

**Guides and
Recommended Procedures
For

Water Treatment
Forms

Annual Report**

ILLINOIS STATE WATER SURVEY

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FOREWORD

These Recommendations for water treatment of boilers and water systems have been prepared by the Illinois State Water Survey for Illinois State Institutions.

These have been adopted as Standard by the Mental Health Department. The standards as set forth shall be the minimum standards and shall be advisory to all Plant Operations of the Mental Health Department, State of Illinois.

Instructions to clerical and plant personnel on the various required report forms and procedures are given in the appendices. Included are calculations and other pertinent information needed in preparing the reports. These instructions supersede all previous directives and are applicable to all Plant Operations of all institutions within the Department of Mental Health.

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1. WATER

1.1 General

Water, by definition, is the liquid which descends from the clouds in the form of rain and which forms rivers, lakes, and seas. Pure water is represented by the chemical formula (H_2O), which signifies that it is composed of 2 parts hydrogen and 1 part oxygen. Water is important to human existence since the human body contains more than 2/3 water and since lack of water can cause death within a few days. Water is most essential to agriculture for the growing of food-stuffs for humans and for animals grown to produce meat for food. Water is also the life blood of industry as its availability and its desirable chemical and physical properties adapt it to many essential uses.

Illinois well water supplies are generally high in hardness and may be highly mineralized if from deep wells. Surface water supplies are lower in hardness but contain oxygen, which may increase corrosive tendencies, and suspended matter, which must be removed by clarification and filtration. These supplies are often treated to reduce hardness at the same time.

Of the 26 Mental Health Institutions, 39% receive their water supplies from wells, 50% from surface water supplies, and 11% from both surface and well sources. Also, 81% of the institutions obtain their water supply directly from the adjacent city supply, while 19% operate their own water supply systems of which 3/4 are from a well source and 1/4 from a surface water source.

1.2 Terminology

Before discussing water and its treatment, definitions of the terms normally employed are necessary. This is particularly important in describing the samples collected in the institutions and in the power plants.

1.2.1 Water terms. *Raw water* is water taken directly from a well or surface supply that has not been treated.

Cold distribution water is treated water, which is circulated in an institutional cold water system.

Hot distribution water is treated water, which is circulated in an institutional hot water system.

Feedwater is water being applied to the feedwater heater or to the boiler and consists of both make-up water and condensate.

Boiler water is water circulated in a boiler.

Condensate is condensed steam which has been cooled in the plant heating or process system and returned to the boiler system.

Heating system water is hot water circulated in a closed system for the purpose of transferring heat for heating a building or institution. HTW refers to high temperature water (above 350F) and MTW refers to medium temperature water (about 225-350F).

Cooling tower water is water circulated in an open system, such as the cooling tower and condenser of an air-conditioning system or a turbine condenser.

Chilled water is cold water, circulated in a closed system, that serves as a medium for transferring cold temperatures for air cooling in an air-conditioning system.

1.2.2 Treatment terms. Some of the more common terms and phrases that are associated with water treatment are as follows:

Scaling or scale formation refers to an adherent deposit formed usually from the precipitation of hardness salts in water. A chemical analysis of a sample of the deposit is usually of interest since the results of the analysis will likely indicate the cause of the scale formation and the possible solution for correcting the problem.

Corrosion is the process in which metal wastes away or deteriorates in the presence of corrosive agents, such as water, oxygen, acids, and salts. Corrosion may also cause the formation of deposits of metallic oxides, like rust.

Pitting corrosion is corrosion that occurs in localized areas, and is distinct from general corrosion. This is a particularly serious type of corrosion since penetration of the metal may occur causing premature failure.

Sludge or suspended matter is insoluble matter in the water, which is usually formed from precipitation of water hardness salts or corrosion products. Sludge is generally suspended in the water, although it may lodge in low velocity areas or "bake" onto heating surfaces.

Caustic embrittlement or inter crystalline cracking in boilers is caused from boiler water leakage into a stressed area, permitting concentration of boiler water solids of embrittling characteristics. As

a result, chemical attack of the boiler metal may occur in the form of intercrystalline cracking of the boiler metal.

1.3 Tests

In control of water treatment, certain tests or water analyses are necessary. The specific test procedures are described in Section 8. The significance, meaning, and purpose of the tests in reference to water treatment are discussed briefly below.

Water analyses are commonly reported in ppm or parts per million parts (17.1 ppm = 1 grain per U. S. gallon). A recent trend is to report results in milligrams per liter (mg/l), which is essentially the same as ppm.

Water hardness is the dissolved calcium and magnesium salt content of water and is expressed in terms of equivalent calcium carbonate (as CaCO_3). Water hardness may also be considered the soap consuming capacity of water.

pH is a measure of the intensity of alkalinity or acidity. When the pH is below 7.0, the solution is considered acidic; above 7.0, it is considered alkaline. Control of pH is necessary in various water systems to control scale and corrosive tendencies.

Alkalinity in a water is usually composed of carbonates, bicarbonates, and hydroxides and is determined by titration with an acid to a certain pH reference point. Alkalinity should be considered as a *quantity*, while pH should be considered as the *intensity* of alkalinity and acidity.

The *chloride* test is a measure of the chloride content, and when considered with the sulfate content may be interpreted as a rough indication of the salt or total *dissolved solids* in a water. Higher corrosion rates are usually experienced with waters having a higher salt or dissolved solids content. Dissolved solids can be estimated by determining the electrical conductivity of a water sample. The electrical *conductivity* is measured in micromhos (with correction for temperature); dissolved solids may then be estimated by multiplying this conductivity value by an appropriate factor of 0.5-0.9, depending on the water constituents.

The *sulfite* test serves as a measure of the sulfite content of boiler water, which provides information on the deaerating efficiency of the feedwater heater and on the need for sulfite addition to the boiler water. The presence of sulfite assures the absence of dissolved oxygen in the boiler water, which, if present, could cause serious corrosion.

The *phosphate* test serves as a measure of the phosphate applied as a supplemental softening agent to boiler water or for corrosion inhibition in cooling tower systems.

The *chromate* test serves as a measure of the chromate applied for inhibiting corrosion in cooling towers or in closed systems.

The *nitrite* test serves as a measure of the treatment (sodium nitrite - borax) concentration, which is employed for inhibiting corrosion in closed systems.

1.4 State Standard Specifications

1.4.1 Treatment chemicals. Treatment with a number of chemicals is required to improve water quality, for example, taste, odor, clarity, bacteriological quality, hardness, and dissolved solids. Also, chemical treatment may be necessary to prevent scale and corrosion when water is used in different processes, such as in laundering, in steam boilers, and in cooling towers. Accordingly, *State Standard Specifications for Boiler Compound and Water Treating Chemicals and Water Testing Reagents and Equipment* have been prepared, and all chemicals are identified as item numbers, i.e., Item 40 Hydrochloric (Muriatic) Acid. These specifications list the complete description of the chemicals so that the correct chemicals will be purchased and may be purchased on a competitive bidding basis.

These specifications are available from the State Purchasing Agent and are issued annually to prospective suppliers for obtaining bids on annual requirements. The State Water Survey suggests the quantity and the chemical items to be purchased, and cooperates with the State Purchasing Agent in checking the quality of the samples submitted. Most of the chemicals listed are individual chemicals, but a few are blends which contain several ingredients and are therefore more convenient to apply than the individual chemicals. However, a policy of purchasing minimum blended chemicals is generally followed since the blended chemicals are more expensive.

1.4.2 Testing chemicals. A complete description of water testing chemicals is listed in the latter part of *State Standard Specifications for Boiler Compound and Water Treating Chemicals and Water Testing Reagents and Equipment*. The testing chemicals are also listed as item numbers so that the correct chemicals may be easily ordered annually when these specifications are sent to prospective suppliers. The State Water Survey cooperates with the State Purchasing Agent in checking the quality of samples submitted.

2. WATER TREATMENT

2.1 Purpose of Treating Water

Water is treated to make its properties more suitable for its various usages. This may mean treating to reduce the potential for deposits or scale formation, or for corrosion and metal deterioration; to make it safe for drinking; to improve taste and odor; to improve its appearance; to reduce its foaming tendencies, etc. A water treated and distributed by a water treatment plant cannot be expected to be of the exact and proper quality for all uses. The varying properties required may be:

- (a) Minimal solids content
- (b) Scale and corrosion-free in high pressure boilers
- (c) Scale and corrosion-free in distribution water systems
- (d) Scale and corrosion-free in cooling tower systems
- (e) Suitable for beverage and cooling purposes
- (f) Suitable for laundering

It should therefore be expected that special treatment methods are necessary to treat water for many of its uses.

In the Mental Health Institutions, it has been estimated that water is used for at least 16 different purposes, many of which require special treatment to prevent serious maintenance problems. Institutional uses requiring special treatment may include domestic hot water, laundering, boiler make-up water, ice cubers, laboratory analytical work, dishwashers, cooling towers and refrigeration systems, and perhaps others.

Alkaline chemicals may be required in some cases to neutralize acidic properties of water, while in other cases, acidic chemicals may be required to neutralize water alkalinity and to remove carbon dioxide more effectively. Strong chemicals such as sulfuric acid, caustic soda, lime, chlorine gas, and chromates are often employed as they are most effective, inexpensive, and require minimum dosages. Devising special combinations of chemicals may be necessary for treatment to yield water of desired properties for many varied uses.

2.2 Safety in Handling Chemicals

Chemicals used in water treating and in related maintenance activities range from highly toxic to mildly irritating to the persons handling them. All water treating chemicals should be handled with care

according to prescribed instructions. The following safety precautions are to be observed:

2.2.1 Acids. Splashing of *acid* should be avoided, particularly onto clothes, skin, or eyes. If acid does contact these areas, immediate and continued flushing with water is recommended. Safety showers are provided so that thorough flushing can be done easily and immediately. In case acid is splashed into the eyes, a physician should be contacted immediately for examination of the patient.

Although diluted acid is much less severe in its reaction, care should still be taken in flushing areas contacted. Even 0.1% acid will cause irritation of the eyes.

The wearing of goggles, rubber gloves, and rubber apron is particularly recommended when handling concentrated or diluted acid of the strength normally used in water treating. Goggles especially should be worn when handling all concentrations of acids used in water treating.

Acids used in removal of scale or sludge, such as inhibited hydrochloric (muriatic) and sulfamic acids, should also be used with the same caution.

2.2.2 Caustic soda. Caustic soda is a strong alkali and in solid form or in the strong solutions used in water treating can cause severe burns or severe damage to the eyes. Just as when acid contacts the skin or the eyes, immediate and continued flushing with water is recommended. If caustic soda is splashed into the eyes, a physician should be contacted immediately for examination of the patient.

2.2.3 Chromates. Chromates, in dust or solid form, as in State Specification Items 34, 43, 61, 64, 70, can cause local irritation of mucous membranes and the skin. Immediate rinsing and flushing of the contacted area with water is recommended.

2.2.4 Other chemicals. Many of the other chemicals used in water treating, such as the amines, soda ash, hydrated or quick lime, sodium aluminate, hydrazine, and the biocides and algaecides, should be used with caution since contact with the skin may cause irritation. Immediate rinsing or flushing with water is recommended.

Upon request the State Water Survey will be glad to supply Chemical Safety Data Sheets describing the safe handling of acids, caustic soda, and chromates. These data sheets are prepared by the Manufacturing Chemists Association and are suitable for display on the water testing bulletin board.

2.3 Storage of Chemicals

Chemicals should be stored in a *dry* location at a *moderate temperature*. Many chemicals, particularly caustic soda and sodium acid sulfate, which are hygroscopic (water-loving), will become caked and difficult to remove from the container unless care is taken to close the container immediately after use. Although these particular chemicals provide the most serious caking problems, it is good practise to keep all powdered chemicals tightly covered when not in use.

Storage at high temperatures may also cause chemicals to cake. In addition, many chemicals cake on aging, so it is good practise to stack or store chemicals so that the older supply is used first. Transfer of over-stocked items to other institutions is suggested.

