, 1975.

Scientific Apparatus Makers Association Standard PMC20-2-1970.

Soisson, H. E., Instrumentation in Industry. Wiley-Interscience Publication, New York, NY, 1975.

SECTION 7

DESIGN GUIDE

INTRODUCTION

This section includes a brief review and discussion of the considerations involved in the selection and documentation of a control system. The following aspects of control system design are addressed:

Project familiarization--Plant processes, construction schedules and operational philosophies should be reviewed in preparation for the actual design of the control system.

Evaluation of control approaches--Alternate control system configurations should be considered relative to the cost effectiveness of the system and the needs of the user.

Documentation of design guidelines--To assist in coordinating the efforts of those involved in any work related to the control system design, it is suggested that general control system design guidelines be established, disseminated and updated as necessary.

Design example--A hypothetical design is discussed to illustrate instrumentation and control specification requirements for a return activated sludge pumping system.

Specification checklist--A list is provided to tabulate the items that should be addressed in a control system specification.

It is hoped that the information in this section will aid engineers, treatment plant owners and regulatory agency personnel in understanding the scope of work involved in control system design.

PROJECT FAMILIARIZATION

The control system design engineer must completely familiarize himself with all aspects of a wastewater treatment project. This can be accomplished by reviewing the facility plan and by interviewing the process design engineers. It is important that involvement of the control system engineer occur early in the Step II design phase for proper consideration of maximum operation and control flexibility.

Process Considerations

Plant process considerations involve identification of: 1) the plant physical characteristics, and 2) new construction versus existing plant facilities.

The plant physical characteristics relate to the overall plant flow train, the individual unit processes and any plant-related remote areas. The plant flow train must be identified as to the normal flow routing, alternate flow routing and any emergency bypass routing. Unit process considerations must include interrelated effects of processes, batch versus continuous operation, and startup/shutdown requirements to meet variable plant loadings. Each unit process must be evaluated for its unique control requirements. Related remote areas (e.g. pump stations, lagoons, remote quality monitors) necessitate evaluation for special communication requirements.

New construction considerations may differ from those associated with the retrofit of an existing facility. In most cases, the control system will be supplied independent of new unit process equipment. However, some unit process specifications will be primarily based on performance, because one supplier will provide the entire process package. In this case, the supplier of the turnkey package may insist of furnishing his own control system in order to guarantee the required performance (e.g. cryogenic oxygen generation systems or incinerators). In the retrofit of existing facilities, all existing control equipment must be evaluated for possible renewal, replacement or additional interface requirements. Special considerations may be necessary for existing equipment which was not initially designed for automatic control.

Schedules

Scheduling, as with all disciplines of engineering, is important. The plant construction schedule can be a factor in selecting the most practical plant control system. If the construction is new and all work is to be done under one contract, the construction schedule is of importance in that the selected control system must be built and installed to coincide with the plant startup.

In other cases, an existing plant is being upgraded to meet NPDES standards and construction is to be accomplished in phases. Schedules of this type are important because interim control systems may be required to start up and operate early phases prior to final completion of the entire plant.

Operational Philosophies

The plant operational philosophy relates to several considerations: 1) the required process control; 2) the desired operator interface; and, 3) the staffing limitations and/or regulations. The operational approach must be both desirable and practical. The evaluation of the control system's needs depends greatly on the operational philosophy.

Each unit process must be examined for control requirements. The complexity of the process may determine areas that require automation. From the control requirements, the extent of the desired operator interaction can be determined. The operator interface must also be evaluated for local versus centralized control interactions.

From each unit process evaluation, the overall plant operational requirements can be determined. Thus, anticipated staffing needs and operation centers can be outlined and evaluated in view of staffing limitations or regulations. This evaluation may require changes to be made in operational philosophy or staffing needs in order to satisfy both criteria.

With this information, the control system designer can establish operational requirements, on a unit process basis and for the entire plant, which must be satisfied by the plant control system.

EVALUATION OF CONTROL APPROACHES

Having developed a thorough understanding of the processes involved, the schedule for their construction and the requirement for their operation, a control system design engineer can now begin evaluating different control approaches to determine which are capable of meeting the pre-established operation and performance criteria. Each unit process must be examined to determine the amount of manual and automatic control required and the information that must be available for operator decision making. This is then reviewed against the overall plant operation philosophy and various control approaches are selected.

The various control approaches selected for further evaluation may be manual, analog, digital or any combination of these. Descriptions and discussions on each of these control approaches are contained in Section 4.

The various combinations of control approaches are then configured into overall plant control systems. Through prescreening based on other engineering considerations, this field is then narrowed to the best two or three possibilities for economic analysis. The cost effectiveness of each system is determined. Detailed examples of how this is accomplished are shown in Section 5.

Having completed the cost effective analysis, the systems can be ranked according to cost. Now each must be evaluated in terms of less tangible advantages/disadvantages as described in the Alternate Control Approaches section. These items might include user background or experience, reliability, flexibility in accommodating future needs, user preference, etc.

The control system engineer must summarize the findings of all evaluations and make a recommendation as to which control system is most desirable. This information should then be presented to the project design team and the user for a final control approach selection.

DOCUMENTATION OF DESIGN GUIDELINES

The next step in generating a control system specification is the preparation of a design guideline. The primary purpose of this document is communication with all project team members whose work is involved with or affected by the control system. In the actual detailed design phase of a project, many people other than members of the control system design team are responsible for work that includes important elements of the control system design. For example, a separate consulting group is often responsible for the preparation of diagrams specifying the conduit and wiring requirements for all plant equipment including the control system. The related nature of the design work being performed should indicate that if the control system is to be successfully implemented, frequent conferences must be held and communication among the various groups must be maintained during the design phase. When appropriate, a representative of the owner should be involved.

The design guideline provides documentation of the selected control approach for the plant and establishes basic control system interface concepts. These are general guidelines to be followed by the control system, electrical and equipment designers to insure compatibility between packages. Since the guidelines may not be applicable in all cases, a procedure should also be established for handling special cases. The design guideline should become a controlled working document which is updated as design details point out the need for modifying the general approach.

Control Approach

This portion of the design guideline describes the control approach selected, illustrates the basic configuration which the control system design will follow and discusses the various levels of control which are to be provided. The levels of control can be classified as: 1) field; 2) area; or, 3) central.

Field control is also referred to as local control. It is the lowest level of control because it is normally performed at the operating equipment location. Examples include start/stop pushbutton stations at a motor, or a hand crank on a pneumatic operated valve. In multilevel control system configurations, these are normally used for maintenance purposes and for operational backup should higher levels of control fail.

Area control is characterized by a control panel in a process area which includes monitoring information and control capabilities. From this area control panel, an operator can execute process changes by controlling equipment and adjusting process parameters. Examples of area operating functions through a control panel include: primary treatment, aeration and final clarification with sludge pumping.

The highest level of control is central control wherein information is presented to an operator who is remote from the process areas. The central operator analyzes the process data and makes necessary adjustments to achieve the desired operations.

Most control systems will be a combination of two or all three levels of control. Early consideration of the unit processes involved and the desired operations staff is necessary in establishing the preliminary control system configuration. As the various design phases are being detailed, it may be necessary to revise the configuration. However, planning early in the design phase is necessary for incorporation of the best control system into the overall plant design.

Interface Design

The term interface, in the context of this report, refers to the compatibility of connections between field instrumentation/equipment and a remote area or central control center. Typical interfaces should be established as guidelines for those designing and specifying equipment monitored or operated by the control system. This eliminates the need to discuss each item with the control system designer.

Signal Transmission--

Basic signal levels for monitoring and control and provisions for transmitting between points should be established (e.g. all pneumatic analog signals will be 3 to 15 psig and transmitted via 1/4" plastic tubing). Where practical, commonly accepted signals should be used.

Following are examples of various signal types used in a control system design with possible levels and methods of transmission between the field and the remote control center. For electronic analog signals, 4-20 maDC transmitted on 18 AWG shielded, twisted pair is frequently used. For status and alarm information displayed at a remote control center, dry isolated contacts are supplied in the field with 120 VAC sensing voltage provided at the control console. Connection between the control center and field is made using 14 AWG twisted pair.

It is important that the specifier of field mounted instrumentation and equipment know the appropriate signal levels required for each signal type to insure compatibility with the remote control center. The electrical designer must know the recommended type of wire for each signal type so the required wire and conduit can be provided between the control center and field mounted devices.

Equipment Monitoring--

Guidelines for monitoring the conditions of electrical or mechanical equipment should be established so the control designers can specify the necessary sensors and who shall provide them. Typically it is preferable to have equipment monitoring sensors provided as part of the equipment assembly. These sensors include: vibration, bearing temperature, motor winding temperature and breaker position transducers. In most cases the equipment manufacturer knows the preferred location for mounting the sensors. In addition, factory installation is more cost effective than retrofitting the equipment with sensors in the field.

Guides or boundaries should be established for monitoring equipment conditions. The following is typical of the equipment monitoring that needs to be stated in a complete design guide.

> "All electrical loads larger than five horsepower will be equipped with run lights on the MCC and auxiliary contacts for remote run indication. Cranes, vent fans, air handling units, etc. are excluded from this list. In addition, equipment one hundred horsepower and above will have current transmitters mounted in the motor starter compartment for remote monitoring."

A special case of equipment monitoring is a unit consisting of the operating equipment and associated controls supplied as a complete package. Examples of this include large compressors, boilers and incinerators. The handling of alarm and shutdown conditions should be addressed. The following is an example guideline:

> "A common isolated contact shall be provided for remote alarming and annunciation of any shutdown condition occurring on a unit. This is based on the premise that an operator will be dispatched to investigate the failed unit and that the first shutdown condition to occur will be indicated on the unit control box. Impending shutdown conditions, such as high boiler pressure, should alarm individually at a remote location prior to final shutdown."

These statements or monitoring guides should alert the equipment specifier to the required monitoring points to be provided with the final equipment. In addition, a control system designer is informed that provisions must be made for remote monitoring of the equipment.

Equipment Control--

As with monitoring, the basic equipment control philosophy has to be stated. This equipment control relates to: 1) the level of control; 2) safety considerations; and 3) modulating/two-state control.

Using the previously established levels of control as a design constraint, priorities must be set and interlocked so conflicts of operation cannot arise between levels. Priority interlocking is accomplished by using H-O-A (hand-off-auto), remote/local and computer/manual switches in appropriate combinations to achieve the desired result.

Safety considerations involve emergency stopping of equipment. When working with rotating equipment in a remote control situation, as a protection to personnel and equipment, local stop and safety interlock controls should be active at all times. The local stop pushbutton will enable an operator to locally shut down a piece of equipment any time an unsafe condition arises, without requesting that control be shifted from a higher level remote source. Remote automatic controls should recognize this as an abnormal shutdown and lock out the equipment until the condition is cleared. The same holds true for equipment safety interlocking. When working with higher control levels involving a computer, the recognition of a safety shutdown condition and the execution of that shutdown should not be dependent on the availability of a computer. As an example, a shutdown switch should be hardwired into the starter controls.

Remote operation of equipment can be classified as two-state or modulating control. Examples of two-state devices include a constant speed pump which can be on or off and an isolation valve which is open or closed. Control of this type of equipment can be accomplished using maintained or momentary control contacts. Maintained contact controlled equipment normally operates when the contact is closed and is off when it is open. With momentary contact control, a start contact closure occurs for a set time interval and is sealed in with an auxiliary contact. The stop function is then accomplished by momentarily opening a second set of contacts which causes the auxiliary seal-in contact to drop out when the circuit is de-energized. Typical schematics are shown for each type of two-state control (see Figures 7-1 and 7-2). Generally, momentary type contacts provide greater control system security.

Modulating control is used for adjusting variable speed pumps, chemical feeders, flow proportioning valves and other variable rate control devices. Control of this type of equipment can be accomplished using positional or incremental outputs. The actuators associated with each of these equipment items must be specified to receive a signal which is compatible with the one generated by the remote control center. The most commonly used signal for position is 4-20 maDC. Incremental modulating control is useful in a multilevel control environment. Incremental control uses a series of up/down or open/close pulses to adjust a final control element. Consideration should be given to feedback of the controlled variable for indication at the control center.

For coordination of design activities it is important that preferred methods of control be established and clearly stated. In this way the control equipment can be specified with a remote interface which is compatible with the signal generated by the remote control center.

Contract Responsibility--

Whether the control system is being procurred for an entire plant or for an area, or if it is being supplied and installed as a subcontract or separate contract, the demarcation of responsibilities between the control system and the field must be clearly defined. The demarcation point may be a terminal strip in a termination cabinet or control panel. Responsibilities can then be split with one contractor to provide the terminal strip and all wiring on one side, and other contractors responsible for all wiring on the other side. This is also important to the design team so each member knows how far his work should be carried.

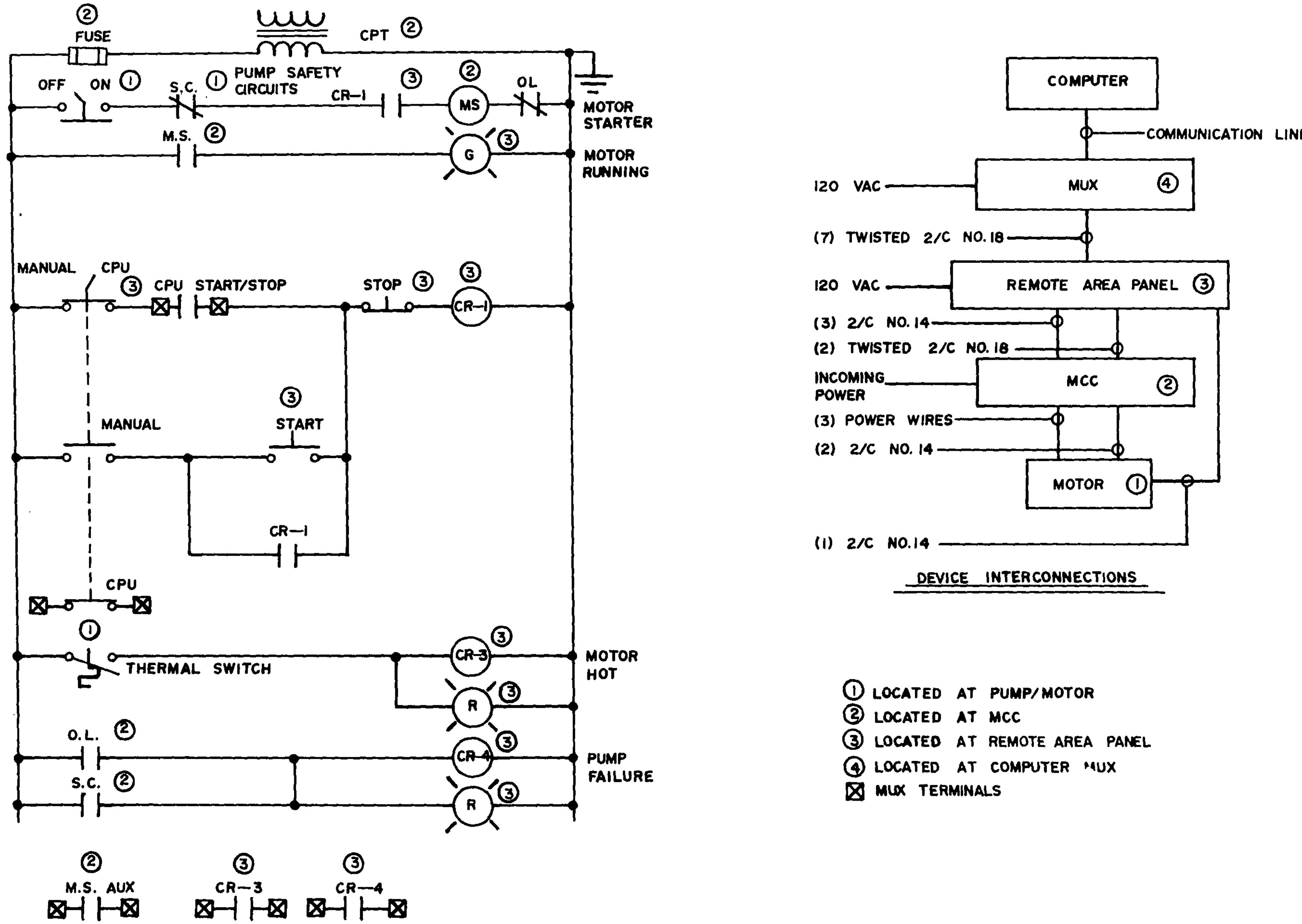


Figure 7-1. Typical constant speed pump interface (maintained contact control).