2.4 Proper Dissolving of Chemicals

Effective use of chemicals requires attention to proper dissolving procedures. Difficulties have been experienced in the plugging of check valves and of the pump delivery lines with undissolved chemicals

The recommended procedure for dissolving chemicals is to fill the chemical vat at least half full of water, turn on the electric mixer, and *slowly sift* the chemical into the vortex of the mixing action. After a few minutes the tank should be filled with water to the "full" level and mixing continued for 10-15 minutes. It should not be necessary to mix the solution again.

Improper location of the mixer shaft in the tank may cause difficulties in dissolving chemicals. The shaft should be located on one side of the tank and slanted into the water to encourage circulatory motion.

Attempting to prepare chemical solutions above 5% strength may cause dissolving problems. Solution strength can be calculated as follows:

$$\frac{\text{Total pounds of chemical dissolved in tank}}{\text{Gallons of solution in tank} \times .0833} = \% \text{ solution}$$

Example:

20 lb dissolved in 50 gal

$$\frac{20}{50 \times .0833} = 4.8\%$$

If the solution strength is above 5%, the number of pounds per tank should be reduced and perhaps two or more tankfuls applied during

the treatment period. An installation of a larger tank or pump may be required.

Generally warm or hot water is not required, although the emulsion type of State Specifications Item 25, Filming Amine, is best dissolved in warm condensate. The alcoholic solution type of Item 25 should be dissolved in *cold water*.

Excessive or continuous mixing of solutions containing sodium sulfite is *not recommended* since air may then be incorporated into the solution partially depleting the sulfite content. Also, sodium sulfite should be dissolved in cold water because hot water will cause depletion of the sulfite.

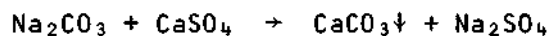
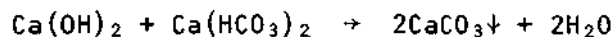
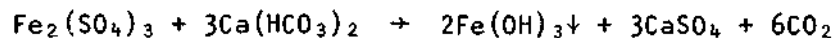
3. DISTRIBUTION WATER TREATMENT

Both softening and corrosion inhibition are usually involved in design of proper distribution water treatment. Proper design and control of softening to provide the correct hardness level and the desired scaling potential serves an important role in inhibiting corrosion as well as scale formation.

3.1 Softening Distribution Water

The more common water softening methods are ion exchange and lime-soda softening. Ion exchange (generally sodium zeolite softening) consists of passing the water through a tank of ion exchanger which exchanges the water hardness salts for sodium salts and produces a "soft" water. Lime-soda ash softening is conducted in open tanks, in which lime and soda ash react with the hardness salts to precipitate the hardness as sludge. After sedimentation and filtration, the effluent water is of softened water quality and lower in alkalinity content.

As an example, the Anna and Tinley Park State Hospitals must clarify and soften their own surface water and well supplies respectively. These water systems employ lime, soda ash, ferric sulfate (or alum), and coagulant aids for treatment of the water in open circulating tanks, where clarification, softening, and sedimentation occur, followed possibly by recarbonation and by filtration and chlorination. The following chemical equations illustrate the coagulation and softening processes:



When the lime-soda softening process is used, adjustment and control of the lime and soda ash is recommended to provide an effluent water having a total hardness of 75-100 ppm, with calcium and alkalinity (as CaCO_3) of about 60 ppm and recarbonation treatment to a pH of 8.5-9.0. This is expected to provide a thin eggshell type scale of calcium carbonate in the distribution system and to prevent undesirable magnesium hydroxide or silicate type scale in the hot water systems.

3.2 Water Softening Recommendations

The water treating plant is limited in its ability to produce a stable non-corrosive water for all uses and at all temperatures. While

it may be relatively simple to provide a water of the desired properties at cold water temperature, desired scale and corrosion inhibitive properties at the higher temperatures may be difficult to achieve.

3.2.1 Cold water. Softening *is not required* for drinking, flushing, sprinkling, and most other cold water uses. Such water should be iron-free and "lime stabilized" if necessary to prevent corrosion. A "lime stabilized" or "stable" water is a water which does not have the tendency to deposit or dissolve calcium carbonate hardness. The preparation of such a water is the objective of the water treatment design, which may require lime, caustic soda, carbon dioxide, etc. to produce a water containing the desired combination of calcium, alkalinity, and pH. Recirculation should not be necessary, but dead ends should be avoided because these accentuate red water troubles if the water has corrosive tendencies.

3.2.2 Hot water. One means of controlling the corrosive and scale-forming properties of circulating hot water is to limit the temperature of the hot water to a *maximum temperature of 140 F.*

Booster heaters in *dishwashers* provide heating of the water to 180 F which may be expected to cause scale and/or corrosion. Occasional cleaning with acid usually proves to be the most economical maintenance procedure since it is impractical to treat water for these small units separately, and since the water treatment for the bulk of the piping system should not be designed specifically for this small water use.

Partial softening (city softened or partial zeolite softening to provide about 60-120 ppm hardness content plus the possible addition of chemical for corrosion and scale control) is desirable for *all hot water systems*. Such water is satisfactory for dishwashing, bathing, and general hot water use.

Complete softening is usually necessary only for *cold and hot* water at the laundry. Such water should best be prepared and heated *at the laundry* with a minimum amount of distribution piping since stabilization is virtually impossible and corrosion of piping may be expected.

Additional small softening units may be required to fulfill limited demands at local points in the system; i.e., superintendent's quarters, laboratories, facilities for preparing distilled water, etc.

3.2.3 Ice-cubers. Water for ice cubes, like drinking water, does not require softening, but water for ice-cubing equipment may require scale inhibiting treatment. Installation of small pot type

feeders for applying Item 58B Slowly Soluble Polyphosphate to the make-up water feeding *ice-aubers* has been employed successfully in reducing scale formation in this equipment.

3.3 Corrosion Inhibition

The corrosive tendencies of hot water are generally much greater than those of cold water, and therefore require much more attention to proper treatment recommendations. In designing treatment for these systems, consideration must be given to the difference in materials in the systems as well as to the difference in corrosive tendencies of the hot waters.

3.3.1 Treatment of various waters. In case of mildly corrosive waters, blending of hard water with completely softened water to provide water of 60-90 ppm hardness content may be all that is necessary.

In case of highly corrosive waters (characterized by high dissolved solids content), blending plus *pH adjustment and silicate* addition is recommended. A pH increase to 7.6-8.3 is the general recommendation; however, specific pH values are usually recommended for each water. In some cases, caustic soda is required to provide the recommended pH, and in others the silicate treatment provides the necessary pH increase. In general, an 8 ppm silica increase is recommended by application of Item 32 Liquid Sodium Silicate. The properties of this chemical as related to its application are as follows:

	% Sodium oxide (Na ₂ O)	% Silicate (SiO ₂)	Weight of 1 quart (lb)	Pounds required per 10,000 gal to provide 8 ppm silica increase
Item 32, Sodium Si 1- icate, liquid	9.2	28.8	2.8	2-1/4

The pH increase makes the water slightly scale forming in respect to calcium carbonate or zinc carbonate solubility, and as a result, a thin protective scale layer is formed. The silicate treatment may also deposit a thin protective film of silicate on the piping and thus reduce the corrosion rate.

The water should be treated by accurate blending and chemical treating equipment at the power plant, where supervision of water treatment and temperature can best be monitored.

3.3.2 Required corrosion testing. Corrosion testers provided by the Illinois State Water Survey shall be installed to monitor the condition or corrosion of the cold and hot water distribution piping. The testing method used shall be the ASTM D2688 Method C (ISWS), as described in ASTM Standards, Part 23, Nov. 1971. Periodic removal of inserts and measurement of the corrosion rate will disclose the need for treatment adjustment.

3.3.3 Corrosion resistant materials. Although chemical treatment is often the best solution to a corrosion problem, change to more corrosion resistant materials may prove to be the most economical solution. This is particularly true where the corrosion problem is confined to a small section of a large water system.

In other words, it would be costly to provide special treatment of the water in a large system not requiring this treatment just to correct a corrosion problem in a small section.

Installation of the wrong piping or equipment material for the particular water supply may be the reason for corrosive failure. Reference to a State Water Survey Reprint 115, "*Materials Selection for Piping in Chemically Treated Water Systems*," by R. W. Lane and C. H. Neff, may be helpful in aiding selection of the right material for a particular water supply.

3.3.4 Hot water tank lining. Hot water generators and storage tanks should be coated periodically with a *cement type coating*, such as Pre-Krete*. Manholes should be provided for inspection as well as application of a coating.

3.4 Cathodic Protection for Elevated Tanks

Cathodic protection may prove to be the most economical solution to some corrosion problems. Cathodic protection is a process involving the use of an impressed current on an electrode to make the equipment metal the protected cathode. In elevated storage tanks, where low velocity conditions exist, chemical treatment methods for inhibiting corrosion are generally effective. By properly spacing electrodes and by applying adequate current, cathodic protection has proven effective in inhibiting corrosion below the water level. Painting is still necessary; however, less frequent painting and more complete corrosion

*A low soluble cement base tank lining material for application to tanks used for hot or cold water, as formulated by Pocono Fabricators, Inc., East Stroudsburg, Pennsylvania 18301, and applied by Andee Boiler and Welding Co., 7649 S. State St., Chicago, Illinois 60619, and others.

inhibition is attained because "holidays" in the paint film (which practically always exist) are prevented from corroding by application of cathodic protection.

In elevated tanks, the electrodes are destroyed during winter freezing conditions, but during this season of the year the temperature is so low that corrosion rates are minimal. This is true because corrosion, like most chemical reactions, proceeds at a much slower rate at lower temperatures. By installation of electrodes in the spring and by close supervision to provide the recommended amperage readings, cathodic protection has been found effective in inhibiting corrosion in elevated tanks.

Amperage readings should be reported weekly in the boiler control report submitted to the State Water Survey.

3.5 Gadgets

Gadgets (or electrical, magnetic, or "catalytic" devices) claiming immunity from scale and corrosion problems are continually appearing on the market. Sale of these devices is mainly directed toward the householder, but uninformed institutional personnel can also be duped.

One should not be deceived by the salesman who offers the "gadget" free-of-charge. Such free installations may be done simply as a sales means, so the salesman may tell his next prospect that *the State or University is using* the item. This implication of endorsement could then reflect adversely on the State if the "gadget" proves unsatisfactory. The claims for these devices, often supported by testimonials, state their effectiveness is due to catalysis, magnetism, electronics, radiation, and other hocus pocus, but present no quantitative data supported by scientific fact. The Inter-Society Corrosion Committee of the Electrochemical Society recommends "extreme caution in the application of devices for control of corrosion and scaling that are characterized by supposed operation without any apparent basis of sound scientific principles and for which no adequate engineering performance data are available."

4. BOILER FEEDWATER TREATMENT

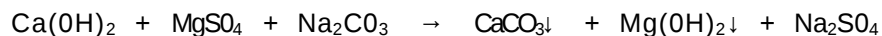
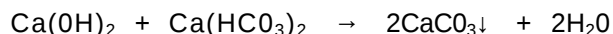
Twenty to thirty years ago or longer, internal boiler feedwater treatment chemicals (soda ash, starch, tannin, etc.) were applied directly to the boiler and the boiler itself was used as a softener. In these low heat release boilers, scale formation was reduced to a sufficient degree that relatively trouble-free operation resulted.

The modern boiler, with water walls and smaller diameter tubes, employs higher heat transfer rates and is not designed for handling feedwaters of high suspended solids content. Therefore, high quality make-up water of minimum hardness, suspended matter, and dissolved mineral content is required for efficient operation and minimum maintenance.

4.1 External Softening

In 1949, make-up water of high hardness content was employed in 18 of the 36 high pressure State Institutional power plants. Since that date external softening equipment has been installed in all plants. The two common methods of softening are lime-soda ash softening and ion exchange (usually sodium zeolite) softening. Sodium zeolite softening is generally employed since it is the simplest and the least expensive method of softening.