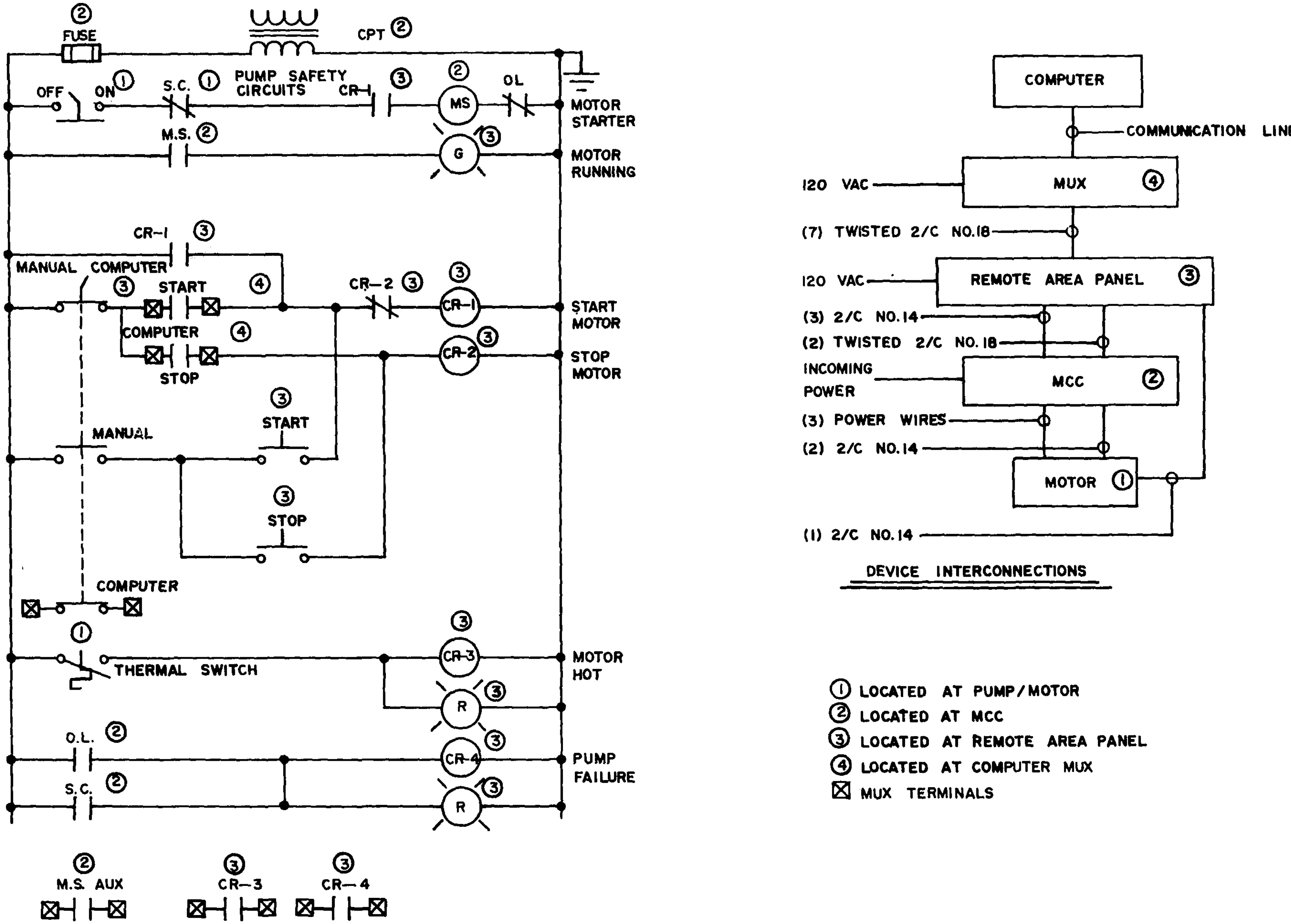


Figure 7-2. Typical constant speed pump interface (momentary contact control).

Site Planning

Early consideration of where data acquisition enclosures, area panels and other control system cabinets will be located is necessary so space will be planned. In addition to locations, special installation requirements should be noted. These would include power, environmental control, cable routing, etc.

DESIGN EXAMPLE

This section describes recommended procedures to be followed in detail design of a specific control system for a wastewater treatment plant. The example used is a particular subprocess in a 30 mgd (1320 dm^3/s) plant, namely return activated sludge (RAS) withdrawal and pumping. The example includes a discussion of computerized control, however, the procedures are applicable to conventional analog control as well.

Statement of Problem

Activated sludge is to be returned from each of three secondary clarifier batteries to three aeration batteries. Each clarifier battery consists of two clarifiers, one sludge underflow line per clarifier, a RAS wet well and two variable speed RAS pumps. The battery piping configuration is shown in Figure 7-3. Total RAS pumping capacity per battery is 10 mgd (440 dm^3/s).

Each of the three batteries is to be controlled in an independent mode. Sludge is to be withdrawn from each clarifier by control of a modulating valve and flowmeter on the associated underflow lines. The sludge flows by gravity to a wet well from which it is pumped to the associated aeration battery. A flowmeter and density meter are located on the common pump discharge line. The hydraulics are such that the wet well will not overflow.

Control System Description

A block diagram of the control system selected for this plant as a result of a cost effective analysis is shown in Figure 7-4. The plant is to be centrally controlled by a digital computer system. Data is concentrated by multiplexers strategically located throughout the plant to minimize wiring costs. One such multiplexer is located in the secondary clarifier area.

Signals are routed to the multiplexer from a local control panel, which is in turn wired to associated field elements and motor control centers. The local panel is to provide manual and/or analog control for backup in the event of computer system failure. The panel will also be used for startup of unit processes before the computer system is brought into full operation.

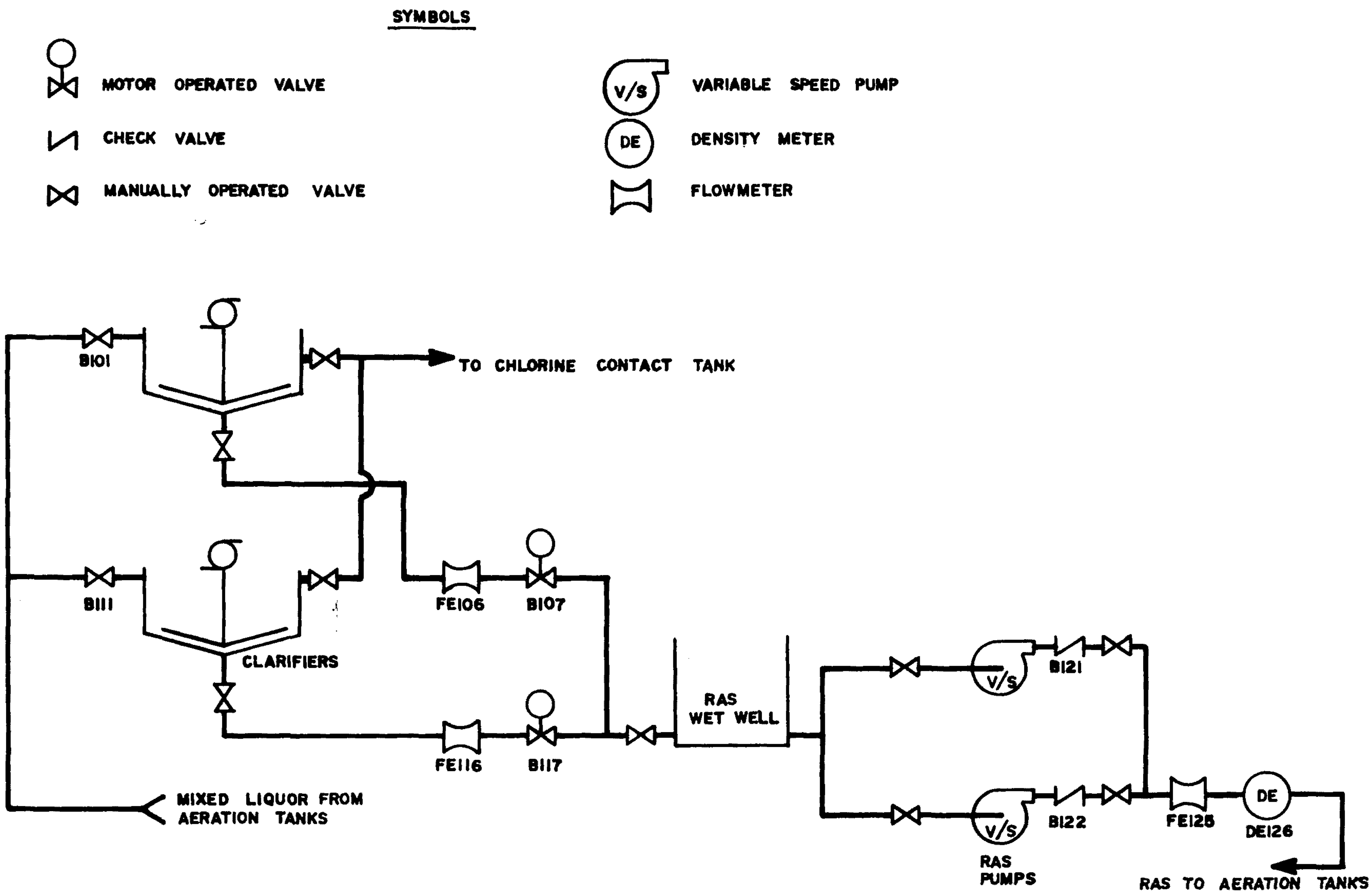


Figure 7-3. Secondary clarification and RAS piping schematic.

Definition of Control Strategy

The first step in the design procedure is the definition of an overall control strategy. The problem should be jointly analyzed by a combination of process and control system engineers. The process engineer provides the knowledge of how the particular system was physically designed to operate. The control system engineer provides the expertise required to properly instrument and control the process to accomplish the required operation.

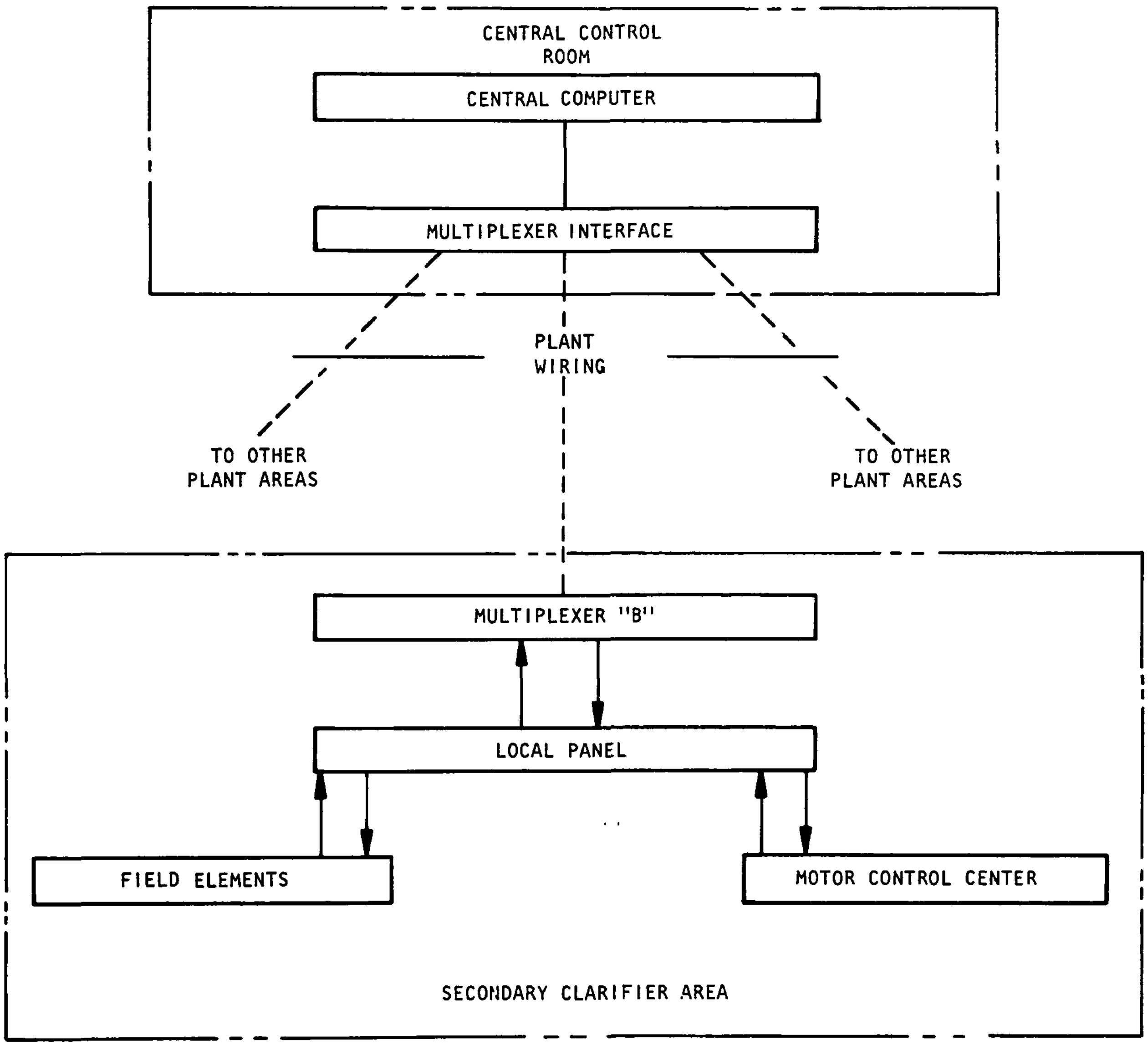


Figure 7-4. Control system configuration.

The process under consideration can be subdivided into two sub-processes; withdrawal of sludge from the secondary clarifiers and pumping of RAS from the wet well to the aeration tanks. The control strategy for withdrawal will be to maintain a relatively constant sludge blanket in the clarifiers. The control strategy for pumping will be to return RAS to the aeration batteries based on one of the following calculations:

1. Food/Microorganism Predictive

$$Q_{RAS} = \frac{K_1\ (Q_p)\ (L_p)}{K_2\ (S_{RAS})}$$

Where: K_1, K_2 = Operator adjusted constants

Q_p = Primary effluent flow

L_p = Primary effluent TOC

S_{RAS} = Return sludge density

2. Ratio to Plant Flow

$$Q_{RAS} = K_1\ (Q_p)$$

Where: K_1 = Operator entered ratio

Q_p = Primary effluent flow

In addition, the operator must be able to disable either calculation and manually set a pumping rate, either from the computer system operators console or from the local panel. This is also a requirement for sludge drawoff flow rate. The designers have agreed to provide local automatic backup for sludge withdrawal and local manual backup for RAS pumping.

Controllability Analysis

The next step in design is to analyze the process from a controllability standpoint. This can involve simply a desk top analysis, or can involve a computer simulation. An example of a control problem could be a high influent flow rate into a small wet well, which presents stability problems from a pumping standpoint. Use of a computer to solve complex control problems should be within a qualified control system engineer's capability.

For purposes of our example, we will assume that the engineer has analyzed the process dynamics and is reasonably confident that the process can be controlled.

Preparation of P&ID

Once the basic control concepts are determined, the engineer should proceed to develop a piping and instrument diagram (P&ID). The purpose of the P&ID is to illustrate the process piping, show all control devices, primary sensors and local instrumentation, and (when applicable) define the computer system input/output signal interface.

A P&ID for the RAS process is shown in Figure 7-5. The control system engineer has used the piping schematic shown in Figure 7-3 and the required control strategy to determine the necessary instrumentation and computer interface requirements.

A standard set of symbols must be selected or developed for use in preparing P&ID's. A subset of those used for this project is shown in Figures 7-3 and 7-6.

Only controlled and/or monitored devices are shown on the P&ID. Manual valves shown on the piping schematic are not shown on the P&ID as these valves are normally left open and are only used for maintenance purposes. The only manual valves shown are those on the clarifier influent lines as these will be monitored by the computer to determine whether a clarifier is in service.

The engineer has located a sludge blanket level transmitter in each clarifier to be used by the computer for blanket control. A local panel indicator is also shown. The sludge collector drive in each clarifier is monitored for status and overload conditions.

A local flow controller (FIC) is provided for automatic control of each sludge underflow valve. It will normally receive its setpoint from the computer. A valve fully closed limit switch (ZB) is provided to be used by the computer for flow control. The flow signal is wired to both the flow controller and the multiplexer. A computer/manual switch contact (YS) is provided to indicate local control status to the computer (the switch is physically located on the controller).

A low level switch is located in the RAS wet well for pump protection and alarm indication to the multiplexer. Note that low suction cutout is to be provided by hardware within the panel and is not dependent on computer operation. This rule should be applied for all safety interlocks.

The controls for the RAS pumps include the following:

- Motor start control, both from the computer and from the panel (MN, HS)
- Motor status indication (MM)
- Motor speed control, both from the computer and from the panel (HIK, SC)
- Motor speed indication (ST)

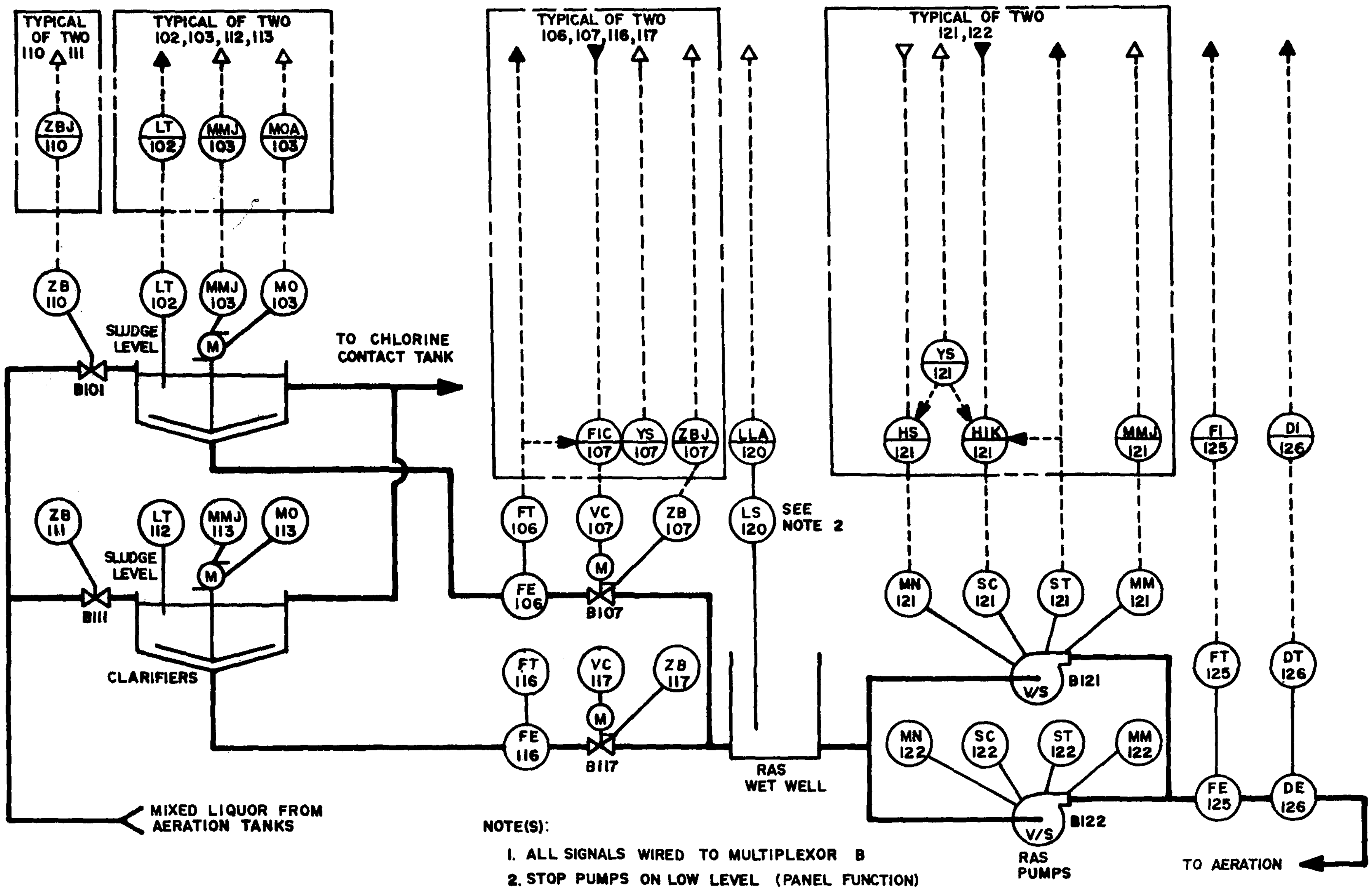
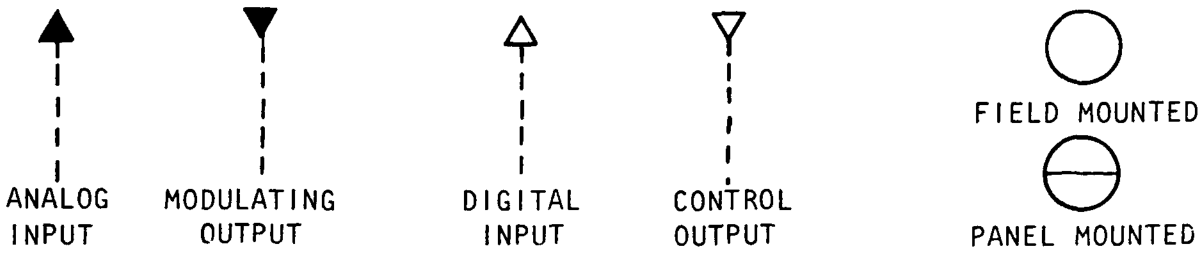


Figure 7-5. Secondary clarification and RAS P&ID.

SYMBOLS



INSTRUMENT AND DEVICE LETTER CODES

AI	ANALYSIS INDICATOR	LS	LEVEL SWITCH
AT	ANALYSIS TRANSMITTER	MM	MOTOR ON/OFF
DE	DENSITY ELEMENT	MMJ	MOTOR RUNNING LIGHT
DI	DENSITY INDICATOR	MN	MOTOR START/STOP
DT	DENSITY TRANSMITTER	MO	MOTOR OVERLOAD
FE	FLOW ELEMENT	MOA	MOTOR OVERLOAD ALARM
FI	FLOW INDICATOR	SC	SPEED CONTROL
FIC	FLOW INDICATING CONTROLLER	ST	SPEED TRANSMITTER
FT	FLOW TRANSMITTER	VC	VALVE CONTROL (MODULATING)
HIK	HAND INDICATING CONTROL STATION	YS	COMPUTER/MANUAL SWITCH
HS	HAND SWITCH	ZB	VALVE CLOSED LIMIT SWITCH
LLA	LOW LEVEL ALARM	ZBJ	VALVE CLOSED LIGHT

Figure 7-6. P&ID Symbol Legend.

- Computer/manual switch for each pump (YS)
- Flow and density measurements (FT, DT)
- Low level switch (LS)

Manual control of the pumps is provided by a start/stop switch and a manual loading station for speed control. Note that both devices are interlocked through a computer/manual switch. The rule applied is that all manual controls associated with a particular device (or process) should be activated by a single switch. Switch status is indicated to the computer for remote control activation/deactivation.

Each "bubble" on the P&ID is assigned a specific number. The numbers are assigned on a device basis, e.g. all points associated with one RAS pump are assigned number 121. The pump itself is then number B121 where B is the area, or multiplexer, designation. By using the same numbering system for instrumentation and equipment schedules, the mechanical and I&C drawings can be linked together (see Figure 7-3, where the same device numbers are used). Similarly, instrument tag numbers are assigned and can be used for all drawings.

Note the use of typicals to avoid clutter. This makes the drawing more readable without loss of clarity. Use of typicals can, however, be more difficult with pure analog systems due to a greater number of "bubble" interconnections. The designer must consider whether use of typicals is appropriate for each individual P&ID.

Other attributes to be noted are the following:

- All process piping is shown.
- Process flow lines are drawn heavier than other lines.
- Electrical connections are shown by dotted lines.

Any future equipment piping, etc. should also be shown on the P&ID's. This will help insure that the vendor provides sufficient expansion capabilities.

The importance of the P&ID cannot be stressed too strongly. It is the link between the process and the instrumentation.

Input/Output Point Listing

Once the P&ID's have been finalized, a complete list of input/output (I/O) points should be developed. The purpose of the I/O list is to provide, in one document, the information necessary to configure the computer system multiplexer interface and system data base. Another use of the I/O list is to provide a check list for other specification sections (such as electrical and mechanical) to insure that the field devices connected to the computer system are accounted for and have been specified with the correct interface.

TABLE 7-1. RAS INPUT/OUTPUT LIST

POINT NAME	POINT DESCRIPTION	TYPE*	RANGE
B101 ZB	SEC CLAR 1 INF GATE OPEN	DI	--
B102 LT	SEC CLAR 1 SLUDGE LEVEL	AI	2-10 ft.
B103 MM	SEC CLAR 1 DRIVE STATUS	DI	--
B103 MO	SEC CLAR 1 DRIVE OL.	DI	--
B106 FT	SEC CLAR 1 SLUDGE FLOW	AI	0-5 MGD
B107 VC	SEC CLAR 1 SLUDGE VLV CONTROL	MO	0-100%
B107 YS	SEC CLAR 1 SLUDGE VLV CTL MODE	DI	--
B107 ZB	SEC CLAR 1 SLUDGE VLV CLSD	DI	--
B111 ZB	SEC CLAR 2 INF GATE OPEN	DI	--
B112 LT	SEC CLAR 2 SLUDGE LEVEL	AI	2-10 ft.
B113 MM	SEC CLAR 2 DRIVE STAT	DI	--
B113 MO	SEC CLAR 2 DRIVE OL.	DI	--
B116 FT	SEC CLAR 2 SLUDGE FLOW	AI	0-5 MGD
B117 VC	SEC CLAR 2 SLUDGE VLV CONTROL	MO	0-100%
B117 YS	SEC CLAR 2 SLUDGE VLV CTL MODE	DI	--
B117 ZB	SEC CLAR 2 SLUDGE VLV CLSD	DI	--
B120 LS	RAS WET WELL LOW LEVEL	DI	--
B121 MN	RAS PUMP 1 CONTROL	CO	--
B121 MM	RAS PUMP 1 STATUS	DI	--
B121 SC	RAS PUMP 1 SPEED CONT	MO	0-100%
B121 ST	RAS PUMP 1 SPEED	AI	0-100%
B121 YS	RAS PUMP 1 CTL MODE	DI	--
B122 MN	RAS PUMP 2 CONTROL	CO	--
B122 MM	RAS PUMP 2 STATUS	DI	--
B122 SC	RAS PUMP 2 SPEED CONTROL	MO	0-100-%
B122 ST	RAS PUMP 2 SPEED	AI	0-100%
B122 YS	RAS PUMP 2 CTL MODE	DI	--
B125 FT	RAS FLOW TO AERATION	AI	0-10 MGD
B126 DT	RAS DENSITY	AI	0-3%

* AI Analog Input   CO = Control Output
MO Modulating Output   DI Digital Input

The list of points associated with RAS pumping is shown in Table 7-1. Included are point names, point description, type and range. The point name is derived from the P&ID's. Each point name follows a specific format. As an example, consider the first point, B101ZB. The first character (B) refers to the plant area/multiplexer into which the point is to be wired. Characters two, three and four (101) are a numeric designation for a field device. The fifth and sixth characters (ZB) designate the variable and the computer function, in this case a full closed limit switch.

The I/O list must be accompanied by a list of areas and abbreviations used in the data base, along with an explanation of the format. The complete I/O list should also include items such as scan times, alarm limits, deadband values, maximum rate of change and scaling information for each point. The points may also be sorted in several different ways, e.g. by point type, by plant area, and/or by control loop.

Future points which can be firmly identified should be included in the I/O list to insure that the system is sized correctly,

Interface Drawings

Clear specification of interface details is essential to control system success. Some which are particularly important are:

- Modulating valves
- Open/close two-state valves
- Constant speed motors
- Variable speed drives
- Local control panel
- Manual loading stations
- Controllers

An example of an interface drawing for the variable speed RAS pumps is shown in Figure 7-7. The level of detail shown is typical of that required for each interface. The drawing shows interconnection between panels and motor control centers. All interlocks and local control logic, as well as signal interface to the multiplexer are shown. An incremental interface is specified for speed control for fail-safe operation, i.e. loss of signal will not cause a change in speed.