4.1.1 Lime-soda ash softening. In this method of softening, lime and soda ash react with bicarbonate and non-carbonate hardness causing precipitation of hardness and reduction in effluent hardness and alkalinity, as follows:

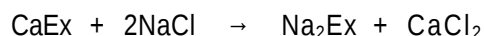


Cold lime and soda softening is often practised to reduce hardness and alkalinity, and to simultaneously clarify water, for an entire institution or city; this process usually is employed to reduce hardness only to the 60-120 ppm level. Hot lime and soda softening (210-250 F) is employed to reduce hardness to the 0-20 ppm level. It also reduces alkalinity as well as hardness, and causes dissolved solids reduction in some waters, thus providing high quality make-up for steam production with use of low cost chemicals. The main disadvantages of the method are the maintenance problems involved in keeping the equipment clean and in good operating condition, and the considerable effort required in control of the treatment.

4.1.2 Ion exchange softening. Sodium zeolite softening, also known as ion exchange, may be defined as a process employing an insoluble reactive material (resin or zeolite) capable of interchanging ions combined with the material, for ions in the water. Technically the ion exchanger now generally used is not zeolite (a synthetic or natural sodium alumino-silicate) but rather an organic ion exchange resin which retains its porous structure during the water treating process. These ion exchange resins are much more stable and have much higher capacities than the zeolites. Hardness (as calcium and magnesium bicarbonate) is exchanged with sodium ions in the ion exchanger, and calcium and magnesium ions are left in the exchanger as follows:



In regeneration, the calcium is replaced by sodium ions in the salt and calcium chloride is discharged to waste:



In order for this process to operate efficiently, suspended matter such as iron should be removed by backwashing from the bed before salt is applied for regeneration; then after regeneration, the calcium chloride is thoroughly rinsed from the zeolite. It is also most important that the ion exchanger not be operated beyond its capacity, since hard water may then be introduced into the boiler.

Since many waters, particularly surface waters, vary in hardness, frequent testing of the effluent is necessary to determine when regeneration is necessary. The modern method is to install monitoring equipment which continually analyzes the softener effluent for hardness content and either operates an alarm when the softener is exhausted or automatically converts the operation to another softener and initiates regeneration of the exhausted softener.

4.2 Condensate Corrosion Control

Since many Illinois waters are high in alkalinity, reduction in hardness by zeolite softening may not be the only external treatment required. The zeolite softening process removes hardness from the water but does not remove alkalinity.

Make-up water with high alkalinity in the form of bicarbonate and carbonate, which decompose to release carbon dioxide to the steam, results in the formation of carbonic acid in the condensate. This causes corrosion of steel return lines. This corrosion may be prevented by removal of carbon dioxide externally before it can enter the boiler, or by internal treatments with neutralizing or filming chemicals.

4.2.1 External removal of CO₂. To remove the carbon dioxide before entrance to the boiler, *direct acid treatment* followed by degasification is practised in many plants, as illustrated in the following chemical reaction:



Sodium bicarbonate + sulfuric acid → sodium sulfate +
water + carbon dioxide

After the acid addition, the water is degasified by blowing air through the water. The water is then treated with caustic soda to raise the pH and provide proper levels of alkalinity in the feedwater and boiler water to inhibit corrosion.

Another method that is employed to reduce alkalinity is the *hydrogen exchanger*, which operates the same as a zeolite softener except sulfuric acid rather than salt is employed as a regenerant. Materials used in hydrogen exchangers must be corrosion-resistant to sulfuric acid. Recently new organic resinous exchangers have become available which not only simultaneously soften and reduce alkalinity but also operate at more efficient sulfuric acid dosages, as illustrated by the following chemical reaction:



Calcium bicarbonate + hydrogen exchanger → water +
carbon dioxide + calcium exchanger

The water must be passed through a degasser to remove the carbon dioxide. This new hydrogen exchanger method is superior to the direct acid method since dissolved solids are reduced in the process. This type of softening-dealkalizing system is being installed at five State Institutions, Joliet Penitentiary, Stateville Penitentiary, Anna State Hospital, and Dixon State School and Governor's State University.

4.2.2 Internal neutralizers and inhibitors. To *neutralize* carbonic acid in the steam condensate, I tern 13 Cyclohexylamine and I tern 30 Morpholine are employed. Cyclohexylamine is more volatile and is therefore applied to treat lower pressure steam and to neutralize condensate at the extremities of a large steam distribution system. Morpholine, being less volatile, is employed to neutralize carbonic acid in condensate formed closer to the power plant. These chemicals are effective but their usage becomes uneconomical for steam with a high carbon dioxide content.

I tern 25 Filming Amine depends on its *filming action* rather than a neutralizing action to prevent the corrosion of steel by carbonic acid. Dosages of 1-4 ppm form a film on the metal which prevents

carbonic acid attack. (It is also reported to prevent corrosion by dissolved oxygen.) Boiler carryover is reported to cause disruption of the film and a reduction in corrosion inhibition.

4.2.3 Condensate corrosion testing. Corrosion testing in the condensate return lines to determine the need for condensate treatment or the need for treatment adjustment is advocated. NDHA type testers (ASTM D2688 Method A, described in ASTM Standards Part 23, Nov. 1971) are supplied regularly by the State Water Survey, and continuous monitoring is thus provided.

4.3 Dissolved Oxygen Removal in Feedwater Heating

Dissolved oxygen removal to prevent corrosion of the boiler and connecting systems is essential in avoiding serious metal deterioration in power plant systems. Efficient removal is usually obtained in the feedwater heater, and residual oxygen is reacted with post chemical feed of sodium sulfite to reduce dissolved oxygen content to minimal levels. Monitoring the feedwater heater operation is therefore an important phase of power plant operation.

In most of the modern types of deaerators, water falls in droplets through a rising current of steam under pressure and air is vented out the top of the heater. An increase in the daily sodium sulfite dosage may indicate that the feedwater heater is not deaerating the water properly. Perhaps insufficient steam is being applied to heat the feedwater, or the vent may be partially closed, or the feedwater may be by-passing the heater or the trays within the heater.

When the efficiency of *deaeration* is questioned, reference should be made to the following chart, which has been taken from the steam tables:

Feedwater heater steam gauge pressure (psig)	Feedwater heater outlet temperature (°F)
0	212
1	215.3
2	218.5
3	221.5
4	224.4
5	227.1
6	229.8
7	232.3
8	234.8
9	237.1
10	239.4

The pressure and temperature should correspond; for example, the temperature should be 227 F at 5 psig pressure. A temperature below 227 F, say 222 F at 5 psig steam pressure, would be evidence of air binding or insufficient venting. In other words, air, which is at a lower temperature than steam, is being retained in the heater. The vent should then be checked to see that proper venting is being obtained. If venting appears proper and good deaeration is still not being obtained, an inspection should be made of the heater internals to determine if the trays or sprays require cleaning or repair.

4.4 Internal or Post-Chemical Treatment

Proper sludge conditioning, softening, and corrosion control are important features of effective *internal or post-chemical treatment*. External softening should remove all but possibly 0.0-2 ppm hardness, but this amount of hardness can cause appreciable scale formation in the modern high heat release boiler. Item 1C, IE or IF Organic Blend containing lignosulfonate is applied at a 2-8 ppm dosage for the purpose of conditioning the sludge (precipitated hardness) so that it has less tendency to stick to the boiler metal. Usually a minimum of 250 ppm phenolphthalein (P) alkalinity is adequate to inhibit corrosion in the boiler and to complete the water softening reaction. Sufficient phosphate (PO_4) is applied to insure complete precipitation of hardness which is then dispersed as calcium phosphate sludge. Maintenance of a sulfite (SO_3) residual insures the absence of oxygen in the boiler and the inhibition of corrosion.

Inhibition of caustic embrittlement is attained by maintaining 40 ppm sodium nitrate (as NO_3) and 100 ppm of Item 1C, IE or IF Organic Blend in the boiler water. This is the general method employed; however, this is not necessary at some institutions because the feedwater may be high enough in sulfate content to meet the recommended ASME sulfate-alkalinity ratio.

Chelants, such as Item 68 (EDTA), the sodium salt of ethylenediamine tetraacetic acid and Item 93 (NTA), the trisodium salt of nitriloacetic acid are being employed to treat boiler water because of their desirable property of dissolving hardness. These treatments are expensive, particularly because of the high dosage of 10 parts required for each 1 part of hardness. Consequently, chelant treatment must be considered a supplemental treatment to be employed with minimal hardness make-up produced by efficient external softening. Chelants react with dissolved oxygen and are rendered ineffective, therefore they must be fed following the feedwater heater or following sulfite treatment. Chelants can also cause corrosion of boiler equipment if fed in excess and must therefore be fed through a stainless steel quill into the feedwater flow and the feed must be accurately controlled. Since there has not been a satisfactory plant control test method developed for chelants, phosphates are applied in conjunction with the chelants, then the knowledge of phosphate test results and dosage requirements are used effectively to monitor the chelant treatment.

Scaling in package high-heat release boilers is becoming an increasing problem, so attention has had to be directed to the continuous production of absolutely zero soft water make-up and feedwater. Also monitoring of return condensate for hardness and dissolved solids contamination is extremely important in controlling scale, corrosion and steam purity. With this close control and chelant treatment to react with residual hardness it is felt that the prevention of scale formation in package boilers may be kept under proper control.

4.5 Condensate Purity

Monitoring the condensate return for hardness or dissolved solids *contamination* is also important in maintaining boiler cleanliness or freedom from scale formation. The most common source of hardness contamination is from leaking steam coils in a domestic hot water heater. Evidence of hardness in the condensate return, higher than normal boiler phosphate requirements, and lower than normal daily make-up gallonage are clues that hard water contamination is occurring and should be eliminated as soon as possible.

There have also been cases of detergent solutions from dishwashers contaminating condensate returns and causing boiler foaming. Such fouling can be detected by measuring the electrical conductivity of the condensate. Contaminated condensate will have a higher conductivity reading than pure condensate.

4.6 Blowdown Control

The success of boiler water treatment is very dependent on accurate and adequate *blowdown control*. The accurate testing of dissolved solids by electrical conductivity measurement has been extremely helpful in attaining this objective.

The tolerance of the modern high heat release boiler for suspended solids is low; therefore close attention to suspended solids content is necessary. Excellent corrosion inhibition in steam condensate lines is necessary so that a minimum of corrosion products (suspended solids) are brought back to the boiler. Accumulation of suspended solids may occur in water walls, and overheating will cause metal failure. Since blowdown of water walls is not too effective, the best practise is to limit the amount of suspended matter (hardness sludge or corrosion products) entering the boiler and to periodically remove the boiler from service for examination and more frequent washout.

4.7 Steam Purity

To continuously attain a proper high level of *steam purity*, the following factors must be watched:

- (a) Control of the boiler P alkalinity, suspended solids, and dissolved solids as directed in the plant control charts.

- (b) Control of oil within the specified limits (less than 7 ppm in the boiler water).
- (c) Control of operating boiler variables to avoid extremes and rapid changes in load and water level.
- (d) Control of design, installation, and maintenance of boiler internals and steam purifying equipment.
- (e) Control of external softener operation to maintain hardness contamination at a minimum level.
- (f) Control of condensate contamination by monitoring condensate and preventing the addition of foaming contaminants to the system.

Carryover cannot be tolerated in the modern power plant because solids in the steam will cause erosion of turbine blades and corrosion of steam-using equipment, which may cause plant shut-downs or serious maintenance problems. Itern 1C Organic Blend applied in the 2-8 ppm dosage range generally provides adequate anti-foam and conditioning of suspended matter to prevent foaming and carryover of boiler water.