An interface drawing for a controller is shown in Figure 7-8. Recall that flow controllers were specified for backup on the sludge underflow control loops (FIC 107, FIC 117). The interface between analog controllers and computer systems is one of the most critical. Bumpless transfer from one control mode to another is crucial to avoid process upsets. The interface shown in Figure 7-8 is for an incremental, or velocity type, DDC controller. Similar to the interface shown for the RAS pumps, the incremental approach is inherently fail-safe. Loss of the computer or multiplexer will cause the controller to revert to the local automatic mode without

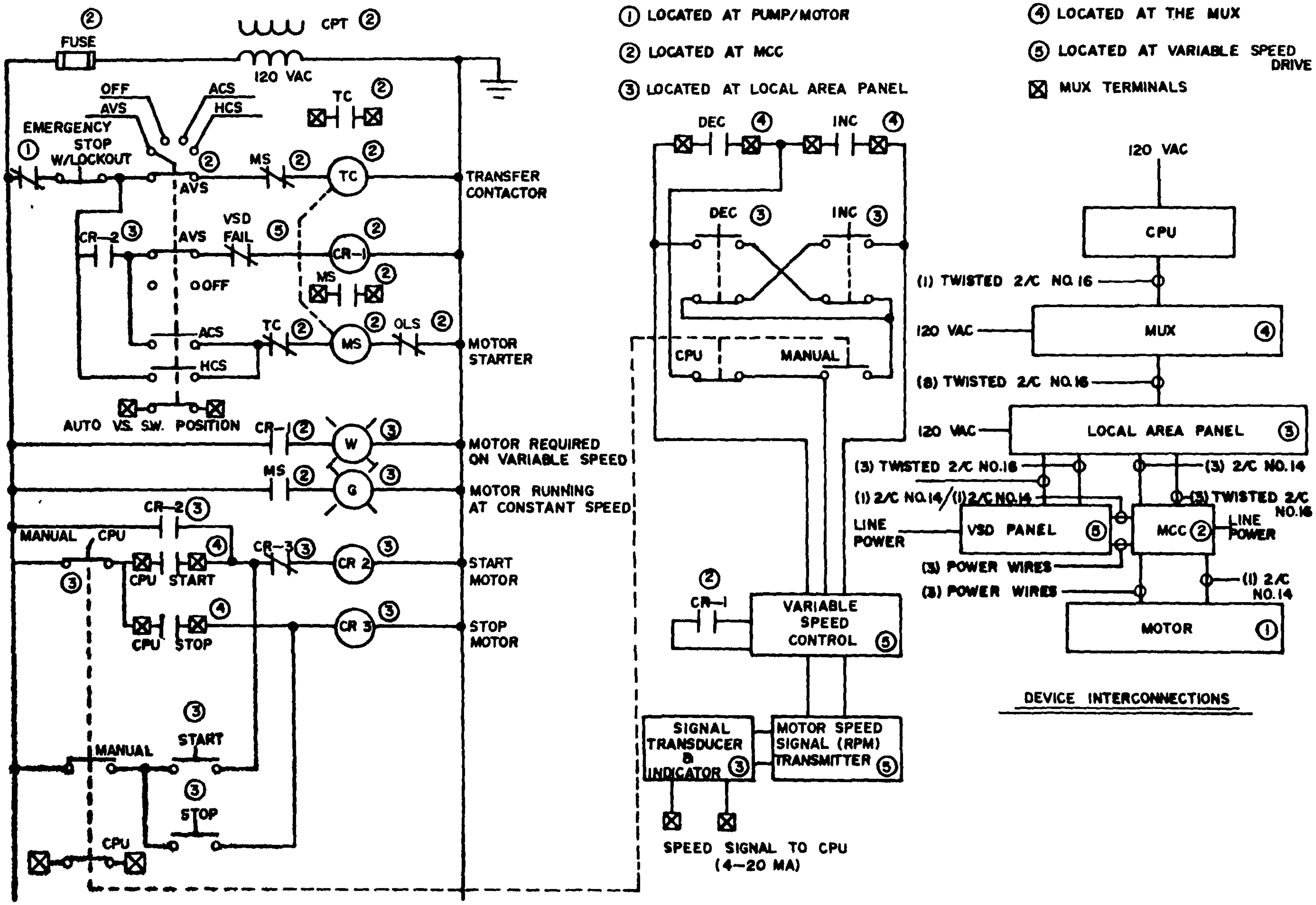


Figure 7-7. Variable speed pump interface.

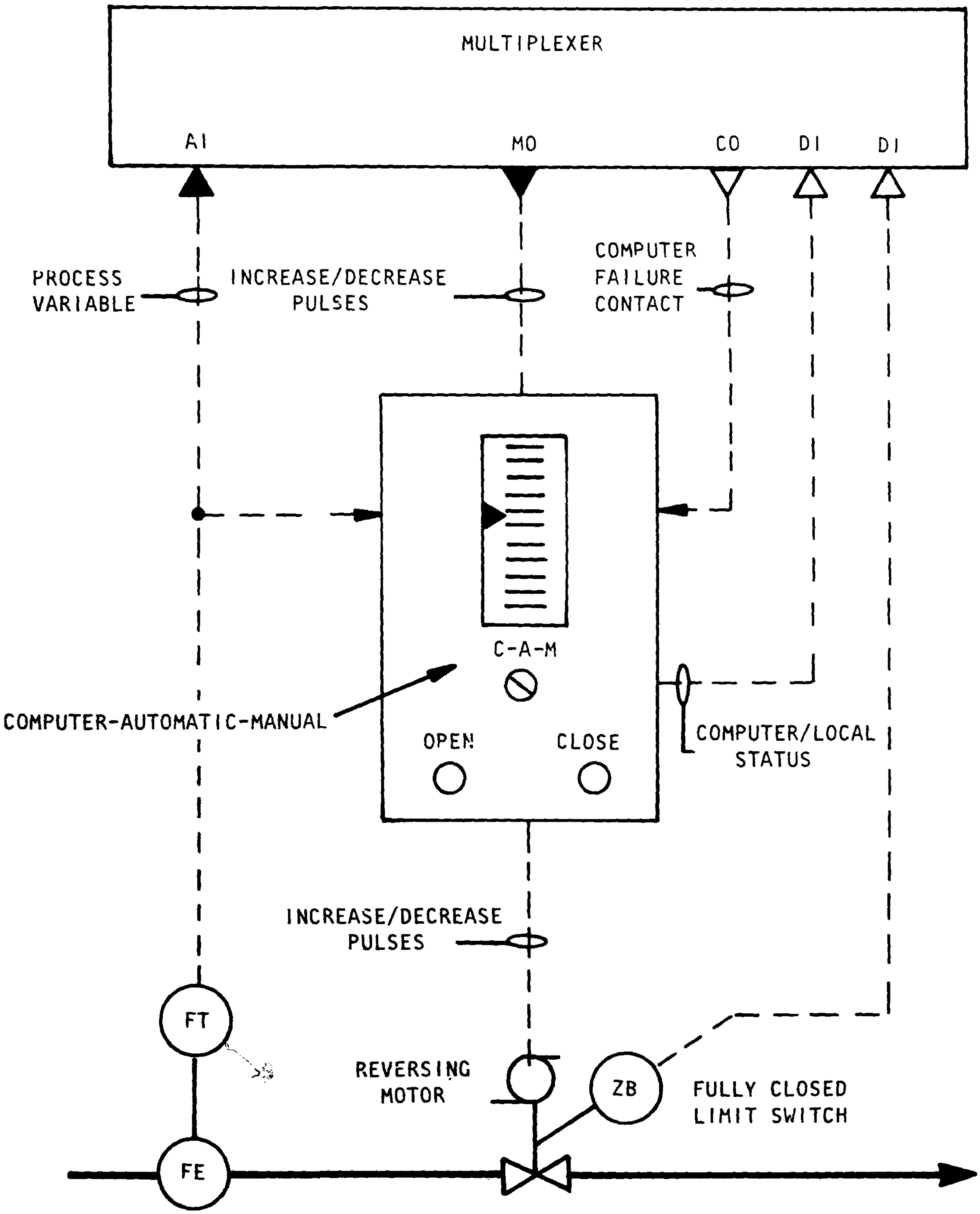


Figure 7-8. Typical incremental controller interface.

bump. In the computer mode, the increase/decrease signals are passed straight through to the valve, without controller action. This is the advantage of a DDC type controller.

With an incremental controller, there is no need to wire the controller output back to the computer. If a positional, or maintained type output (e.g. 4-20 ma) is used in lieu of incremental, the controller output must be wired to the computer multiplexer. In order to provide bumpless transfer from local automatic to computer with a positional controller, the software must track the controller output.

These are a few examples of interface considerations which must be taken into account. The control system engineer must carefully address the interface to every controlled and/or monitored type of device in the plant.

Review of Electrical & Mechanical Specifications

Often, the specifications for electrical and mechanical equipment are written by departments, or even companies, separate from the control system engineer's domain. These specifications, however, must contain the "hooks" for the control system. Typical examples of items which must be called out are:

- Auxiliary contacts for motor starters
- Motor starter 120 VAC pilot circuits, with provisions for remote control
- Spare limit switches for valves
- Valve actuators
- Air compressors
- Pneumatic piping
- Control panels supplied with various package equipment items
- Instrument wiring for interconnection between panels
- Communication wiring

Each item must be carefully reviewed and coordinated to insure that the process equipment can be controlled and monitored.

Instrumentation Specifications & Schedules

Following completion of the P&ID's, each instrument should be listed in schedules and specified in detail from a performance standpoint. The first step is the preparation of an instrument summary list for all sensors in the plant (see Table 7-2). This list includes tag numbers (from P&ID's), multiplexer or area designation, equipment description, application, P&ID drawing cross reference and specification reference.

TABLE 7-2. INSTRUMENTATION SUMMARY LIST

TAG NO.	MUX	EQUIPMENT	APPLICATION	P&ID DWG.	SPEC. REF.
LT 102	B	SLUDGE LVL TRANSMITTER	SEC. CLARIFIER #1	PI-110	
LT 112	B	SLUDGE LVL TRANSMITTER	SEC. CLARIFIER #2	PI-110	
FE/FT 106	B	FLOW TRANSMITTER (MAG)	SEC. CLAR. #1 UNDERFLOW	PI-110	
FE/FT 116	B	FLOW TRANSMITTER (MAG)	SEC. CLAR. #2 UNDERFLOW	PI-110	
FE/FT 125	B	FLOW TRANSMITTER (MAG)	RAS	PI-110	
DE/DT 126	B	DENSITY TRANSMITTER	RAS	PI-110	
HIK 121	B	MANUAL LOADING STATION	RAS PUMP 1 SPEED CONTROL	PI-110	
HIK 122	B	MANUAL LOADING STATION	RAS PUMP 2 SPEED CONTROL	PI-110	
FIC 107	B	FLOW CONTROLLER	SEC. CLAR. #1 UNDERFLOW CONTROL	PI-110	
FIC 117	B	FLOW CONTROLLER	SEC. CLAR. #2 UNDERFLOW CONTROL	PI-110	

For each type of sensor, the engineer should prepare a performance specification and an instrument schedule. For information of specific devices and on instrument specifications in general, refer to Section 6, Available Instrumentation. It is suggested that a standard outline similar to the Construction Specification Institute (CSI) format be used to maintain uniformity in writing the specifications. An example outline of a specification of this type is provided on the following page.

A typical instrument schedule is shown in Table 7-3 for the magnetic flow meters used in the RAS control example. For each meter, the schedule includes tag numbers, application, size, liner material, range and indicator requirements.

In addition to the specifications, a mounting detail should be provided for each instrument on the plans. Proper mounting is crucial to proper instrument operation. The engineer should clearly show the contractor exactly how each instrument is to be mounted. A typical mounting detail for an optical density meter is shown in Figure 7-9.

During the past several years, many new sensors have been developed, especially for analysis of the physical and chemical characteristics of wastewater. Examples include TOC analyzers, ultrasonic sludge blanket level detectors (continuous output type), nitrogen analyzers and new types of flow measuring devices. Before specifying these, the engineer should carefully investigate the design and operating principles and, if possible, user references. Frequency and duration of maintenance requirements are especially critical. A good way to check out a new instrument is to convince the vendor to loan one for trial by the engineer or his client in an operating plant. The continuous reading sludge blanket detector shown on the RAS P&ID is a good example of a sensor which should be carefully evaluated before being specified.

Control Panel Design

Control panels are required for manual, analog and digital control systems. Function and interface are the key words in panel design. Interface has already been addressed. Function requires that the panel be laid out with the operator in mind. Components should be arranged in an orderly and logical manner. Controls associated with a specific process or device should be grouped together.

A typical control panel for our RAS example is shown in Figure 7-10. The controls for the clarifiers are grouped together, as are the controls for the RAS pumps. The specifications for the panels should include a list of panel mounted instruments complete with tag numbers (again from the P&ID's), description and indicator scale requirements.

SECTION ____________

(INSTRUMENT OR DEVICE)

PART 1 - GENERAL

1.01 WORK INCLUDED

1.02 RELATED WORK SPECIFIED ELSEWHERE

1.03 SUBMITTALS

A. Shop Drawings

B. O&M Manuals

1.04 SPECIAL TOOLS AND EQUIPMENT

A. Spare Parts

B. Test Equipment

1.05 STANDARDIZATION

1.06 RESPONSIBILITY AND COORDINATION

1.07 MANUFACTURER'S SERVICES

1.08 GUARANTEE

PART 2 - PRODUCTS

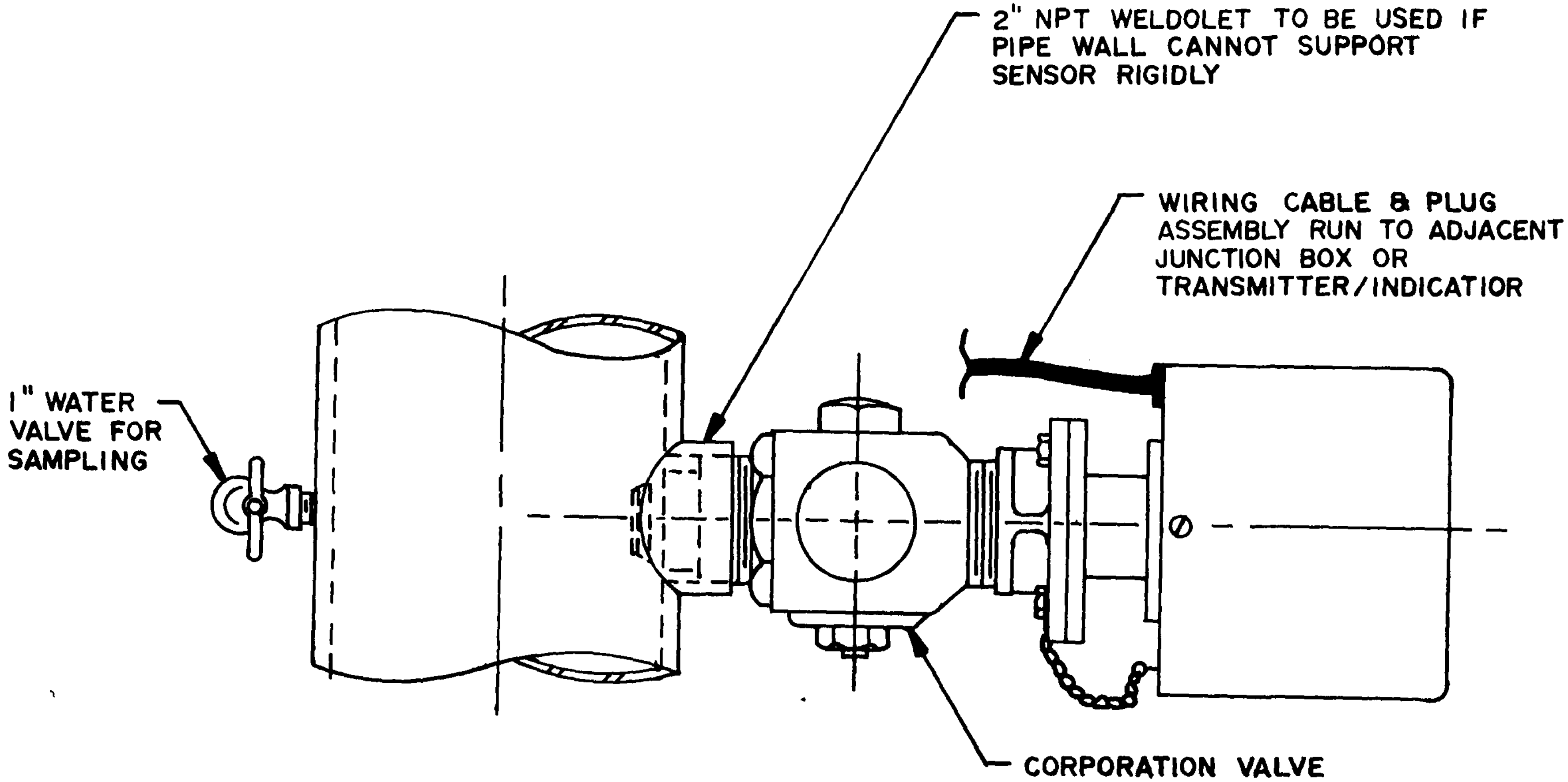
2.01 (INSTRUMENT OR DEVICE)

A. Specification

1. Operating principle
2. Accuracy
3. Repeatability
4. Linearity
5. Indicator accuracy
6. Environmental requirements (e.g., temperature range)
7. Enclosure
8. Power requirements

TABLE 7-3. MAGNETIC FLOWMETER AND TRANSMITTER

TAG NO.	APPLICATION	SIZE	LINER MATERIAL	CALIBRATED RANGE	INDICATOR	NOTES
FE/FT 106	Secondary Clarifier No. 1 Underflow	8"	Polyurethane	0-5 MGD	Yes	Indicator Panel Mounted
FE/FT 116	Secondary Clarifier No. 2 Underflow	8"	Polyurethane	0-5 MGD	Yes	Same as FE/FT 106
FE/FT 125	RAS	12"	Polyurethane	0-10 MGD	Yes	Same as FE/FT 106



NOTES:

1. IF SENSOR IS MOUNTED ON A HORIZONTAL PIPE RUN, THE SENSOR AXIS SHOULD LIE IN A HORIZONTAL PLANE.

2. ALL SIZING OF CONDUITS, CABLE LENGTHS, DIMS ETC. TO BE IN ACCORDANCE WITH MFG'S. RECOMMENDED INSTALLATION PRACTICES.

Figure 7-9. Typical mounting detail-sludge density analyzer.