Steam Purity Analyzers are installed in all the State plants in which turbine generators operate. These instruments are helpful in monitoring plant operating variables, such as water level, boiler load, water treatment, and blowdown, which may affect steam purity. An analyzer is available at the State Water Survey for use in those plants not having one. The Steam Purity Analyzer measures the dissolved solids in condensed steam by electrical conductivity. Interference due to amines in the steam is eliminated in this test method.

Corrosion-erosion of turbine valves, nozzle rings, and turbine casing may result from high velocity steam containing carbon dioxide and moisture. In plants applying saturated steam to turbines, installation of stainless steel nozzle and diversion rings and installation of stainless steel stripping on the inside of the casing have been necessary. Application of higher amine treatments has also been proven experimentally to reduce this corrosion. Conversion to superheated steam has been arranged in the newer plants and has prevented this type of corrosion.

4.8 Role of Boiler Operation

4.8.1 Operation scheduling. Just as maintaining proper boiler water levels and scheduling boiler loads to prevent extreme fluctuations in steam demand are important in providing high steam purity, boiler cleanliness can be improved by proper boiler operation.

If sludge accumulations are noted in particular areas of the boiler during inspection, increased blowdown should be applied at these locations. If the boiler is inadequately designed to tolerate minimal sludge concentrations derived from minimal hardness from the external softening system, or hardness or rust contamination from the return system, more frequent boiler wash-outs and shorter continuous runs must be scheduled.

4.8.2 Removal of boiler from operation. The proper procedure for the removal of a boiler from operation is of primary importance. While the boiler is in operation, it has the benefit of certain treatment and control procedures established to prevent the formation of scale on the boiler heating surfaces. However, if the boiler is removed from operation improperly, much of the good work of proper treatment and control can be undone.

During operation the boiler water contains suspended solids (or mud) which are held in suspension by circulation of the water and by the action of the treatment. Unless the boiler is properly drained, these suspended solids may settle out on the boiler surfaces and air dry as adherent deposits, sometimes requiring turbinizing of the boiler tubes. In addition, unless the deposits are examined carefully, it may be assumed incorrectly that they are scale formed during operation. This assumption could lead to unwarranted changes in the water treatment.

Therefore, in order to properly judge the effectiveness of the water treatment as well as to eliminate unnecessary boiler cleaning, great care must be taken in removal of the boiler from operation. The following procedure is recommended:

- (a) A half hour before shutting down a boiler, alternate bottom and surface blowdown, applying 5-second blows over 6 evenly spaced intervals.
- (b) After firing is stopped, continue blowdown for longer periods at least every hour, maintaining the normal operating water level and replacing much of the boiler water with hot feedwater.
- (c) Continue this procedure until the boiler is cool enough to open, then drain and flush drums and wash down tubes with a heavy stream of water from high pressure hoses. Residual sludge will thus be kept wet, will not be allowed to dry on the hot tube surfaces, and will be flushed effectively from the boiler.

If it is not convenient to wash out the boiler immediately on draining, it should be refilled with water because there may still be sufficient heat left in the boiler setting to cause baking of residual

sludge on the tubes. However, the boiler should never be left filled with water for more than a few days without taking proper measures to prevent corrosion and pitting.

4.9 Prevention of Corrosion in Idle Boilers

Serious *pitting corrosion* of boilers (costing \$10,000 or more for repairs) has occurred during *out-of-service* periods. This is a more serious problem now than ever before because boilers are cleaner, more free of scale and therefore have more exposed metal than in past years. A boiler held half full of water for one to two weeks or more before operation or following operation may become seriously pitted or corroded at the water line.

4.9.1 Storage method selection. A boiler may be stored wet or dry. If recommended procedures are followed, results should be equally effective. The decision as to the method to use should depend on which method can be best adapted to the particular plant operation.

Dry storage is the simplest and easiest procedure and therefore is generally preferred if practical. However, dry storage is effective only if boiler internals are kept completely dry. In case limited leakage of stop and check valves is experienced, wet storage methods may be a solution; however, if overflowing is then experienced, this method of storage will also be ineffective and valve repair or replacement is the only solution.

There are two methods of *wet storage* depending on whether the boiler is stored without cleaning (Method A) or is stored after cleaning or when empty (Method B).

Wet storage *is required* for boilers with superheaters since superheater tubing cannot be drained dry. In a memorandum dated April 22, 1968, recommendations were given to fill superheater tubing completely full and to provide for complete removal of treated water before start-up. Since these procedures were recognized to be difficult operations, incorporation of amine treatment (Item 13 Cyclohexylamine or Item 25 Filming Amine) has been recommended to provide distillation of these alkaline or film-forming volatile chemicals into the superheater tubing to provide the necessary corrosion inhibition.

Wet storage may be preferred in electric generating plants in which rapid start-up is required in case of an emergency. Boilers stored wet require only draining to 1/4 level, then filling to operating level before starting operation. Boilers stored dry require closing of manholes and valves and filling before starting operation.

4.9.2 Dry method. The following procedures should be applied in storing boilers internally by the dry method.

- (1) Drain boiler.
- (2) Dry thoroughly, including all parts where pockets of water might be trapped. A light wood fire or circulation of air may be necessary to obtain complete dryness.
- (3) Open all manholes, blowdown valves, etc., which will allow free circulation of air through the boiler drum and tubes.
- (4) Eliminate all water dripping into drum or tubes.
- (5) Swab out all tubes which do not drain dry. Some boilers have connecting tubes which curve downward between the top two or three drums. These tubes particularly require attention in removal of all moisture.
- (6) Check boilers weekly to see that they are completely dry.

4.9.3 Wet Method A. The following procedures should be applied for wet storage when the boiler is not to be cleaned internally.

- (1) Blowdown boiler thoroughly.
- (2) At least 15 minutes before boiler comes off the line, add the following chemicals:
 - (a) 6 lb of sodium sulfite per 1000 gal of boiler capacity (average boiler capacity is 4000-6000 gal).
 - (b) 1 lb of organic blend per 1000 gal of boiler capacity.
 - (c) Sufficient caustic soda (about 8 lb per 1000 gal of boiler capacity) to produce a P alkalinity reading of 1000-1700 ppm.
 - (d) Only for boiler with superheater: 1-1/2 lb of Itern 13 Cyclohexylamine or 1/2 lb of Itern 25 Filming Amine per 1000 gal of boiler capacity.
- (3) Watch boiler carefully for foaming tendencies and take it off the line in case foaming develops.

- (4) After taking boiler off the line, fill boiler to top, overflowing vents or safety valves to make sure complete filling is accomplished. It is essential that boiler be filled completely and that no air pockets be present. Close all valves except those on the top of the boiler. Place a cap on the high water whistle when water flows out.
- (5) When boiler is completely full, close all valves in order to seal boiler from possible entrance of air.
- (6) If water level falls during the storage period, add more water and chemicals (if need is indicated by test) to keep boiler completely filled. A small drum filled with water and connected to the steam take-off tap, vent, or safety valve connection may be installed to provide make-up water in case of leakage and to operate as an indicator of the boiler water level.
- (7) Test boiler water for proper sodium sulfite and P alkalinity content each 30 days.
 - (a) Recommended minimum sulfite residual (SO₃) is 50 ppm.
 - (b) Recommended minimum P alkalinity is 1000 ppm.
 - (c) Add more chemical as needed to meet the above minimum recommendations.
- (8) Before starting operation, drain boiler contents to 1/4 drum level, remove cap from high water whistle, and then fill the boiler with feedwater to operating level.

4.9.4 Wet Method B. The following procedures should be applied for wet storage after boiler has been cleaned or if boiler is empty.

- (1) Prepare a solution of the chemicals (a-c and d with superheaters) described under step (2) in section 4.9.3.
- (2) Feed the above solution continuously with the boiler feedwater being applied to the boiler. *It is very important that a uniform concentration of this solution be provided throughout the boiler.*
- (3) For *boilers with superheaters*, start a light wood fire to provide sufficient steam to volatilize the amine over into the superheater. Steam should issue from

the superheater vent. After the fire has subsided, *it is essential that the boiler be filled completely and that no air pockets be present.*

- (4) During filling, close all valves except those on the top of the boiler. Place a cap on the high water whistle when water flows out.
- (5) When boiler is completely full, close all valves in order to seal boiler from possible entrance of air [see step (3) above for boilers with superheaters].
- (6) During the storage period, keep the boiler completely full by adding more water and chemicals (if indicated by tests) as described in steps (6) and (7) in section 4.9.3. A light wood fire will likely be required to provide circulation and uniform distribution of *additional chemicals*. Test the boiler water at different locations in the boiler to determine the uniformity of chemical treatment and the need for further circulation within the boiler.
- (7) Before starting operation, drain boiler contents to 1/4 drum level, remove cap from high water whistle, and then fill the boiler with feedwater to operating level.

4.9.5 Supplemental storage recommendations. In addition to proper internal methods of storage, cleaning of all soot, fly ash, and slag from *fire-side surfaces* is necessary. Idle boilers have a tendency to sweat (particularly if wet storage methods are applied) under adverse atmospheric conditions. Combination of moisture with such deposits will form acids, and rapid corrosion can be expected.

Also, during a periodic boiler cleaning, *painting* of Apexior #1* on boiler drum surfaces and on tube surfaces (within 1 foot or more of the drum) has been beneficial. Although any paint is only as good as the completeness of the coating, this particular paint has been helpful in reducing pitting and corrosion, and is recommended as a supplementary aid in reducing corrosion, particularly in cases of continued serious corrosion problems.

4.9.6 Out-of-service boiler records. It is requested that operating engineers keep an accurate weekly record on the status of the individual boiler, to be recorded in the lower righthand corner of the present weekly report. The weekly inspection of each out-of-service

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boiler should include the following:

Dry storage - Note whether the boiler is completely dry in drums and tubes, particularly that tubes which do not drain dry have been swabbed out. If boiler is not dry, the wet condition should be corrected and arrangements made to prevent further occurrences.

wet storage - Note that boiler is *completely full*. If water loss has occurred, find reason and correct. *Test the P alkalinity and sulfite monthly and apply further treatment if necessary.*

An example of the report submitted would be:

<u>Boilers</u>	<u>P</u>	<u>SO₃</u>
#1 , 2, 6 - in service		
#3 - wet storage	1200	70
	1100	100
	1100	90
#4 - dry storage		
#5 - dry storage		

The benefit of submitting these records will be to call everyone's attention to the status of each individual boiler so that the *out-of-service boiler will not be allowed to stand half-full of water for periods longer than a few days.*

4.10 Effect of Make-up, Blowdown, and Boiler Efficiency on Treatment

The make-up water, blowdown, and boiler efficiency percentages are of interest in power plant operation. For example, a water treatment program for a boiler system employing a high make-up percentage must operate more efficiently (produce lower hardness make-up) than one employing feedwater diluted with a large percentage of condensate. Also for comparing treatment efficiencies, the percent blowdown calculated for the different treatments is important in deciding the most efficient treatment. Further, the feedwater treatment is an important factor in determining the degree of total boiler operating efficiency, and the boiler efficiency calculation may in turn yield a comparison in effectiveness of different methods of treatment. Operation at minimum make-up and blowdown and a high boiler efficiency are advocated for overall high power plant efficiency.

4.10.1 Calculating percent make-up. The percentage of make-up water in the total feedwater entering the boiler is of interest because it is a measure of the losses in the system and the consequent

loading and efficiency of the make-up water system. It may be calculated from metered make-up water and steam flow as follows:

$$\frac{\text{gal make-up per day} \times 833}{\text{lb steam produced per day}} = \% \text{ make-up}$$

Example:

$$\frac{39,600 \text{ gal} \times 833}{1,000,000 \text{ lb steam}} = 33\% \text{ make-up}$$

Or, the percent make-up may be determined by analyzing the feed-water for chloride or M alkalinity (if no alkaline chemicals are applied to feedwater) and calculating as follows:

$$\frac{\text{Cl}^- \text{ or M of feedwater} \times 100}{\text{Cl}^- \text{ or M of make-up}} = \% \text{ make-up}$$

Example: Cl^- (feedwater) = 4; Cl^- (make-up) = 12

$$\frac{4 \times 100}{12} = 33\% \text{ make-up}$$

4.10.2 Calculating percent blowdown. The percentage of blowdown is important because it is a measure of the necessary losses from the system to prevent excessive solids or deposit accumulations. Different methods of water treatment require different rates of blowdown, so a comparison of blowdown rates is necessary to evaluate treatments. After analyzing the feedwater and boiler water for chloride contents, the percentage of blowdown is calculated as follows:

$$\frac{\text{Cl}^- \text{ of feedwater} \times 100}{\text{Cl}^- \text{ of boiler water}} = \% \text{ blowdown}$$

Example: Cl^- (feedwater) = 4; Cl^- (boiler water) = 200

$$\frac{4 \times 100}{200} = 2\% \text{ blowdown}$$

4.10.3 Boiler efficiency. The boiler efficiency provides an indication of the operating efficiency of the boiler in respect to heat input and output. The boiler efficiency is calculated as follows:

$$\text{Actual evaporation} = \frac{\text{lb of steam generated}}{\text{fuel burned}^*}$$

$$\text{Factor of evaporation} = \frac{h_g - (t-32)}{970.3}$$

in which

h_g = enthalpy of steam at absolute steam pressure
(obtained from steam tables)

t = feedwater heater temperature

Equivalent evaporation = factor of evap x actual evap

$$\text{Boiler efficiency} = \frac{970.3 \times \text{equivalent evaporation} \times 100}{\text{BTU of fuel per unit}^*}$$

* Unit of fuel burned is lb of coal, gal of oil, or cu ft of gas

Example:

$$\text{Boiler efficiency} = \frac{\text{heat output}}{\text{heat input}}$$

The total BTU output = total steam generated multiplied by the following quantity:

$[(h_g \text{ from Steam Table 2, column } h_g \text{ at a pressure equal to operating gauge pressure} + 15) - (\text{feedwater temperature} - 32)]$

Example:

Steam pressure = 245 psig + 15 = 260 psia = 1201.5 (from Steam Table 2)

Feedwater temperature = 235 F - 32 = 203

Steam Generated = 750,000 lb

Output = 750,000 x (1201.5 - 203)
= 750,000 x 998.5
= 748,875,000 BTU's
= 748.875 x 10⁶ BTU's

The total BTU input = total units of fuel burned multiplied by the BTU content per unit.

Assume a total BTU input of 1,000,000,000 or 1,000 x 10⁶ BTU from burning 100,000 lbs coal at 10,000 BTU/lb or 10,000 therms of gas.

Therefore:

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{748.875 \times 10^6}{1,000 \times 10^6} \times 100 = 74.9\% \text{ Efficiency}$$

5. CLOSED HOT AND CHILLED WATER SYSTEMS AND TREATMENT

There is now a definite trend to employ hot water rather than steam for heating. The advantages are that more heat (BTU's) can be carried by hot water than by steam in the same sized pipe and no steam traps are required.

Years ago, the household hot water heating system consisted of piping and old style radiators with large sized passageways. Materials were steel, cast iron, and brass valves -- equipment in which water losses were not usually experienced. Present day hot water systems include thousands of feet of small diameter piping, hundreds of small control valves and temperature sensing devices, and dozens of pumps having mechanical seals; further, among these, many dissimilar metals are involved. Therefore more potential sources of water losses are present, and if make-up water usage is excessive, corrosion and scale may become a serious matter.

5.1 Kinds of Systems

There are various kinds of hot water heating systems, some fired and some unfired. These systems are all considered closed systems, but the more common are the unfired systems, some of which are heated by steam from steam boilers by means of heat exchangers, and others of which are heated by heat exchangers and separate HTW and MTW hot water generators. There are also closed chilled water systems for air conditioning, which are chilled by refrigerating systems having electrical or absorption (steam or hot water) power sources to provide the necessary cooling. Much of the following discussion concerns the unfired systems and particularly the hot water systems because there are so many of these, of all sizes, and because maintenance problems are generally more serious and require attention.

The HTW systems (pressurized hot water of above 350 F in temperature) are usually large systems supplying heat to an entire institution. Since the heating system is centralized in the power plant, proper and complete water treating facilities and control provide the necessary preventive maintenance. MTW systems (pressurized hot water of 225-350 F in temperature) are similar to the HTW systems but are operated at a lower temperature. Both systems, usually pressurized by nitrogen gas, are fired systems, which include hot water generators of considerably different internal design from steam boilers. These generators have no drums and are composed of few but long continuous water tube circuits, which completely cover the internal heating surfaces of the generator in order to derive efficient heat transfer and high boiler efficiency.

5.2 Treatment and Testing of Closed Systems

Unfired closed systems should be expected to be relatively free of scale and corrosion difficulties largely because little if any make-up water should be required for operation. However, make-up requirements are generally higher than desired, usually because of mechanical seal and split-case pump seal leakage, or because of poor design or inadequate sizing of expansion tank systems. If *continued application* of hard water is required, serious *scale* difficulties may be expected in these systems. If a corrosive water (one containing appreciable dissolved salts and oxygen) is applied continuously, *corrosion* of the system also may be expected. After such scale or corrosion difficulties have developed, the removal of the deposits is usually difficult and expensive.

Closed system equipment may be protected from corrosion by applying a corrosion inhibitor, such as Item 70 Corrosion Inhibitor Blend (chromate-soda ash) or Item 62 Hot Water Boiler Blend (nitrite-borax). In initial filling of these systems, 4 1/2 lbs of Item 70/1000 gals volume is required to provide 250 ppm Chromate (as CrO_4) and 11 1/4 lbs of Item 62/1000 gals volume is required to provide 600 ppm Nitrite (as NO_2) in the systems. By periodic testing of the inhibitor concentration, the building engineer may calculate the water loss, correct the leakage problem, and estimate the additional chemicals required. The water loss may be estimated by calculating the percent of initial chemical concentration and then referring to the chart below. The leakage is usually too small to be detected by water meters, unless water addition is made by solenoid valve control.

<u>% of initial concentration</u>	<u>Water loss (% of system volume)</u>
100	0
95	6
90	12
85	17
80	22
75	30
70	37
65	46
60	55
55	64
50	72
45	83
40	94
35	108
30	122
25	143
20	163
15	190
10	230
5	300

Example:

If the chromate tested 300 ppm at the start of one month and tested only 200 ppm at the end of the month, the percent of initial concentration is calculated as follows:

$$\frac{200}{300} \times 100 = 67\% \text{ of initial concentration}$$

Reference to the chart then shows:

67% = about 40% loss of system volume per month

Since a closed system is defined as one that *loses less than 5% of its volume annually.*, (0.42%/month, 0.014%/day), this particular system is operating with too much loss, approximately 100 times too much. If this amount of loss had occurred in one year instead of one month, the percent loss would have been 3.3%, a satisfactory loss for a closed system.

To provide proper corrosion inhibition and control, monthly tests for chromate (minimum 250 ppm CrO_4 or nitrite (minimum 600 ppm NO_2) are recommended.

In all new installations, the State Water Survey has recommended the installation of a *make-up water system*, including an air gap, which prevents contamination of the potable water system by the chemicals used for treatment in the closed water system. If a Public Health approved make-up system (including an air gap) were not installed, contamination of the potable water system could occur whenever the closed system pressure exceeded the make-up water or potable water system pressure.

5.2.1 Source of leakage. In installations having the recommended make-up water systems isolated from the potable water system, periodic testing (at least monthly) of the chromate content of the closed system water provides a check on the water loss or make-up water usage. If continued high chromate (Item 70) consumption is required (substantial monthly additions rather than annual additions) to maintain the recommended chromate test of 250+ ppm chromate (as CrO_4 , it may be concluded that *serious losses are occurring* and that the *causes of losses or leakage should be immediately corrected.*

The losses are likely to be located at:

- (a) Expansion tanks
- (b) Multiple make-up water connections

- (c) Make-up station having faulty valving or design
- (d) Air eliminators
- (e) Connections with other piping systems
- (f) Pump seals

In the case of (e) above, passage of make-up water to consumptive usage in a domestic hot water system or in a cooling tower can cause introduction of hard water and dissolved oxygen continuously. This may result in serious scale formation or corrosion. A heat exchanger for heating domestic hot water may develop a leak and cause this condition. If the domestic hot water pressure is higher than the closed system pressure, flooding of the closed system may occur resulting in similar bad effects.

5.2.2 Cleaning closed systems. The cleaning of new closed systems is of considerable importance because the original water fill may be recirculated in these systems for months and is not replaced. However, in once through and steam systems, the introduction of new make-up water, and in the case of steam systems, trapping and blowdown (or replacement) occur which provides continuous rinsing and removal of suspended matter.

Cleaning with caustic soda and trisodium phosphate and thorough flushing have been recommended in the specifications; however, the design of these systems makes thorough, efficient cleaning and rinsing difficult. Black magnetic iron oxide often scales off and may score mechanical seals. The installation of traps containing magnets is being considered as a solution to this problem.

5.3 HTW and MTW System Treatment

5.3.1 HTW system. Zeolite softened make-up water is employed in the HTW or high temperature (above 350 F) hot water systems. This water is then treated with caustic soda to provide a pH of 9.5-10.5 and with sodium sulfite to provide a sulfite test of 50-100 ppm to control corrosive tendencies. It would be better if make-up water requirements for these systems conformed to the 0.014%/day generally specified for closed systems; however, 0.1-0.5% (of the total system volume) make-up per day is the more normal requirement. Daily tests are necessary to provide the exact water treatment control required.

Accurate corrosion testing under measured flow conditions is provided by installing weighed pipe nipples in a metered by-pass. The State Water Survey provides these specimens in order that continuous monitoring of the effectiveness of the treatment may be obtained.

5.3.2 MTW system. For medium temperature (225-350 F) hot water systems, two methods of treatment have been employed; namely, the caustic soda-sulfite treatment of zeolite-softened water and the nitrite-borax treatment of hard or preferably zeolite-softened water described in 5.2. The first method has been most successful because the second is a high solids type of treatment causing excessive solids deposition at leaks.

5.3.3 HTW-MTW steam generators. Steam generators heated by HTW and MTW systems often are used to produce process steam, which is not returned to the steam generator system. The steam may be used for humidification, for cooking, or for other purposes. Careful attention to water treatment for these generators is necessary because the make-up water percentage is often high, with the result that the boiler water composition becomes high in hardness, suspended matter, and dissolved solids. Automatic blowdown equipment may be required to provide accurate blowdown control.

Treatment requirements usually consist of alkali (caustic soda, soda ash) and sodium sulfite, to provide the necessary softening and oxygen-free conditions required for low pressure boilers.

5.4 Chilled System Treatment

Scale or corrosive difficulties may also be experienced in chilled water systems, but likely to a lesser degree. Chilled water systems are treated with the same dosage of Item 70 chromate and a somewhat lower dosage (8 1/2 lbs/1000 gals volume) Item 62 nitrite-borax to maintain 450 ppm nitrite (as NO₂) to provide proper corrosion inhibition in these closed circulatory water systems. In case the make-up supply is hard water (>150 ppm hardness) or if appreciable quantities are required, zeolite-softening is recommended.

6. COOLING TOWERS AND TREATMENT

Cooling towers or evaporative condensers are water-saving devices for providing cooled water or cooled refrigerants for air-conditioning or refrigeration systems. Instead of providing costly once-through cooling, water is cooled by evaporation through circulation in an aeration system (or cooling tower) and returned to the heat exchanger to repeat the cooling operation. In passage through a cooling tower, 1% of the circulating water is evaporated for each 10 F temperature decrease.

As vapor from evaporation of the water leaves the water surface, concentration of water solids (including hardness) occurs. This feature must be considered in designing water treatment for scale and corrosion inhibition and in designing blowdown control. Sufficient blowdown to maintain a maximum of 4 concentrations (4 x original water solids) is most often prescribed, although the quality of the make-up water in respect to hardness, pH, alkalinity, and total solids, the completeness of the prescribed treatment, and other factors may affect this recommendation.