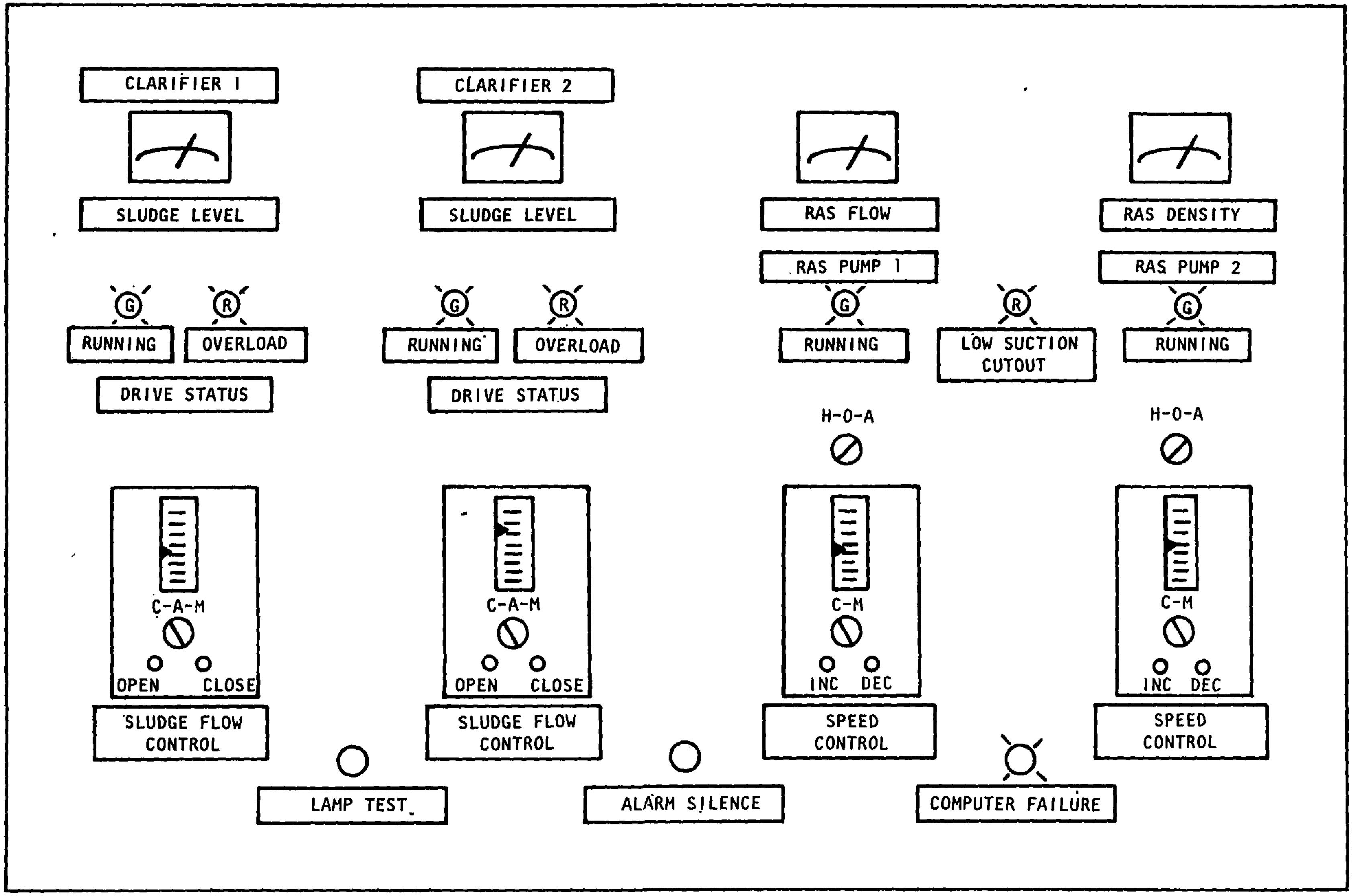


Figure 7-10. RAS local control panel.

Important items to be considered in specifying panels include the following:

- Sheet metal material and workmanship
- NEMA type (for each panel)
- Paint specification
- Device specifications for all components
- Nameplates
- Power supplies
- Panel wiring

The engineer may also choose to do schematic drawings of panel wiring. These should be done functionally to allow the vendor to adhere as closely as possible to his standard procedures to minimize costs. The requirement for detail schematics and/or loop drawings may be more important for a pure analog system, as the degree of panel complexity will typically be greater than for a digital system. This is a design decision which must be made early in the project.

<u>Control Loop Description</u>

The specifications must include a complete description of control requirements for each loop. For analog systems, the description will encompass functions to be performed by hardware; for computer systems, the functions will be implemented by software.

The loop description should include the following:

- Overall control strategy diagram and description
- Different modes of control required
- Supervisory control requirements, e.g. flow control
- Sequence control requirements, e.g. motor start/stop
- Interface to other control loops
- Contingencies (Failure/restart considerations and effects of device failures)
- CRT displays (computer systems only)
- List of input/output points

For our example, automatic control is implemented by a software program, often called an algorithm. The algorithm details the strategy to be used for sludge withdrawal and pumping. The highest level of control is based on the RAS calculations, sludge blanket measurements and sludge flow and density measurements. A second level of control is specified to be used by the operator to set flows and pumping rates from his CRT console. A basic level of control should always be specified to be used during system startup or in the event of sensor failure.

One of the more difficult and frequently neglected tasks is to attempt to anticipate all of the things that can go wrong with a process and the associated equipment (contingency analysis). In each situation identified, it must be decided whether the control system is to initiate automatic response actions or if the situation is to be handled by manual intervention. In the RAS control example, some of the contingency situations that might arise include:

- Power failure (momentary and long-term)
- Failure of one or both pumps
- Flow meter failure
- Density meter failure
- Sludge blanket level detector failure
- Clarifier drive failure
- Clarifier out of service

The above contingencies are in addition to events encountered in normal operation such as high and low wet well level, and high and low sludge blanket level. The latter must be handled by the control system as a minimum.

The control loop description should also call for certain performance requirements. In our example, a typical requirement would be to maintain a sludge blanket within a certain level range and to maintain a certain RAS sludge density range. The performance requirements should be realistic and measurable.

The method of documenting control loops should provide enough detail to give the vendor a clear understanding of the requirements. Drawings should be used to illustrate the control strategy and CRT screens (if applicable). The loop may be described verbally, or a combination of description and flow charts may be used. The important point is functional detail. Many control systems have not functioned properly because the vendor was not given sufficient information to properly implement the control strategy.

Computer System Specification

The specification of a computer system can be accomplished by preparing either a detailed design or a performance document. A detail design is on the "nuts and bolts" or component level for the computer, its related equipment and the programs which will make the system work, while the emphasis of a performance specification is on function or capabilities of the computer system. For the purpose of this design example, a performance specification will be used.

Detailed computer designs have few advantages compared to a performance specification. Detail is here referred to as the internals of how things are done in the computer system. This type of design can lead to many problems. If they are prepared without regard for the commercial availability of the items specified, there is the risk that no supplier or contractor can furnish the specified system. Another risk with this type of specification is that the system supplied per the contract documents is likely to be a first time product which has not been field tested and, as such, it may be difficult to obtain maintenance and service. Of course, the specifying engineer concerned about the commercial availability of a computer system could, in preparing a detailed design, tailor the specifications around a particular system or equipment. In so doing, competition is restricted and the engineer risks being faced with a protest regarding proprietary specifications. As a result, the engineer may be forced to rewrite the specification.

The disadvantages presented for a detailed computer system design should not de-emphasize the need for detail in the design of a control system. In addressing the interface between a computer system and its data acquisition hardware to operations, processes or equipment external to the computer system, clarity of the interface requirements and functions is a must. This clarity can only be achieved by providing the detail as described for the input/output point listing, interface schematics and control loop descriptions.

A performance oriented specification for a computer system encourages competition and insures receipt of a representative number of bids. Also, there are numerous ways of building a computer system to perform the same task. Few standards have been established by the computer industry, consequently there are as many ways of achieving the same end as there are suppliers of hardware and software. Also, a performance specification allows more flexibility for innovation in the approach to a control system design. However, the engineer must still be realistic in specifying performance requirements and in evaluating new technological approaches to a design.

From a supplier standpoint, a performance specification allows more use of off-the-shelf equipment and programs to meet the specification requirements. This is advantageous because it aids in keeping down the system price by minimizing new product development. Not only is a cost savings of benefit to the user, but thoroughly tested and field proven hardware and software is likely to be supplied. This will help minimize system startup difficulties and there is assurance that long-term support will be available.

Computer Hardware Specification--

The hardware specifications should establish minimum equipment to be supplied, and minimum performance criteria. A basic configuration should be defined, identifying the functions and primary capabilities to be performed by the computer system. This would include requirements for redundant or backup equipment, however, specific items to be supplied and their interconnection are the responsibility of the control system supplier.

Each of the major components are then specified individually by establishing guidelines for sizing and performance. These guidelines are considered minimum based on experience and knowledge of requirements for other systems similar in size and complexity. The final sizing and speed of equipment furnished shall be the responsibility of the system supplier. To make sure that the system is flexible to meet today's demands and those of tomorrow, known future expansion capabilities need to be defined plus a reasonable unassigned spare capacity.

Computer Software Specification--

The computer software can be generally classified as operating system software, development software and application software. General requirements for each group and the computer programs which comprise them must be defined along with the purpose of each program, what it is supposed to accomplish and how it can be used. Clear definitions are necessary when specifying programs because with few exceptions, program types and capabilities are vendor dependent with proprietary names.

The operating system is normally a program produced and supported by the computer. Since this program or package of programs can be considered as the central nervous system of the system, it is recommended that it be specified as an unmodified standard product of the computer manufacturer. The operating system keeps track of what is going on in the computer, responds to requests from equipment external to the computer and schedules other programs to run when they are required.

Development software is comprised of all programs which can be used for modifying existing programs or generating new ones. Most commonly this would consist of assemblers and compilers. Other programs useful to a user would permit adding and deleting control system monitoring and control points, development of new programs, generating operating reports and modifying operation displays. These programs make the system flexible to accommodate future expansion or changes with a minimum of difficulty. Therefore, when specifying these programs, the use and the degree of flexibility has to be clearly stated.

Applications software includes all process control programs, operating reports, special operator console displays and all special software which is unique to the project.

Man/Process Interface (MPIF)--

The MPIF is an operators console containing equipment by which an operator can retrieve information regarding plant status and can also perform operations. The equipment to accomplish these tasks consists basically of a cathode ray tube (CRT) and keyboard. Configuration of the operators console may consist of multiple CRT's and keyboards, however, the operation is the same for each.

Both hardware and software are involved in defining the MPIF. However, the separation between the two is not always clear. For this reason, when specifying a MPIF, the emphasis is placed on operations and the steps to perform them. Of utmost importance is simplicity for an operator to perform any given task. First, the presence of the computer should be transparent to the operator; in other words, the operator should not be concerned that a computer is involved. Next, an operator trained on the console and with a few weeks on-the-job experience should be able to retrieve any process information and perform all operation tasks without a need to reference data listing or manuals. A system with five hundred or more input/output points is obviously too large for a person to remember coded point names associated with each piece of information. Therefore, a hierarchial design with computer directed prompting should be required as a method for directing the operator to the desired point.

Testing--

Thorough testing of the computer system at key points during the project is necessary to determine whether the hardware and software are being correctly integrated. As a minimum, testing should be performed before the system is shipped from the contractor's facility, upon completion of field installation and for a period of extended operation.

Before delivery to the job site, the hardware and software as a total system must be debugged. This is done to minimize problems during startup. If the debugging is postponed until on-site installation, the number of problems likely to occur can weaken the confidence of operations personnel in the ability of the system to ever work. It is inefficient to perform all debugging on site as it will unnecessarily prolong the entire startup procedure. The factory test should thoroughly exercise the system using test panels to simulate process conditions with reports generating and operator tasks being performed simultaneously. Each input and output point should be tested to determine if it is wired and performing correctly.

The field test is conducted following installation of the system on site. All input/output points are wired into the plant equipment, control loops are tuned and operating, reports can be printed and the plant personnel are ready to take over operations via the computer.

Since the computer system availability is necessary for normal plant operations, reliability is an important factor. It is not possible during a few days of actual testing to experience many of the combinations of events that can occur during day-to-day operations. Therefore, it should be a specification requirement that the system operate for an extended period of time while meeting a minimum level of performance and on-line operation. The duration and performance level for the extended test should be determined based on the configuration, i.e. redundant equipment and the dependency on the control system to maintain smooth operations with a normal staff. An example would be to require a 98% availability for a period of 30 consecutive days with a single computer system that controls six loops. Longer periods and higher performance may be required for more complex systems with multiple levels of backup. However, 30 days should be a minimum period for any test.

System Support--

For continuous long term operation, the user must be prepared to take over the support of the system. The specification must address several items which may differ from the normal requirements associated with the purchase of equipment. These include:

- Warranty
- Maintenance contracts
- Test equipment

- Spare parts
- Operations training
- Maintenance training
- Maintenance manuals
- Software documentation
- Program source code

Even if the user plans to enter into a maintenance contract, all of the support items should be addressed by the specification. In this way the user has the option of entering into a contract with an independent service organization for long-term support.