A cooling tower might be considered a boiler operating at atmospheric pressure to cool water for re-use. Although temperatures are much lower than with boiler operation, the aeration and continuous exposure of water in the system to air promotes both scale and corrosion problems. Controlling scale formation can probably not be considered as important as in boiler operation; however, interruptions in refrigeration and air-conditioning service caused from scale, corrosion, and algae growths may be serious and their correction costly.

6.1 Chemical Feed Equipment

Probably the most important phase of cooling tower treatment in control of scale and corrosion is the installation of good quality automatic chemical proportioning and blowdown equipment. Cooling towers operate under extremely varying load conditions, and consequently constant feed and blowdown equipment should not be expected to provide acceptable results.

Since the gallons of make-up water employed is a good measure of the evaporation, blowdown, and windage loss of the system, treatment control should best be based on the make-up water required. Accordingly, electriccontact water meters including timers have been specified for all towers of 100 tons and over. These water meters provide signals through adjustable timers to chemical pumps and

solenoid blowdown valves to provide automatic treatment application and blowdown control. In some cases, electrical conductivity devices have been specified which automatically maintain a set dissolved solids content by solenoid blowdown valve operation.

In order that toxic chemicals, which are the more effective corrosion inhibiting chemicals, may be employed, all make-up should be applied at least 12 to 24 inches above the maximum water level or overflow to prevent possible back-siphonage into the drinking water supply. The entire circulatory system should be completely isolated from the city or domestic water piping.

6.2 Calculation of Cooling Tower Treatment and Blowdown

As discussed in the introduction to this section, cooling of water is accomplished by evaporation of water in passage through the cooling tower, and this as well as other factors must be considered in the design of water treatment and its control. Methods of calculating the amount of evaporation, the make-up water and the blowdown, which are necessary information in the design of the proper water treatment dosage and blowdown, are shown below.

Evaporation (E):

3 gph evaporation/ton occurs in absorber air-conditioning systems; 1.5 gph/ton in centrifugal air-conditioning

Make-up water (MU) :

Make-up (MU) = evaporation . (E) + blowdown (B)

Concentration (C) = number of times that original water solids concentrate as water evaporates in the cooling tower system

$$MU = E + B = E + \frac{E}{C-1} ; \text{ by algebra, } MU = \frac{E C}{C-1}$$

Blowdown (B):

$$\text{Blowdown (B)} = \frac{E}{C-1}$$

Example:

Equipment -- 200-ton absorber operating at 4 concentrations

100 gal/contact water meter

2 timers, 0-20 min range, one for chemical pump and one for solenoid blowdown control

- 1 - 50-gal chemical tank
- 1 - 1/2-inch solenoid blowdown valve
(wide open, provides 350 gph flow)

Treatment and control -- 30 ppm scale and corrosion inhibitor dosage

Timers to be set at 3/4 of time interval between contacts to prevent over-lapping of contacts

Refilling of chemical tank is planned every 48 hours based on 100% air-conditioning load

Maximum solution strength is to be 5%

$$E = 200 \times 3 \text{ gph} = 600 \text{ gph}$$

$$MU = \frac{E \ C}{C-1} = \frac{(600)(4)}{(4-1)} = 800 \text{ gph}$$

$$B = \frac{E}{C-1} = \frac{600}{3} = 200 \text{ gph}$$

$$\frac{800 \text{ gph}}{100 \text{ gal/contact}} = 8 \text{ contacts/hr or every 7.5 min}$$

$$7.5 \text{ min} \times 0.75 = 5\text{-}5/8 \text{ min timer setting, as set at 75\%}$$

Treatment is 30 ppm or 1/4 lb/1000 gal to be applied from 50 gal tank in 48 hr

$$\frac{50 \text{ gal}}{48 \text{ hr}} \times \frac{1}{0.75(\text{time pump operating})} = 1.4 \text{ gph pump stroke setting}$$

$$800 \text{ gph MU} \times 48 \text{ hr} = \frac{38400 \text{ gal}}{1000} = 38.4 \times 1/4 \text{ lb/1000 gal}$$

$$= 9.6 \text{ lb dissolved in 50 gal}$$

as 8.33 lb in 1 gal

$$\frac{9.6 \times 100}{50 \times 8.33} = 2.4\% \text{ solution, which is below 5\% maximum strength}$$

Blowdown = 200 gph

Assuming 1/2-inch blowdown valve provides 350 gph flow, set valve at wide open position and set timer at 5-5/8 min (75% of the time)

$$350 \text{ gph} \times 0.75 = 260 \text{ gph, slightly more blowdown than required}$$

6.3 Treatment for Scale Control

The evaporation occurring in a cooling tower water system causes the scale-forming constituents (hardness and alkalinity) to

concentrate and to increase the scaling potential. This is controlled by one of the four following methods, of which the first two are classified as scale inhibitors:

- (1) Polyphosphate and organic (lignosulfonate) (Item 63)
- (2) Sodium salt of aminotrimethylphosphonic acid (Item 84)
- (3) Sodium zeolite softening for reducing hardness
- (4) Sulfuric acid for reducing alkalinity and pH

Accurate blowdown control is necessary to provide proper control of scale formation.

Scale formation in cooling tower systems may prove to be most serious in the tubular heat exchangers or absorbers, where temperatures are highest, and also in spray nozzles. Cleaning these areas can be most simply done by application of inhibited acid (see section 7.2).

6.4 Treatment for Corrosion Control

In boiler feedwater treatment, use of oxygen-free feedwater is a practical solution to the prevention of corrosion, since a closed system is maintained and the costs of deaeration and sodium sulfite treatment are negligible. In the cooling tower, continuous aeration makes oxygen-free conditions impractical to attain; therefore, corrosion inhibiting chemicals, such as chromates, zinc salts, and phosphates, plus pH adjustment to neutrality are required to prevent corrosion by these concentrated waters of rather high corrosion potential. Since scale and corrosion control is less critical at the lower temperatures maintained in cooling towers compared with boilers, these methods of internal treatment control are generally successful.

The same *corrosion testing method* (ASTM D2688 Method C; see 3.3.2) as employed for distribution water shall be employed for monitoring the scale and corrosion occurring in cooling towers. The controlled flow (by means of an orifice) of these testers shall be taken from the vertical inlet piping going to the top of the tower and shall be directed into the cooling tower basin. This flow is designed to provide the same velocity (4 fps) as that in the main circulating piping.

Corrosion will be most prevalent under debris, leaves, etc., so attention to frequent cleaning is important. Stoppage problems by leaves, insects, etc., of intakes and blowdown may be reduced by installation of screen wire above distribution water decks or on the outside air intakes of the tower. Sludge conditioning agents to remove sediment from cooling tower basins have been tried, but to date have not been found consistently successful.

There have been a few cases of corrosion of steel between the tubes of absorber condenser heads. Inspection of condensers has shown that this has usually occurred while the water was held in the system when it was out-of-service. After conferring with absorber manufacturers, recommendations are to drain condensers during the out-of-service period and to store the equipment dry, preferably removing the heads and leaving the condenser open to the atmosphere. Water treatment is applied only in sufficient concentration to inhibit corrosion while the water is circulating at full velocity and not in sufficient quantity to inhibit corrosion under static, low velocity conditions that exist when the system is not operating.

6.5 Blowdown

Accurate blowdown control is essential to proper cooling tower maintenance. The number of water solids concentrations is maintained at a maximum level consistent with efficient scale and corrosion control by automatic blowdown control.

Blowdown (or bleed-off) should be discharged to the sanitary sewage system. In some institution systems in which there is inadequate dilution of cooling tower blowdown, changing from chromate type chemicals to other chemicals (such as phosphate) may be recommended since chromate (CrO_4) is considered a pollutant above 5 ppm in the sanitary sewage systems.

6.6 Treatment to Control Algae and Slime Growths

Algae and organic growths often accumulate throughout the cooling tower system causing decreased heat transfer and flow rates. Item 60 Sodium Pentachlorophenate and Item 46 Calcium Hypochlorite fed alternately in dosages of 4 ounces and 1 ounce, respectively, per 100 tons of air conditioning to the cooling tower distributors or to the basin is usually effective in controlling these growths.

6.7 Vulnerability of Wood to Fungi and Chemical Attack

Cooling towers constructed of wood are subject to attack by high pH and alkalinities (chemical attack), by high continuous residuals of strong oxidizing agents (such as chlorine of 0.5 ppm and above), and by biological attack (fungi). Applying acid to reduce the pH below 7.5 and avoiding continuous chlorine residuals above 1.0 ppm will prevent chemical attack.

To date, neither fungi nor chemical attack of wood cooling towers has been experienced at any of the State Institutions. However,

since these attacks may be internal or external and may cause complete disintegration and collapse of wood tower structures, periodic close inspection of towers is advocated. Inserting an ice pick into the wood to find whether the wood is solid or not is one means' of determining whether there has been any internal attack. One solution to this problem is to construct towers with wood pretreated with copper chromate and arsenate or to spray towers with similar solutions after construction.

7. SCALE REMOVAL BY CHEMICALS

Cleaning scaled surfaces can often be most efficiently done by exposure to acid. These scaled surfaces may be heat exchangers, such as domestic hot water heater coils, or may be the heating surfaces in coffee urns, steam tables, and water stills. Such surfaces may be inaccessible for mechanical cleaning, so cleaning with acid may be the simplest, the easiest, and the only convenient method.

Inhibited acid should be used since it contains a corrosion inhibitor that prevents attack of the metal by the acid but does not prevent dissolution of the scale by the acid. Methods of cleaning with inhibited acid may be (a) the fill and soak method, or (b) the circulation method, which makes better use of the acid by bringing fresh acid continually to the scaled surface.

7.1 Safety Precautions

It must be recognized that safety precautions are necessary in handling acid; however, experience usually indicates that the advantages gained justify the extra care or attention required. Safety in handling acids is outlined in detail in 2.2.1.

Since there is always the possibility of hydrogen being formed from the reaction of acid with metal, flames should be kept from the acid cleaning area. Good air circulation should be maintained at all times. The use of inhibited acid, which reduces the corrosion of metals and accompanying hydrogen gas formation, reduces the hazard of the presence of hydrogen and its possible explosibility.

7.2 Chemicals Employed for Scale Removal

Hydrochloric or muriatic acid (Item 40A) is the most effective acid for removal of scale, particularly calcium carbonate. Sulfamic acid (Item 38), a powdered acid, is safer to handle, but is much slower in action and required heating to provide effective scale removal. EDTA (sodium salt of ethylenediamine tetra-acetic acid) is an alkaline liquid solution, which is also much slower in action and requires heating to obtain rapid scale dissolution. The phosphonates, as Items 84 and 95, may also be used for dissolution of scale, including calcium sulfate.

Corrosion inhibitors should always be employed with the acids to prevent attack of steel and other metals by the acids.

7.2.1 Hydrochloric (muriatic) acid. Hydrochloric acid *should not be*

used to clean stainless steel because the chloride ion may cause pitting or stress corrosion cracking. Also, hydrochloric acid should not be used for removing scale from galvanized steel surfaces since the zinc in the galvanizing is corroded by it.

Specifications for hydrochloric acid, as listed in the specifications for Boiler Compound and Water Treating Chemicals, are as follows:

Item 40A Hydrochloric (Muriatic) Acid, Technical,
18° Baume¹, 27.9%, in 6-1/2 gal (63 lb) carboys and
Item 40B in 13 gal (126 lb) carboys.

This concentrated acid may vary in price from 6 to 10¢/lb or from 60¢ to \$1/gal.