SPECIFICATION CHECKLIST

There are a large number of control options open to the designer of a control system. The level of complexity varies from low, such as a start/stop station at a motor, to high, consisting of all field sensors and equipment monitored and controlled by a computer with multiple levels of backup. At first, the wide array of factors contributing to the design of a control system may appear confusing. To help the control system designer sort out the items that contribute to the specification, the following checklist has been prepared to aid in selection of pertinent topics which the contract documents should address.

SPECIFICATION CHECKLIST

1. P&ID'S

   A. Symbology clearly defined
   B. One per major process (minimum)
   C. All process piping shown
   D. All control devices shown
   E. All primary sensors included
   F. All panel mounted devices shown
   G. Interface to computer system or master control panels clearly defined

2. I/O POINT LIST

   A. Numbering system defined
   B. All analog and digital points included
   C. Logically linked to P&ID's
   D. Point names and descriptions specified
   E. Point type indicated for each point
   F. Signal ranges, scan times, alarm limits, deadbands, rate of change and scaling information given for each point
   G. Points listed by multiplexer and/or plant area
   H. Points listed by control loop
   I. Points listed by point type

3. INTERFACE DRAWING

   A. Constant speed motor interface
   B. Variable speed motor interface
   C. Open/close valve interface
   D. Modulating valve interface
   E. Local panel/multiplexer
   F. Manual loading stations
   G. Controllers
   H. Major equipment items (e.g. blowers, chemical feeders, etc.)

4. ELECTRICAL & MECHANICAL SPECIFICATIONS

   A. Valves/actuators/limit switches
   B. Motor starters
   C. Package control panels
   D. Instrumentation wiring
   E. Communication wiring
   F. Power wiring

5. INSTRUMENTATION

A. Instrument summary list
B. Instrument schedule for each instrument type
C. Operating principles
D. Enclosures
E. Environmental requirements
F. Accuracy
G. Repeatability
H. Linearity
I. Indicator accuracy
J. Power requirements
K. Spare parts and tools
L. Mounting details

6. CONTROL PANELS

A. Panel layouts
B. Enclosures
C. Size limitations
D. Future expansion provisions
E. Paint
F. Nameplates
G. Schematic drawings
H. List of components for each
I. Component specifications:

1) Relays
2) Indicators
3) Recorders
4) Switches
5) Controllers
6) Manual loading stations
7) Power supplies

7. CONTROL LOOP SPECIFICATION

A. Overall control strategy diagram and description
B. Modes of control
C. Supervisory control
D. Sequence control
E. Failure/restart considerations
F. Sensor/device failure considerations
G. Contingencies
H. Interface to other control loops
I. CRT displays
J. I/O points
K. Performance requirements

8. COMPUTER SYSTEM SPECIFICATIONS

A. Performance

1) Computer system availability
2) Failure response

B. Hardware specifications

1) Configuration
2) Computer

a) Size
b) Speed

3) Peripheral equipment

a) Disk/drum drives
b) Communications links
c) High speed printer
d) Magnetic tape recorder
e) Failover detection module
f) Low speed data logger

4) Process input/output controller/multiplexer

a) Analog input

DC voltage	Thermocouple
Resistance measurement	AC voltage

b) Digital input

Binary coded decimal (BCD)	Binary
Pulse duration	Pulse train
Status/event	

c) Data integrity

Common mode rejection (CMR)	Accuracy
Normal mode rejection (NMR)	Other performance conditions

d) Analog outputs

DC voltage
DC current

e) Digital outputs

Solid state	Relay
Electrical hold	Latching
Timed	Voltage rating
Current rating	

f) Expandability

5) Uninterruptible power supply (UPS)

C. Software specifications

1) Operating system
2) Peripheral drivers
3) System development

a) Compilers
b) Interpretors
c) Assemblers

4) Diagnostic and test
5) Operating reports
6) Regulatory agency reports
7) Data acquisition
8) Process control
9) Special application

D. Man/process interface

1) Operator station

a) Panel
b) Keyboards
c) CRT
d) Entry security

2) CRT displays

a) Data points
b) Process graphics
c) Lab data entry
d) Time/date
e) Data summary
f) Alarm summary
g) Process parameter entry

3) Operation

a) Start/stop equipment
b) Display response
c) Activate/deactivate automatic controls
d) Display request
e) Display update

4) Alarm handling

   a) Setpoint adjustment
   b) Alarm reporting
   c) Alarm silence/acknowledge
   d) Number of alarm limits
   e) Alarm annunciation
   f) Alarm clear

E. Testing

   1) Factory
   2) Field

F. System support

   1) Warranty
   2) Maintenance contract
   3) Test equipment
   4) Spare parts
   5) Training
   6) Submittals
   7) Final documentation

G. Site planning/installation

   1) Computer room location and size
   2) Control room location and size
   3) Cable routing provisions
   4) Grounding provisions
   5) Power availability
   6) Remote located equipment
   7) Remote equipment communication lines
   8) Electrical environment
   9) Ambient environment

SECTION 7
BIBLIOGRAPHY

How to Specify Valve Actuators, Instrument & Control Systems. January, 1976.

Selecting an Air Dryer, Instrument & Control Systems. April, 1976.

Kessler, Evan, Checklist for Data Logging/Acquisition Equipment, Instrument & Control Systems. February, 1978.

McKenzie, R. D., Working With a Construction Contractor....How to Handle Control System Projects, Instrumentation Technology. April, 1977.

Reinarts, Thomas M., EM & C Systems - How to Design and Specify Them, Specifying Engineer. February, 1978.

SECTION 8

RECOMMENDED FUTURE ACTIVITIES

The basic purpose of this document is to serve as a guide to consulting engineers and governmental officials involved in the design and/or specification of instrumentation and automation for activated sludge treatment plants. This document thus presents the present technological status of the application of instrumentation and automation in activated sludge plants. The information basically reflects the observations which were made on the field visits and the general knowledge and experience of the authors and the EPA officials involved in the project.

It was found that the application of instrumentation and automation in the field was significantly below that which was technologically achievable. The reasons for this discrepancy are discussed below under the general terms of Design Problems, Process Control Problems and Instrumentation Problems. This discussion is an expansion of the technology based problems mentioned in Section 1 of this handbook. In order to overcome these problems, a series of research, demonstration and technology transfer based activities is recommended here.

In addition, a hindrance in the fruitful application of instrumentation and automation was surfaced by this study. The problem is a lack of application of effective modern management techniques to municipal wastewater control organizations. This is not a new problem per se, but a new realization of the adverse effects of this problem on the proper application of available technology. Because of its importance, the management problems and proposed solutions will be discussed prior to the technical problems mentioned above.

Management and Organizational Problems

Similar types of management and organizational problems appeared with great regularity. This general observation is, of course, not applicable to all the organizations visited; however, management problems were observed both in small and large organizations with enough frequency to be a cause of concern. Often these problems resulted in under-utilization of available instrumentation and poor performance of the treatment facility. Management problems generally fell into the categories discussed below.

Ineffective Management Execution--

In general, an adequate hierarchial organizational structure was observed in the management of wastewater organizations. However, the use of the chief executive's time was observed to be random and unordered. The day-to-day administrative problems associated with running a growing, new organization dominated his actions. Union problems, personnel problems and fiscal problems were observed to have a much greater impact on his time than operations or maintenance planning. At the lower levels of the organization, there were many situations where an operator would receive direction from more than one person, leading to confusion. Management execution and time management must be improved. A starting point would be improved policies and procedures.

Policies and Procedures--

There was a lack of specifically defined actions and reactions for line managers and operating staff. Policies and procedures make better use of all managers time because basic issues do not have to be presented or discussed, they are simply executed in accord with policy. In this way the actions are more consistent. Policies and procedures also enhance the concept of hierarchial communication which was observed to need improvement.

Communication--

There appeared to be many road blocks to good communication at most organizations. Regular staff meetings at the executive level were infrequent. Line managers often complained that it was difficult to be heard because other problems were always more critical. At the lower levels, operators very rarely heard from management, other than an occasional memorandum. This lack of management/staff communication often caused a definite attitude problem. Regular communication is a must and should become better with improved management discipline.

Discipline--

Management actions and reactions should be consistent and predictable. During field visits, managers and operators commented that policies, procedures and schedules were often not followed. This lack of discipline through an organizational hierarchy often led to the management philosophy of "everyone doing their own thing," causing operational consistency to be reduced. In every instance where a solid management discipline did not exist, crisis management reigned. Discipline must start with management taking time to listen (feedback) and act (followthrough).

Lack of Feedback--

On numerous occasions plant operators expressed a need for management feedback. Management, on the other hand, only rarely expressed a need for operator feedback. Feedback, on a consistent basis, improves both parties and is a necessary element for management success. Field visits indicate that often the only feedback management hears is union grievances. This situation must improve. Effective feedback should lead to effective followthrough.

Lack of Followthrough--

Operators very frequently commented that management and/or their supervisors lacked the time or the desire to follow through on instructions. Line managers would "expect" something to be done and not "inspect;" therefore, operators would not take verbal instructions seriously. Without followthrough, the management cycle is incomplete. Followthrough is effective management execution.

Recommended Solution

Managers need ongoing management training specifically aimed at this industry. The American Management Association, the Water Pollution Control Federation and the Environmental Protection Agency can provide this training. A handbook should be developed by a management consultant (supported by EPA) specifically for this industry. This handbook must involve all facets of management and address the real-life problems of managing a process organization where a profit motive does not exist.

TECHNOLOGY BASED PROBLEMS

Design Problems

Frequent complaints from management and operations people at the facilities visited indicated that inadequate design hampered their ability to maintain good, consistent treatment. In some cases, problems which were due to improper design or construction were wrongly attributed to poor management and communication. These design problems can be categorized as follows.

Inoperable Process Equipment--

In many situations process equipments were found to be either incapable of performing as specified or requiring too much operation/maintenance and hence were shut down.

Hydraulic Control--

At many of the plants visited, the operational personnel indicated they could not adequately control routing of the flow to the multiple tanks of the various unit processes through the plant. This difficulty led to severe control problems in trying to maintain consistent treatment.

Distributed Control Centers--

Distributed control, whether it be executed with manual pushbuttons or automatic controllers, was a consistent complaint of management personnel. There were often as many as ten or eleven local control centers at a plant which led to poor communication and poor process consistency.

Physical Engineering--

Often equipment was installed in such a way that it could not be accessed. Control panels are often not logically laid out and frequently instrumentation mounting was such that it was difficult to maintain.

Instrumentation Specifications--

Often specifications were written primarily by a vendor and incorporated in a general equipment specification by a consultant. The lack of an independent design and specification by the consultant often resulted in poor instrumentation of the plant and, consequently, poor process control. This occurred even when the vendor who wrote the specifications was awarded the procurement.

Control Strategies (Lack of and nonapplication)--

In Section 3 of this report a large number of process and unit operation control strategies in use in the field were detailed. Unfortunately, for some important treatment steps such as activated sludge and sludge dewatering, truly adequate control strategies have not been developed. The control strategies given in Section 3 must be considered sub par, and process efficiency and cost effectiveness are seriously impaired as a result. Fundamental understanding of these processes upon which a rational control strategy can be based is not available. In addition, for many other treatment steps, the control strategies used are inadequate. For most, a superior alternate has been devised but has not yet been applied at other than pilot scale.

Process Control Problems

During the field investigations included in this report many operators and management people were interviewed. The concept of process control was discussed in every case and questions were asked relative to how control of the plant was achieved. The following widespread problems were evident from these interviews.

Conceptual Understanding of Process Control--

The concept of process control on a real-time basis was not generally understood by personnel responsible for management and operation of wastewater treatment plants. The most important concept which was not understood is the need to continuously control a flow, a pressure, a level or any of a number of other process variables. The opinion was that processes in treatment plants are inherently stable and do not need to be controlled. In addition, these people are unfamiliar with the procedures for implementing process control. Often inappropriate techniques were applied to a process control problem. Needless to say, these situations resulted in "automation failures."

Process and Control Dynamics--

An understanding of the dynamic nature of the flow into the plant and the dynamic nature of the treatment process did not exist. This problem amplifies the effect of the lack of conceptual understanding of process control.

System Approach--

Because of the use of distributed control centers throughout the plant, the approach of looking at a treatment plant as one system is not utilized. The control procedures used are based on a particular unit process, typically with little regard to the impact of a change on upstream or downstream processes.

Crisis Control--

In an alarming number of cases, operators would not apply process control on a predetermined basis but would control on a crisis basis. A plant often would be controlled from one failure to another. If solids started bulking from a clarifier, that problem would be dealt with. If the mixed liquor suspended solids got to an alarmingly low level, that problem would be dealt with. Problems would be handled when they reached a critical level, not early in the game when it would be easier to cope with. This is a result of a lack of appreciation of process control concepts and the dynamic nature of wastewater treatment systems.

Unclear Objectives--

In many cases, control objectives were not specifically clear to operators. Often, they felt their job was to keep the process running rather than to attain a certain efficiency with a minimum level of energy, chemical use and labor.

Changing Strategies--

Because procedures were not typically nailed down and objectives not clearly called out, shift operators would tend to use their own experience or prejudice in controlling a particular unit process. This would lead to changing strategies on a shift basis and cause many problems with process consistency from shift to shift.

Instrumentation Problems

In general, the field investigations generated a good deal of negative comments relative to instrumentation. From field observations, the negative comments are well founded and can be traced to either management problems, design problems or process control problems. The most repetitive problems with instrumentation are as follows.

Misapplication--

Misapplication of instrumentation was the dominant cause of malfunction. In many instances an instrument with an inappropriate span was being used to measure a quantity. Also, many instruments were poorly mounted such that the sample was not meaningful or the analyzer could not receive proper maintenance. Finally, some instruments could not adequately measure the parameter that they were purchased to measure. This points up the need for improvements in instrumentation specifications.

Underutilization--

Because of the process control problems and the lack of a conceptual understanding, instrumentation which in some instances was properly installed and specified was not utilized because it was not thought of as necessary or of any value for process control.

Maintenance--

For whatever reason (management problems, design mounting problems, process control understanding problems), a large portion of the instrumentation was found to be inoperable because it had not received the appropriate maintenance. This led to the inoperability of the equipment and helped develop the negative attitude toward instrumentation.

PROPOSED SOLUTION TO TECHNOLOGY BASED PROBLEMS

The problems described above are complex and fall in several categories. Some problems are due to a lack of understanding or lack of knowledge. Potential solutions to some problems are available but have not been tested. Other problems are well understood and solutions have been demonstrated but the results of the latest technology simply have not been distributed to the industry.

Hence, proposed solutions must take three forms:

- Research to develop a better understanding and better knowledge.
- Demonstrations to show the industry that theories can be successfully applied to process control with use of instrumentation.
- Technology transfer to distribute state-of-the-art information to the industry in a timely fashion.

Recommended Research

To develop a better understanding of wastewater treatment technology, the following research should be undertaken as soon as possible.

Activated Sludge Processes--

Many versions of the activated sludge processes were observed in the field. There are also numerous theories with regard to controlling activated sludge processes in terms of F/M, SRT, etc. The research which is recommended involves the development of a practical integrated control strategy utilizing the degrees of freedom offered by the activated sludge process (RAS, WAS, DO control and location of influent or sludge return).