Item 41, an inhibitor for prevention of corrosion of steel and other metals exposed to the acid, should be dissolved to the extent of 1% in the concentrated acid (1-1/2 oz/1 gal acid). This inhibitor does not affect the action of the acid on scale, but does reduce attack of steel and other metals by the acid. Item 41 costs approximately 55¢/lb and may be purchased in minimum lots of 5 gal (42-1/2 lb, costing about \$24).

One of the advantages in purchasing concentrated acid (Items 40A, 40B) is that custom-made diluted acid may be prepared for the particular use or cleaning job. For example, if plumbers and others use appreciable diluted acid, preparation of diluted inhibited acid in the shop or storeroom may be arranged.

To prepare about 33 gal, add about 26 gal of water to a 55-gal steel tank, then add 1% (10 oz) Item 41 Corrosion Inhibitor B, and finally one 6-1/2 gal carboy of Item 40A Hydrochloric Acid; then mix and draw off into plastic 1-gal bottles for later use.

To clean heavily scaled equipment, it may prove best to employ stronger acid (1 part acid to 1-3 parts water), particularly if volume requirements are small, in order to complete the cleaning effectively in a short time.

In case a considerable volume of acid is required to circulate through the coils of a large heat exchanger, or to contact the coils in a large vat, more dilute acid (1 part acid to 4-10 parts water) may best be used.

A transfer pump of the following specifications should be purchased to aid transference of acid from the carboy to the point of use.

1 - All-polyethylene manually operated pump for transferring acid, with 3/4" NPT threaded neck with 2" buttress and

gasket plus 83 mm buttress carboy cap (as Plastics Division/Container Corp. of America, 1350 W. Fullerton, Addison, Illinois 60101, Model DP4000 plus above adapters costing about \$15)

7.2.2 Commercially prepared inhibited acids. Item 53, a commercially prepared concentrated or diluted inhibited hydrochloric acid (containing 7-28% hydrochloric acid and an inhibitor) may be purchased under various trade names in 1-gal (Item 53A), 13-gal (Item 53B), 30-gal (Item 53C), and 55-gal (Item 53D) lots and at prices 4 to 30 times the costs of the ingredients.

Advertisements of some of these products may claim that cotton clothes and skin are not attacked by the acid. These claims are usually based on the use of such a dilute solution of the acid that attack on clothes or skin is minimal; however, the economics of scale removal is seriously affected. It should be recognized that the handling of hydrochloric acid *in any strength* must be performed with considerable care and caution.

Since purchasing diluted acid is expensive, the user is encouraged to purchase Item 40 and to make dilutions with water to usable strengths of 1 part of acid to 2-10 parts of water and to add corrosion inhibitor, instead of purchasing Item 53. It is appreciated that users of small quantities (possibly less than 10 gallons of diluted acid per year) cannot justify the purchase of Item 40 and the spending of time, cost, and effort in (1) adding the inhibitor to the acid, (2) diluting the acid to usable strengths, and (3) maintaining an inhibitor supply.

7.2.3 Sulfamic acid. Since hydrochloric acid should not be used in cleaning stainless steel, a sulfamic acid solution is a good substitute; however, it must be heated to about 130-160 F to dissolve scale rapidly.

Sulfamic acid, Item 38, is more expensive (about 22¢/lb) than hydrochloric acid and costs about four times as much to dissolve the same amount of scale. It should also be used with a corrosion inhibitor. Corrosion Inhibitor A, Item 39, is recommended. Item 39 costs 80¢/lb and is purchased in minimum lots of 5 gal (40 lb, costing \$32).

Since most inhibited acid formulations, including hydrochloric acid, attack galvanized steel, care should be taken in the choice of acids used for removing scale in cooling towers, evaporative condensers, and other equipment. Inhibited sulfamic acid used at maximum temperatures of 90-110 F will not corrode galvanized steel and is recommended for this purpose. This can be applied to the equipment while operating,

but should be drained from the system after a few hours. If foaming due to the presence of excessive scale causes the pump suction line to be filled with foam, close supervision should be provided during cleaning; in fact, the cleaning should be done by the fill and soak method, if possible (see section 7.3.2). After drainage the system should be neutralized with a dilute water solution of soda ash (1 lb/100 gal) and then be thoroughly flushed with water.

Sulfamic acid is safer than hydrochloric acid to handle, since it is a dry powder, is a weaker acid (less corrosive), and the fumes are less corrosive and noxious. A 5-20% (5-20 lb to about 10 gal water) solution is used for removing scale from metal surfaces; however, the solution must be heated to 130-160 F to obtain the same fast cleaning action expected from hydrochloric acid. In cleaning scale from galvanized metal surfaces, a maximum temperature of 90-110F is prescribed.

Inhibited sulfamic acid mixtures in a dry powdered form are available commercially for cleaning. If appreciable quantities are required, it will prove more economical for the institution to prepare the powdered mix in the shop or storeroom from Items 38 and 77. This can be done by mixing the dry powders with shovels on a concrete surface, as cement and sand are mixed. Costs may be expected to be 1/2 to 1/10 of the commercial products. The dry mix should be prepared by mixing 1 lb of Item 77 (1,3-Diethyl Thiourea) with each 100 lb of Item 38 Sulfamic Acid.

7.2.4 Ethylenediamine tetra-acetic acid (EDTA). The sodium salt of ethylenediamine tetra-acetic acid (Item 83) can also be used to dissolve scale. It is a liquid chemical, which may be diluted with 4 parts of water, and is reported to be effective in dissolving practically all scales, including calcium sulfate, iron, and copper deposits. It is a safer material to use than the acids previously mentioned since it is mildly alkaline in dilute solution; however, solutions must be heated to 130-160 F to obtain rapid scale dissolving action. It is an expensive chemical to use for scale removal since 10 lb costing \$2.25 is required to dissolve 1 lb of scale (calcium carbonate).

7.2.5 Cost comparison of acids. A comparison of the costs of solvents for dissolving scale is shown below:

Solvent	%	Cost (\$/lb)	Amount (lb)	Acid required to dissolve 1 lb CaCO_3 Cost (\$)	
				Acid	Inhibited acid
Item 40A Hydrochloric Acid	27.9	.074	2.62	0.194	0.21
Item 53B-Commercially prepared HCl					
Concentrated	25.7	.316	2.5		0.79
Diluted	7-14	.12-.83 (est.)	3.7-7.3		1.25-6.00 (est.)
Item 38 Sulfamic Acid	99	.22	1.94	0.427	0.44
Item 83 Sodium EDTA (as Vertan 650)	—	.25	10.0		2.50

It will be noted that:

- (1) Commercially prepared diluted hydrochloric acid (Item 53B) may cost 5-30 times more than inhibited dilute acid prepared by plant personnel.
- (2) Inhibited sulfamic acid costs twice as much as inhibited hydrochloric acid.
- (3) Sodium EDTA costs 12 times more than inhibited hydrochloric acid.

7.3 Methods of Removing Scale with Acids

7.3.1 Circulation method. Circulation of acid is usually advantageous in cleaning enclosed vessels or hot water heater coils. The periodic cleaning of air-conditioning condensers and hot water heater coils may prove to be an important part of a successful preventive maintenance program. Installation of sill cocks at the bottom of the water inlet of the heat exchanger and at the top of water outlet makes it possible to connect 3/4-inch garden hose direct from the pump and from the heat exchanger to return used acid to the acid container. See Figure 1.

An acid cleaning assembly may consist of a small cart on which is mounted a pump, and a 5- to 50-gal steel or polyethylene tank with

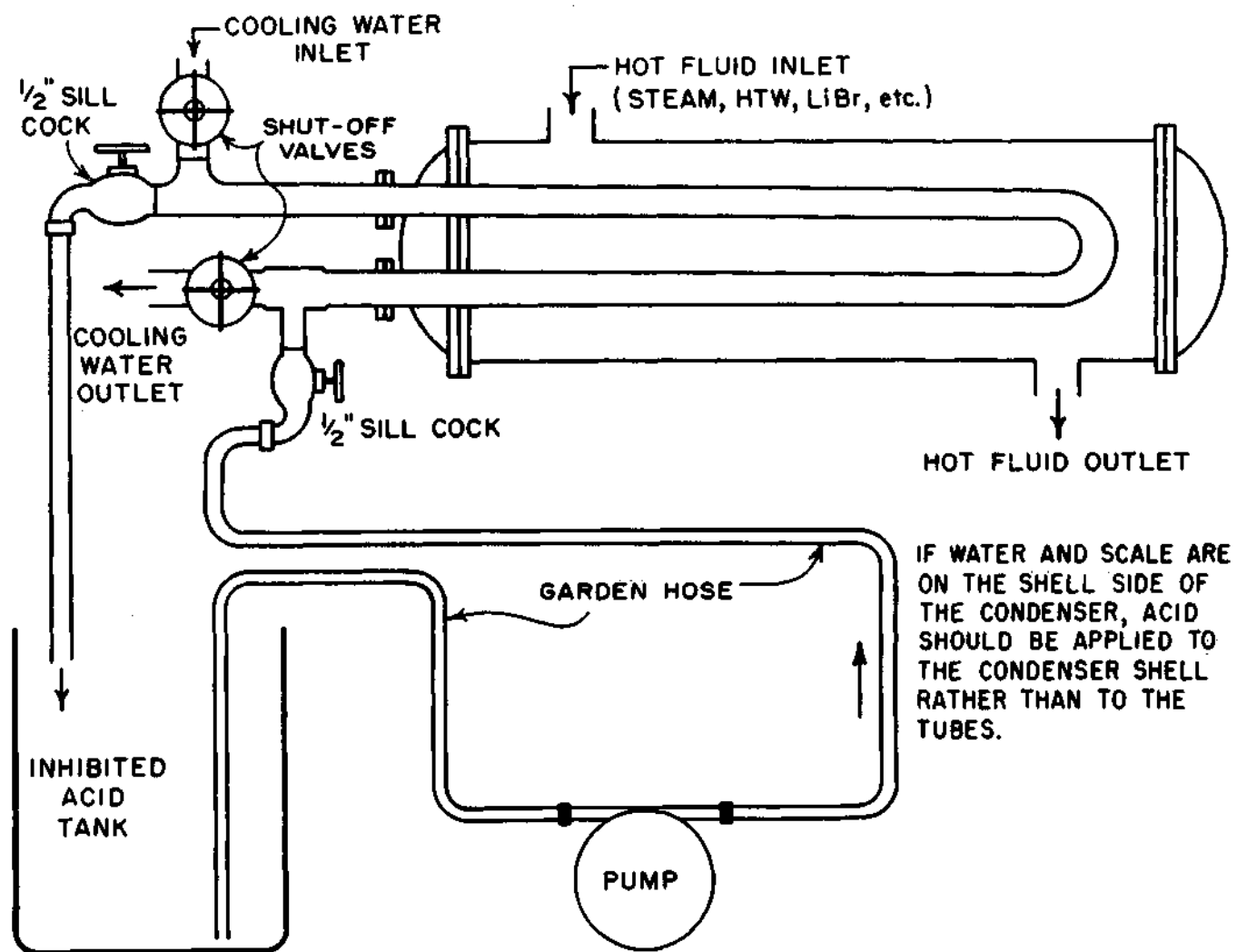


Figure 1. Acid cleaning diagram for heat exchangers

bottom outlet to the pump. The tank outlet should be a male garden hose connection so that the tank and pump may be connected by a garden hose.

Specifications for the purchase of the pump for this purpose are as follows:

- 1 - Positive pressure pump, 3/4" port size, capacity 5.7 gpm at 10' head, maximum 21.6 psig, bronze pump body material, neoprene impeller material, stainless steel shaft, 3/4" external garden hose connections, 1/8 hp with relay start and thermal overload protector, totally enclosed, 1750 rpm, 115 v, 60 cycle ac, with service kit (as Cole-Parmer pump, cat. no. 7036-1, and 7036-6 service kit, available for \$69.40 from Cole-Parmer, 7425 North Oak Park Ave., Chicago, Illinois 60648)

The dilute inhibited acid is prepared in the acid cleaning assembly, as previously described in 7.2 or as described below in 7.3.2, and is pumped into the heat exchanger through the hose connection, then is returned by hose connection to the acid tank. Circulation is continued until the cleaning is complete as indicated by subsidence of foaming or depletion of the acid. Additional acid should be added if required, and recirculation and cleaning should be continued until scale removal is complete. Usually an hour of circulation is adequate. The acid strength may be checked as described in 7.3.3. On completion of cleaning, a 1% soda ash solution (about 1 lb/100 gal) should be circulated briefly, after which thorough circulation and flushing with water is recommended.