The complicating factor is that these parameters are not completely independent. Over several hours that sludge which is not returned to the aerator must be wasted because of the limited storage capacity of the secondary clarifier for sludge. The position of feed and recycle in the aerator (step aeration) can have a marked temporary effect on the solids load to the final clarifier, which in turn will effect both the effluent solids and concentration of sludge in the RAS. In addition, any attempt to effect a control strategy which will keep the rate of feed of organics and the rate of return of sludge in proper balance will produce hydraulic transients in the system unless a good deal of off-line sludge storage is provided. In many situations these transients will temporarily overload the final clarifier yielding a poor effluent. The strategy developed must deal with the physical limitations of the system and the interrelationships of these control parameters.

A research study is needed to establish and document an integrated operational control algorithm based on theoretical or empirical relationships which can be presented to the industry as a standard.

Sludge Collection, Removal and Thickening--

On frequent occasions, plant superintendents and operators commented on the difficulty of collecting and removing sludge from clarifiers. This seemingly very simple requirement turns out to be a difficult task. Removal problems lead to adverse effects on effluent water quality. A study is needed to develop improved methods of collecting, removing and thickening sludge so that a more consistent material can be routed to downstream unit processes.

Dewatering Processes--

The most frequent observation at the plants visited with regard to dewatering was labor intensity, irrespective of the dewatering process. Basic research is needed to establish a practical measurement which can determine or predict dewaterability. This measurement would replace presently used manual techniques. This parameter and reasons for its variation must be studied so that its measurement can be utilized for automated control of dewatering processes.

Man/Process Interface Research Needs--

In both digital and/or analog control systems, the relationship of the operator to the process control equipment seems to be a weak point. Large analog systems are difficult for an operator to use in a moment of crisis. Some computer systems have cumbersome methods for an operator to access and enter data, therefore, they are not convenient to use. The advantages and disadvantages of various methods of operator interface to different types of control systems need to be examined to determine the simplest and easiest method for an operator to interact with the process. A research grant is needed to study the human engineering aspects of automation to prepare the wastewater industry for the future.

Energy Management Research Needs--

One of the most disturbing observations at many of the treatment plants visited was the lack of energy conservation efforts. Because the plants are often operated in the crisis mode, conservation of energy is a low priority. Consumption of energy, chemicals and materials represents over 50% of a typical operating budget. A study of how automation and instrumentation techniques could reduce energy consumption at treatment plants is needed. This research could then be the basis of a demonstration grant to implement the plan and document the results.

Profit Motive Research Needs--

Many of the plant superintendents and operators mentioned the need to get positive motivation into the water pollution control program. Fines for not meeting effluent standards simply are not enough to motivate plant management to operate the process more efficiently with less utilization of energy, materials and labor. A study is necessary to examine the practical aspects of implementing positive incentives in the water pollution control program. The document could serve as an initial plan for promoting such a program to Congress should the research study illustrate justification.

Demonstrations

A number of control strategies which are discussed below may be better than the control strategy presently used in the field. Demonstrations should be conducted at full scale to illustrate relative efficiencies.

Strategy #1 - Constant velocity and/or constant overflow rate controlled grit chambers--

Advantages: Grit separation could possibly be improved over that achieved in aerated grit chambers.

Requirements: Multiple parallel grit chambers of any of the following types:

a) Parbolic crossection

b) Rectangular crossection

c) Rectangular crossection with discharge through sutro weirs

d) An automated system to bring grit chambers on and off line so as to maintain velocity within a certain range must be supplied.

Strategy #2 - Primary sludge pumping on a continuous basis to prevent sludge from collecting in the primary clarifier--

Advantages: Minimize odors, minimize floated sludge, improve pumping capability, less maintenance on sludge pumps.

Requirements: A clarifier and thickener with the appropriate pumping facilities. Clarifier should be equipped with either a sludge level detector or a suspended solids analyzer on the sludge discharge. The strategy is to pump sludge continuously and stop pumping if the sludge level or concentration fell below a minimum requirement.

Strategy #3 - SRT control of activated sludge wasting rate by directly wasting mixed liquor--

Advantages: More direct method of controlling SRT, ease of automation.

Requirements: An activated sludge system with the necessary valves, pumps and meters enabling wasting of mixed liquor on an automated basis. Also needed would be a thickener or chamber for direct receipt of the mixed liquor wasted.

Strategy #4 - The use of activated sludge respiration rate to proportion available reactor volume between sludge reaeration and contact in a contact stabilization or step aeration system--

Advantages: More efficient use of activated sludge system (higher loading), improved stability.

Requirements: An activated sludge system with a compartmentalized reactor and provision to return sludge and feed wastewater independently to any combination of compartments. Some method of measuring sludge respiration rate is required.

Strategy #5 - Use of the secondary clarifier only for clarification, not for sludge compaction or storage. The sludge will be continuously withdrawn from the clarifier to maintain a very low blanket level. Sludge will be stored off line in an intermediate storage chamber so it can be returned to the reactor as needed to meet process requirements--

Advantages: No septicity or sludge carryover in the clarifier, a more controlled return rate, avoidance of hydraulic overloads, a more consistent process performance.

Requirements: Clarifier sludge level and return activated sludge suspended solids measurements with separate return activated sludge storage. All necessary control devices such as variable speed drives and modulating valves must be provided.

Strategy #6 - Pace chemical coagulants based on feedforward measurements and feedback measurements to optimize chemical use in process performance--

Advantages: The demonstration that money can be saved due to optimized addition of chemicals utilizing a load following technique with feedback trim. More consistent removals of coagulated materials could also be demonstrated as a result of a controlled chemical dose.

Requirements: Necessary instrumentation to allow measurement of load variables and measurement of resultant process performance, a mechanism for pacing the chemical feed over a sufficient range compatible with the loads imposed on the process, and computation capability to allow implementation of an optimized strategy would be required.

Strategy #7 - Optimization (for energy conservation) of ozonation based on feedforward parameters such as flow, suspended solids, soluble organics, nitrite and ammonia, and the feedback parameter of effluent COD--

Advantages: A demonstration could show significant reduction in energy use due to optimized ozonation. Note: Ozonation is a very high power user and over-disinfection must be practiced because of the difficulty of determining bacteriological kills.

Requirements: Available instrumentation for measurement of the necessay feedforward or load parameters would be required. In addition, the necessary sensing instrumentation for feedback measurement and computation capability allowing the execution of an optimized strategy would also be necessary. A potential demonstration location is Springfield, Missouri.

Strategy #8 - Optimization and control of chlorination with a load following feedforward strategy utilizing measurements of flow, soluble organics and suspended solids and a feedback mechanism of chlorine residual measurements at various points in the contact chamber--

Advantages: The demonstration could illustrate a significant reduction in use of chlorine as well as a more consistent effluent residual and hence a more consistent bacteriological kill. Field results have shown that chlorination is typically a difficult process to optimize. The problems involve the large time constants in the contact chamber and the difficulty in making the necessary measurements.

Requirements: The instrumentation to measure the necessary load variables must be available. In addition, the configuration of the chlorine contact tank and the chlorine residual analyzers in the chlorinator itself must be such that the time constants involved are minimized. Necessary feedback instrumentation is required as well as the computation capability allowing the execution of an advanced strategy.

Strategy #9 - Optimization of gravity thickening based on maintaining a stable sludge blanket and consistent underflow sludge concentration--

Advantages: It can be expected that a consistent operation of a gravity thickener will improve the operation of downstream dewatering and stabilization processes. A stable blanket should maximize capture in the gravity thickener, thus lowering the impact of the recycle liquors on the liquid process. A limited demonstration of these advantages has been shown at Minneapolis-St. Paul.

Requirements: The necessary instrumentation for consistently controlling the feed flow to the unit and the underflow from the unit would be necessary. Instrumentation for control of dilution water and for measurement of sludge blanket level and underflow concentration, indication or measurement of overflow conditions, and the necessary computation capability for implementing this strategy would also be necessary.

Strategy #10 - Automate a flotation thickener to maintain a constant air-solids ratio while dosing polymer on the basis of feed-forward mass flow of solids and feedback of thickener overflow suspended solids with limits to assure overdosing is avoided--

Advantages: Improved solids capture and a more consistent floated cake can be achieved through automation of flotation thickener. This process rarely receives the operational attention required because of the disagreeable environment in the process area.

Requirements: A flotation thickener would have to be equipped with control of influent flow as well as the sensor instrumentation for measurement of the concentration of the feed sludge. Control of the recycle flow and control of recycle pressure, instrumentation for control of polymer addition and computation capability allowing implementation of this strategy would also be necessary. Measurement of the blanket thickness and measurement of overflow suspended solids as well as thickened sludge suspended solids would be advantageous.

Strategy #11 - Adjust the flocculator speed automatically to maintain a root mean square velocity gradient (G) in a restricted range--

Advantages: Improved performance of the flocculator and hence improved process performance could be expected.

Requirements: The capability of varying the speed or applied power of a mixer-flocculator as flow varies, and measuring the power transmitted to the liquid would be required.

Strategy #12 - Automate the complete cycle of a continuous filter press operation. The feed cycle will be terminated based on pressate volume which will initiate the cake removal cycle. Automation of the removal cycle should be demonstrated as well as readying the press for the next charge cycle--

Advantages: Field investigations have shown that the plate press is a very labor intensive operation. If complete automation could be demonstrated, significant savings could be achieved in fairly menial operational labor functions. In addition, complete automation could lead to programmed utilization of the plate press based on load which would lead to solids inventory control capability. Finally, ending of a press cycle based on volume of pressate is a more discrete and specific means of determining when the charge cycle has ended.

Requirements: A plate press equipped with automatic sludge removal and properly instrumented with a means of measuring pressate volume would be required. Measurement of influent sludge concentration and flow as well as pressate suspended solids concentration, control of polymer addition (if utilized) and execution capability to enable implementation of the advanced strategy would also be required.

Strategy #13 - Inventory Scheduling and Control in the Solids Process Train Including Thickening, Holding, Stabilization and Final Disposal--

Advantages: Field investigations indicate that planning and consistently executing control of solids inventory is one of the most difficult problems in wastewater treatment. Solids inventory control would enable optimized utilization of the various solids treatment processes and would lead to better management of a very difficult treatment area. Reduced costs for labor, chemicals and power can be expected from a unified strategy of inventory scheduling and controlled solids processing.

Requirements: A treatment plant equipped with a solids processing train would require centralized control to implement an inventory scheduling strategy. This would include the necessary instrumentation and control devices, as well as execution capability for programmed inventory scheduling.

Strategy #14 - Control of anaerobic digestion by:

a) Feeding in response to daily methane production per unit of volatile solids fed.
b) Daily measurement of alkalinity and volatile acids with addition of alkaline material to keep alkalinity at least 100 mg/l less than volatile acids.

c) Maintain temperature at setpoint $\pm$ 1°C. Recommended setpoint is in range of 33 to 37°C.

d) Feed schedule to insure reasonable mixing of new feed with digester contents. If digester is well mixed, feed can be done over a one to two-hour period with low solids cutoff on feed pumps and volume of feed not to exceed the detention time setpoint. Recommended detention time setpoint is 10 to 30 days.

e) Withdrawal of digested sludge based on average setpoint detention time. Sludge removal prior to feed cycle.

f) Monitor mixer gas flow or torque to insure mixing is taking place.

Advantages: Improve consistency of gas production in terms of volume as well as composition leading to more effective energy management. More consistent volatile destruction within the digester leading to more consistent dewaterability. A demonstration of a unified control strategy that can lead to consistent operation of anaerobic digesters.

Requirements: An anaerobic digester equipped with the necessary instrumentation to identify the volume and composition of the charged materials as well as the gas flow and composition and allowing for the addition of supplementary alkalinity. The necessary program and interface capability to allow execution of an automated strategy as well as recording of results in a consistent manner.

Strategy #15 - Optimize the operation of a continuous low pressure oxidation unit to demonstrate reduced steam utilization and consistent dewaterability without the use of chemicals--

Advantages: A better understanding of the low pressure oxidation unit process would be forthcoming as well as demonstration that pressure/temperature stabilization can be effectively executed yielding a reduction in dewatering chemical usage. As a result of the optimized control, improved energy management of the low pressure oxidation process would be forthcoming.

Requirements: A low pressure oxidation treatment train equipped with the necessary sensor instrumentation, centralized control and computation as well as data retention capability to implement and monitor the results on a continuous basis would be necessary.

Strategy #16 - Automate a vacuum filtration operation based on a real-time measurement of sludge of specific resistance. Control vacuum level, drum speed and submergence and chemical feed to produce a constant solids level in the cake--

Advantages: A more consistent sludge cake would lead to better energy management in the final disposal of the sludge through incineration. More consistent operation based on the predetermined strategy could lead to reduced chemical usage. More consistent strategy and demonstration of automation will lead to less operational intensity and the associated cost savings.

Requirements: An instrumented vacuum filter would be necessary allowing centralized control of feed as well as removal including the chemical additions. The mechanism for programming the automated strategy and recording the results on a continuous basis would also be necessary. Note: This demonstration is presently taking place at Minneapolis-St. Paul under an EPA Grant.

Strategy #17 - Automation of sludge incineration to:

a) Maintain a minimum excess oxygen content in the discharge gases by adjusting combustion air.
b) Control temperature profile by adjusting rabble arm drive speed.
c) Control hearth temperatures on a closed loop basis--

Advantages: Automation of this unit process will lead to substantial reductions in energy utilization either of fuel oil or natural gas. In addition, because of the volatile nature of the process, labor intensity is high and automation of the process could lead to substantial savings in operational costs.

Requirements: The necessary instrumentation for measuring the load and the process temperature and pressure measurements as well as centralizing the control capability of the entire process is necessary. The necessary computation capability and data retention in reporting capability is also necessary.

Strategy #18 - Recycled liquors handling and treatment. Two strategies should be demonstrated. One strategy involves storing the return liquors for return to the influent plant during times of low plant load. The second strategy involves treating the return liquors prior to return to the head end of the plant--

Advantages: The advantages to be expected are improved liquid process performance on a consistent basis. Field observations indicate that the hydraulic, solids and organic loads imposed by return liquors are often the cause of many process problems.

Requirements: For the two strategies discussed above, two equipment configurations are required for demonstration. A plant must have a large vessel capable of routing return liquors and the appropriate control devices and instrumentation to allow programmed release of the material on a control basis to the head end of the plant. The second strategy involves having a treatment plant specifically for return liquors handling and treatment where it can be demonstrated that the load (predominantly organics and solids) can be reduced significantly through treatment. A demonstration should include improvement of process performance due to the treatment of return liquors on a continuous basis. The Metro Plant of the Metropolitan Minneapolis-St. Paul Waste Control Commission or the Mill Creek Plant of Greater Cincinnati MSD could be used for this purpose.

Technology Transfer

Publications are needed on a continuing basis to transfer information to the industry regarding instrumentation and automation. It is recommended that the following technology transfer documents be published as soon as possible and that others be planned on a continuing basis.

Case History of Automation Benefits--

A frequently heard comment was that automation is more trouble than it is worth. Studies of automated plants should be conducted to document the control system operation in these projects to serve as models for other potential users and should be published as Technology Transfer manuals. Case studies of situations where automation resulted in improvement in plant performance and/or reduction in costs would document the actual benefits of automation at wastewater treatment plants.

Instrumentation Specifications-

Instrumentation and control very frequently received bad ratings. Poor reliability and excessive maintenance requirements were often given as reasons. Lack of training and a feeling of not knowing the purpose of instrumentation were other very prominent causes of lack of acceptance of instrumentation. To improve the reliability of instrumentation applied in future wastewater treatment facilities, sample instrument specifications should be published including information on application, installation, maintenance and the like.

Combustion Processes--

Many variations of final sludge disposal were observed. Frequently these included combustion, in one form or another. Incineration of sludge is not only a labor intensive process, but in most of the installations observed, an expensive, energy inefficient process. A Technology Transfer grant is needed to develop a "sludge combustion control manual" for the wastewater industry.

Hydraulics--

Plant operations personnel and superintendents often mentioned that hydraulics appear to cause many of their process problems. On numerous occasions, it was stated that the concept of the hydraulic design was to split flow evenly with weirs or splitter boxes throughout the plant. Repeatedly flow was found not to split equally, causing overloading on some clarifiers and washouts in aeration tanks. The reason why flow is not controlled is because design techniques used to cope with load variations from design conditions are not adequate. What is needed is a full theoretical and practical analysis of the dynamics of flow splitting to multiple unit processes, illustrating anticipated comparative results between weirs, splitter boxes, valves and meters.

Control and Centralization Review--

Observations of various installations illustrated that operations were conducted from centers of control distributed around the plant and that it was desired to centralize these functions. The usual reason centralization of information and control was not implemented was the cost involved for such a system. A preliminary economic analysis (see Section 5) indicates that with modern equipment, centralization should be cheaper than distributed control. A case history is needed to document the advantages of centralization and the techniques available to the designer for implementing centralization.

Automation and Process Control Training--

A training program should be developed to familiarize operators with automation systems and training them to function with this new technology. This will alleviate their fear of the unknown, and prevent the establishment of an adversary relationship between man and machine.

GLOSSARY

access time: 1. The time it takes a computer to locate data or an instruction word in its storage section and transfer it to its arithmetic unit where the required computations are performed. 2. The time it takes to transfer information which has been operated on from the arithmetic unit to the location in storage where the information is stored.

actuator: A mechanism for translating a signal into the corresponding movement or control. Typically the actuator moves a valve. See also final control element.

algorithm: A prescribed set of well-defined rules or processes for the solution of a problem in a finite number of steps, for example, a full statement of an arithmetic procedure for evaluating sin X to a stated precision.

alphanumeric: Pertaining to a character set that contains both letters and digits and usually, other characters such as punctuation marks.

amplifier: A device that enables an input signal to control power from a source independent of the signal and thus be capable of delivering an output that bears some relationship to, and is generally greater than, the input signal.

analog: Pertaining to representation of numerical quantities by means of continuously variable physical characteristics. Contrast with digital.

analog control: Implementation of automatic control loops with analog (pneumatic or electronic) equipment.

analog device: A mechanism which represents numbers by physical quantities, i.e. by lengths, as in a slide rule, or by voltage or currents as in a differential analyzer or a computer of the analog type.

analog signal: An analog signal is a continuously variable representation of a physical quantity, property, or condition such as pressure, flow, temperature, etc. The signal may be transmitted as pneumatic, mechanical or electrical energy.

analog-to-digital (A/D): The conversion of analog data to digital data.

analog-to-digital converter (AD): Any unit or device used to convert analog information to approximate corresponding digital information.

annunciator: A visual or audible signaling device and the associated circuits used for indication of alarm conditions.

ANSI: Abbreviation for American National Standards Institute, Inc. Formerly called USASI.

ASCII: Abbreviation for American Standard Code for Information Interchange. Also known as USASCII, Q.V.

asynchronous: Pertaining to a lack of time coincidence in a set of repeated events where this term is applied to a computer to indicate that the execution of one operation is dependent on a signal that the previous operation is completed.

asynchronous transmission: Transmission in which each information character is individually synchronized, usually by the use of start and stop elements.

automatic control system: A control system which operates without human intervention.

batch processing: 1. Pertaining to the technique of executing a set of programs such that each is completed before the next program of the set is started. 2. Loosely, the execution of programs serially.

bias: 1. The departure from a reference value of the average of a set of values; thus, a measure of the amount of unbalance of a set of measurements or conditions. 2. The average DC voltage or current maintained between a control electrode and the common electrode in a transistor.

binary coded decimal (BCD): Describing a decimal notation in which the individual decimal digits are represented by a group of binary bits, e.g., in the 8-4-2-1 coded decimal notation each decimal digit is represented by a group of four binary bits. The number twelve is represented as 0001 0010 for 1 and 2, respectively, whereas in binary notation it is represented as 1100.

bit: 1. An abbreviation of binary digit. 2. A single character in a binary number. 3. A single pulse in a group of pulses. 4. A unit of information capacity of a storage device. The capacity in bits is the logarithm to the base two of the number of possible states of the device. Related to storage capacity.

buffer: 1. An internal portion of a data processing system serving as intermediate storage between two storage or data handling systems with different access times or formats; usually to connect an input or output device with the main or internal high-speed storage. 2. An isolating component designed to eliminate the reaction of a driven circuit on the circuits driving it, e.g. a buffer amplifier.

byte: 1. A generic term to indicate a measurable portion of one or more contiguous binary digits, e.g., an 8-bit or 6-bit byte. 2. A group of binary digits usually operated upon as a unit.

capacity: The ability to store material or energy which acts as a buffer between the input and the output of a control loop element.

cascade control: The use of two conventional feedback controllers in series such that two loops are formed, one within the other. The output of the controller in the outer loop modifies the setpoint of the controller in the inner loop.

cathode ray tube (CRT): 1. An electronic vacuum tube containing a screen on which information may be stored for visible display by means of a multigrid modulated beam of electrons from the thermionic emitter, storage effected by means of charged or uncharged spots. 2. A storage tube. 3. An oscilloscope tube. 4. A picture tube. 5. A computer terminal using a cathode ray tube as a display device.

central processing unit (CPU): A unit of a computer that includes circuits controlling the interpretation and execution of instructions.

closed-loop: A signal path formed about a process by a feedback measurement signal (input to a controller) and the signal delivered to the final control element (controller output signal).

compile: To prepare a machine language program from a computer program written in another programming language by making use of the overall logic structure of the program, or generating more than one machine instruction for each symbolic statement, or both, as well as performing the function of an assembler.

compiler: A computer program more powerful than an assembler. In addition to its translating function which is generally the same process as that used in an assembler, it is able to replace certain items of input with series of instructions, usually called subroutines. Thus, where an assembler translates item for item, and produces as output the same number of instructions or constants which were put into it, a compiler will do more than this. The program which results from compiling is a translated and expanded version of the original.

computer: 1. A data processor that can perform substantial computation, including numerous arithmetic or logic operations, without intervention by a human operator during the run. 2. A device capable of solving problems by accepting data, performing described operations on the data, and supplying the results of these operations. Various types of computers are calculators, digital computers and analog computers.

control: 1. Frequently, one or more of the components in any mechanism responsible for interpreting and carrying out manually initiated directions. 2. In some application, a mathematic check. 3. Instructions which determine conditional jumps are often referred to as control instructions, and the time sequence of execution of instructions is called the flow of control.

control mode: A specific type of control action such as proportional, integral or derivative.

control sequence: The normal order of selection of instructions for execution. In some computers one of the addresses in each instruction specifies the control sequence. In most other computers, the sequence is consecutive except where a transfer occurs.

control system: A system in which deliberate guidance or manipulation is used to achieve a prescribed value of a variable.

control valve: A final controlling element through which a fluid passes, which adjusts the size of flow passage as directed by a signal from a controller to modify the rate of flow of the fluid.

controller: A device which operates automatically to regulate a controlled variable by comparing a measurement of the variable with a reference value representing the desired level of operation.

dead band: A specific range of values in which the incoming signal can be altered without also changing the outgoing response.

dead time: The interval of time between initiation of an input change or stimulus and the start of the resulting observable response.

derivative action: A controller mode which contributes an output proportional to the rate of change of the error.

differential gap control: Two-position control in which the controller output changes only after the controlled variable passes through a dead band range.

digital: Pertaining to representation of numerical quantities by discrete levels or digits conforming to a prescribed scale of notation.

direct acting controller: A controller in which the value of the output signal increases as the value of the input (measured variable) increases.

direct digital control (DDC): A control technique in which a digital computer can be used as the sole controller and its output can be connected directly to the final control element. Used to distinguish from analog control.

disturbance: A change in the operating condition of a process, most commonly a change in input or output loading.

error: The difference between the setpoint reference value and the value of the measured signal.

feedback: The signal in a closed-loop system representing the condition of the controlled variable.

feedback control: Control in which a measured variable is compared to its desired value to produce an actuating error signal which is acted upon in such a way as to reduce the magnitude of the error.

feedforward control: Control in which information concerning one or more conditions that can distrub the controlled variable is converted, outside of any feedback loop, into corrective action to minimize deviations of the controlled variable.

final control element: The device used to directly change the value of the manipulated variable.

instrumentation: A collection of instruments or their application for the purpose of observation, measurement or control.

integral action: A controller mode which contributes an output proportional to the integral of the error.

integral time: The time required after a step input is applied for the output of a proportional plus integral mode controller to change by an amount equal to the output due to proportional action alone.

loop gain: The ratio of the change in the return signal to the change in its corresponding error signal at a specified frequency. Note: the gain of the loop elements is frequently measured by opening the loop, with appropriate termination. The gain so measured is often called the open loop gain.

loop gain characteristics: Of a closed loop, the characteristic curve of the ratio of the change in the return signal to the change in the corresponding error signal for all real frequencies.

main frame: 1. The central processor of the computer system. It contains the main storage, arithmetic unit and special register groups. Synonymous with CPU and central processing unit. 2. All that portion of a computer exclusive of the input, output, peripheral and in some instances, storage units.

manipulated variable: The process variable that is changed by the controller to reduce or eliminate error.

manual reset: Elimination of offset by adjustment of the output bias level of a proportional controller.

multi-element (multi-variable) control system: A control system utilizing input signals derived from two or more process variables for the purpose of jointly affecting the action of the control system.

multi-processing: Pertaining to the simultaneous execution of two or more programs or sequences of instructions by a computer or computer network.

multi-programming: Pertaining to the concurrent execution of two or more programs by a single computer.

multi-tasking: The facility that allows the programmer to make use of the multi-programming capability of a system.

multiplexer (MUX): A device which samples input and/or output channels and interleaves signals in frequency or time.

offset: The steady-state deviation of the controlled variable from the setpoint caused by a change in load.

on/off control: A system of regulation in which the manipulated variable has only two possible values, on and off.

open-loop: A signal path without feedback.

optimization: A process whose object is to make one or more variables assume, in the best possible manner, the value best suited to the operation at hand, dependent on the values of certain other variables which may be either predetermined or sensed during the operation.

primary element: The device which converts a portion of the energy of the variable to be measured to a form suitable for amplification and retransmission by other devices.

priority: Level of importance of a program or device.

priority interrupt: The temporary suspension of a program currently being executed in order to execute a program of higher priority. Priority interrupt functions usually include distinguishing the highest priority interrupt active, remembering lower priority interrupts which are active, selectively enabling or disabling priority interrupts, executing a jump instruction to a specific memory location, and storing the program counter register in a specific location.

process: 1. The collective functions performed in and by industrial equipment, exclusive of computer and/or analog control and monitoring equipment. 2. A general term covering such items as assemble, compile, generate, interpret and compute.

process control: Descriptive of systems in which controls are used for automatic regulation of continuous operations or processes.

process I/O: Input and output operations directly associated with a process, as contrasted with I/O operations not associated with the process. For example, in a process control system, analog and digital inputs and outputs would be considered process I/O whereas inputs and outputs to bulk storage would not be process I/O.

proportional action: A controller mode which contributes an output proportional to the error.

proportional band: The range of the controlled variable that corresponds to the full range of the final control element.

range: The region between the limits within which a quantity is measured, received or transmitted, expressed by stating the lower and upper range values.

rate time: For a linearly changing input to a proportional plus derivative mode controller, it is the time interval by which derivative action advances the effect of proportional action.

ratio control: Control in which a secondary input to a process is regulated to maintain a preset ratio between the secondary input and an unregulated primary input.

repeats per minute: Controller integral mode adjustment units. The inverse of integral time.

reset windup: In a controller containing integral action, the saturation of the controller output at a high or low limit due to integration of a sustained deviation of the controlled variable from the setpoint.

reverse acting controller: A controller in which the value of the output signal decreases as the value of the input (measured variable) increases.

setpoint: A reference source which represents the desired value of the controlled variable.

signal: 1. The event or phenomenon that conveys data from one point to another. 2. A time dependent value attached to a physical phenomenon and conveying data.

simulation: The representation of certain features of the behavior of a physical or abstract system by the behavior of another system, for example, the representation of physical phenomena by means of operations performed by a computer or the representation of operations of a computer by those of another computer.

software: A set of programs, procedures, rules and possibly associated documentation concerned with the operation of a computer system, for example, compilers, library routines, manuals, circuit diagrams.

steady-state: A characteristic of a condition, such as value, rate, periodicity, or amplitude, exhibiting only negligible change over an arbitrary long period of time. It may describe a condition in which some characteristics are static, others dynamic.

supervisory control: A control technique in which a digital computer is used to determine and fix setpoints for conventional analog controllers. Used to distinguish from <u>direct digital control</u>.

synchronous transmission: Transmission in which the sending and receiving instruments are operating continuously at substantially the same frequency and are maintained by means of correction, in a desired phase relationship.

telemetering: The transmission of a measurement over long distances, usually by electromagnetic means.

throttling control: Control which directs a final control element to intermediate points within its operating range; distinguished from <u>on/off control</u>.

time constant: The time required for the output of a single capacity element to change 63.2 percent of the amount of total response when a step change is made in its input.

transducer: An element or device which receives information in the form of one physical quantity and converts it for transmission, usually in analog form. This is a general definition and applies to specific classes of devices such as primary element, signal transducer and transmitter.

transfer function: A mathematical, graphical or tabular statement of the influence which a system or element has on a signal or action compared at input and output terminals.

transmitter: A transducer which responds to a measured variable by means of a sensing element, and converts it to a standardized transmission signal which is a function only of the measured variable.

watchdog timer: An electronic internal timer which will generate a priority interrupt unless periodically recycled by a computer. It is used to detect program stall or hardware failure conditions.

word: A character string or a bit string considered as an entity.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/8-80-028	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE DESIGN HANDBOOK FOR AUTOMATION OF ACTIVATED SLUDGE WASTEWATER TREATMENT PLANTS		5. REPORT DATE August 1980 (Issuing Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Alan W. Manning David M. Dobs		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS EMA, Inc. St. Paul, Minnesota 55101		10. PROGRAM ELEMENT NO. 1BC821 11. CONTRACT/GRANT NO. 68-03-2573
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory--Cinn., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268		13. TYPE OF REPORT AND PERIOD COVERED Final Report 7/77-2/79 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Project Officer: Irwin J. Kugelman (513-684-7633)

16. ABSTRACT

This report is a systems engineering handbook for the automation of activated sludge wastewater treatment processes. Process control theory and application are discussed to acquaint the reader with terminology and fundamentals. Successful unit process control strategies currently in use are discussed. Alternative methods of control implementation are presented where other considerations such as reliability or flexibility are important. A method for preparing a cost effective analysis is detailed through the use of examples. Currently available instrumentation is reviewed to serve as a guide for the selection of instruments for specific applications. The design guide section reviews some of the aspects of control system design and includes examples of documentation required to convey the engineer's and user's requirements. The concluding section presents recommendations for further studies which will advance the application of automation in wastewater treatment.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Automation, Automatic Control, Automatic Control Equipment, Data Processing, Digital Computers, Instruments, Waste Treatment , Wastewater Process Control, Centralized Control	Activated Sludge Process Control Theory Treatment Plant Design	13B

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 426
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980-657-165/0141