If it is desired to clean small diameter (3/8- to 5/8-inch) copper tubing, as in a dishwasher booster heater, plastic tubing and connections for forcing the tubing into the scale area may prove most efficient. Specifications for this equipment are as follows:

- 1 - FBI Male connector, brass, 1/2" pipe, 1/4" tube, Part 4-8 FB 12-B 12 ft Parker - POL tubing, polyethylene, 1/4" OD tubing (available from Parker-Hannifin Corp., 501 South Wolf Road, Des Plaines, for a few dollars)

7.3.2 Fill and soak method. Prepare inhibited dilute acid, as previously described, in a 55-gal steel drum or equivalent. Prepare 33 gal of dilute acid by adding 26 gal of water, then 10 oz Item 41 Corrosion Inhibitor B and one 6-1/2 gal carboy of Item 40A muriatic acid, and mix the contents. The part to be cleaned is immersed in the diluted acid for several hours until the scale is removed.

7.3.3 Test method for checking strength of acid. As the acid is consumed in dissolving scale, it may be desirable to check the acid strength to determine if it is adequate. The procedure is as follows:

Measure 10 ml of the acid solution accurately in a graduated cylinder and place in a casserole. Add 2-4 drops of phenolphthalein indicator and titrate with 1N sodium hydroxide* to a faint pink color. This is the endpoint. The ml of 1N sodium hydroxide required multiplied by 0.35 = % of hydrochloric acid in the sample, or multiplied by 0.97 = % sulfamic acid in the sample.

Concentrated hydrochloric acid diluted with 3 parts of water will test approximately 7.7% or will require about 22.0 ml of 1N NaOH to neutralize the 10 ml acid sample. Also, 20 lb of sulfamic acid dissolved in about 10 gal of water should test approximately 20% or will require about 20.6 ml of 1N NaOH to neutralize the 10 ml acid sample.

When the acid strength has decreased to 2-3% or below, it may be discarded since most of its scale dissolving property will have been lost.

*The State Water Survey will furnish 1N Sodium Hydroxide solution on request.

8. SAMPLING AND METHODS OF WATER ANALYSIS

8.1 Sampling

Water tests are of no value unless the sample tested is representative of the water being analyzed. In sampling water from wells, it is essential that the well has been pumped long enough to insure that the sample being taken represents the ground water from which the well is fed. Usually a sample will be representative if the well is pumped for at least 15 minutes. In sampling from lakes or reservoirs, choice of a location for obtaining a representative sample may be more difficult; in general, the sample should not be taken too close to the shore line, too close to incoming flows, or in sluggish areas. In sampling from a faucet, the water should be allowed to flow long enough so that it is of fairly constant temperature as representative of temperature conditions in the larger piping, and flow should be regulated so that minimum splashing and aeration of the sample occurs during sampling. Cooling tower samples may be collected from a tap in the circulating line previous to chemical addition or may be collected from the cooling tower basin away from the make-up water addition. Explicit directions are given for sampling boiler water and condensate in 8.1.1 and 8.1.2.

Glass or plastic bottles may be employed for sampling raw, distribution, cooling tower, boiler, feedwater, or condensate samples. Plastic bottles should be employed if accurate silica results are required. Boiler water, feedwater, and condensate should be sampled in glass bottles if analyses for oil content are required. Samples should be stoppered as soon as collected.

8.1.1 Sampling boiler water. The following procedures should be applied in collecting boiler water samples:

- (1) First, open the cooling water valve to provide adequate flow for cooling.
- (2) Blow sample lines free of stagnant water and sediment by opening the boiler water sampling valve for a 15-30 second period. A continuous flow of approximately 1 pint per minute, cooled to less than 120 F, should be maintained before collecting sample.
- (3) Rinse the sample container at least three times by filling to 1/4 its capacity with boiler water, shaking, and then emptying.
- (4) Take the sample when the boiler is operating under normal

load conditions, when the boiler water is at normal operating water level, and before manual blowdown for control of solids concentration. After the tests, the amount of manual blowdown or adjustment of the continuous blowdown can be determined from the test results.

- (5) Collect the boiler water sample through a pipe extending to the bottom of the container. Allow the container to overflow at least five volumes, and then close it with a stopper previously rinsed with the sample water. (If the sample is to be tested within 20 minutes, it is not necessary to stopper the container.)
- (6) After the sample is taken, shut the boiler water valve off; *then* shut the cooling water valve off.

8.1.2 Sampling condensate. The following are procedures for collection of condensate samples:

- (1) Sample the condensate from the total flow of condensate returning to the power plant. The test of purity then indicates whether raw or softened water contamination is occurring anywhere in the system.
- (2) Before testing, cool the sample to room temperature by passage through a sample cooler.
- (3) Use the container, preferably glass, *only for condensate* and label it accordingly. Containers that have been used for raw and boiler water samples often contribute dissolved solids contamination from seams, etc., even after being scrupulously cleaned.
- (4) Rinse the sample container at least three times with condensate before collecting the sample to be tested.
- (5) Test the sample immediately to avoid contamination from air or dust. Samples should not be filtered.

8.1.3 Preparing and shipping of water samples. If the water test is to be made at the State Water Survey, these instructions should be followed:

- (1) After sampling in a clean container as recommended above, stopper the bottle tightly. The screw cap on plastic containers *should be tightened very securely.*

- (2) Label the sample bottle, including the following information:
Name of Institution
Kind of water and location
(include boiler and cooling tower numbers)
Date
- (3) If bottle is loose in the sample container, pack paper or cardboard around it.
- (4) Address the package to:
Illinois State Water Survey
605 East Springfield Avenue
Champaign, Illinois 61820
- (5) Send the package by parcel post or United Parcel. It should not be shipped Special Delivery, unless requested.

8.2 Water Testing and Methods of Water Analyses

The only purpose of water testing is to provide proper control of recommended treatments. It is *not* for the purpose of record-keeping or of completing forms. When tests indicate undesired results, adjustments in treatment, blowdown, etc., as recommended in the control charts, should be immediately applied. A minimum number of tests are prescribed, and these results are essential in maintaining institutional facilities in the desired proper operating and maintenance-free condition.

Annual and replacement requirements of testing equipment and reagents shall be ordered from the State Standard Specifications for Water Testing Reagents and Equipment. Reagents, with exception of Items 113-115 Ortho Tolidine, will maintain the specified concentration for at least one year. A fresh supply of Ortho Tolidine should be obtained at least every six months. Occasionally standard solutions from a particular bottle or supply are off-standard. When test results change radically with use of a new bottle of reagent, it is possible that the new supply may be off-standard. A sample of the off-standard solution may be sent to the State Water Survey for checking, or the condition may be reported to the State Water Survey during plant visits.

Testing equipment should be kept scrupulously clean. Unless this is done the test will be unreliable. Testing equipment should be kept in good order. All bottles should be properly labeled. Spilled chemicals should be cleaned immediately from table tops. Graduated cylinders and casseroles should be rinsed with the water to be tested before conducting the analysis. Care should be taken in measuring the test volume of water, in reading the automatic burettes, and in reporting the ppm results. The following test methods are recommended for control of water treatment in the State Institutions.

8.2.1 Hardness test (H)

Apparatus

Burette, 10 ml Automatic (for Standard Hardness Titrating Solution)
(Item 5155)
Graduated Cylinder (Item 5150)
1 oz Bottle, with calibrated 0.5 ml dropper (item 5154)
Porcelain Casserole (Item 5152)
Stirring Rod (Item 5153)
Brass Measuring Cup, 0.1 gm size (Item 5197)

Reagents

Standard Hardness Titrating Solution (1 ml = 1 mg CaCO_3) (Item 5002, 5003)
Hardness Buffer Solution (Item 5011)
Hardness Indicator Powder (Item 5014)

Method

- (1) Measure the amount of water to be tested in the graduated cylinder in accordance with:

Hardness (as CaCO_3)	Recommended sample size (to keep titration less than 10 ml)		Factor
Up to 100 ppm	100 ml		10
100 to 400 ppm	50 ml		20
Above 400 ppm	20 ml		50
	10 ml		100
	5 ml		200

- (2) Pour into the casserole.
- (3) Add 1 ml Hardness Buffer and 1 brass measuring cup (0.14 gm) of Hardness Indicator Powder. If the water turns blue, no hardness is present, the hardness is reported as "zero," and the test is discontinued. If the water turns red, hardness is present and the test should be continued.
- (4) Squeeze the Standard Hardness Titrating Solution from the plastic bottle to just above the zero mark on the burette, then allow excess solution to drain automatically back to the bottle.
- (5) While stirring the water constantly and vigorously with the glass rod, add Standard Hardness Titrating Solution drop by drop from the burette until the red changes to blue. This is the endpoint. Read the burette to the nearest 0.1 ml.

Results

When testing a 100 ml sample:

Burette reading in ml $\times 10$ = ppm hardness (as CaCO_3)

Example: 5.6 ml $\times 10$ = 56 ppm hardness (as CaCO_3)

8.2.2 Calcium (Ca) and magnesium (Mg) hardness tests

Apparatus

Burette, 10 ml Automatic (for Standard Hardness Titrating Solution) (Item 5155)
Burette, 10 ml Automatic (for Standard Acid Solution, N/50) (Item 5155)
Graduated Cylinder (Item 5150)
Porcelain Casserole (Item 5152)
Stirring Rod (Item 5153)
Bottle, with dropper (for Methyl Orange Indicator) (Item 5154)
1 oz Bottle, with calibrated 0.5 ml dropper (for Sodium Hydroxide) (Item 5154)
Brass Measuring Cup, 0.1 gm size (Item 5197)

Reagents

Standard Sulfuric Acid (N/50) (Item 5021, 5022)
Methyl Orange Indicator (Item 5029)
Standard Hardness Titrating Solution (1 ml = 1 mg CaCO_3) (Item 5002, 5003)
Sodium Hydroxide Solution (1.0 N) (Item 5095)
Calcium Indicator, powder (Item 5099)

Method

- (1) Measure the amount of water to be tested in the graduated cylinder in accordance with:

Calcium (as CaCO_3)	Recommended sample size (to keep titration less than 10 ml)	Factor
Up to 100 ppm	100 ml	10
100 to 400 ppm	50 ml	20
Above 400 ppm	20 ml	50
	10 ml	100
	5 ml	200

- (2) Pour into the casserole.
- (3) Squeeze the Standard Sulfuric Acid and the Standard Hardness Titrating Solution from the plastic bottles to just above the zero marks on the burettes, then allow excess solutions to drain automatically back to the bottles.
- (4) Add 2-3 drops of Methyl Orange Indicator and titrate with N/50 Sulfuric Acid until the color changes from yellow to orange or faint pink.
- (5) Now apply 1 brass measuring cup (0.20 gm) of Calcium Indicator and 2 ml (1 N) Sodium Hydroxide.

- (6) Then titrate immediately with Hardness Titrating Solution. If calcium is present, the sample will be salmon pink in color, and as the endpoint is approached, it will develop a purple tinge. The endpoint is orchid purple. Once the endpoint is reached, additional titrating solution *will not produce any further color change. The endpoint* should always be checked by adding one additional drop of titrating solution and observing whether further color change occurs. If further color change occurs, the endpoint has not been reached and the titration should be continued. Read the burette to the nearest 0.1 ml.

Results

Calcium hardness (as CaCO_3) :

When testing a 100 ml sample

Burette reading in ml $\times 10$ = ppm calcium hardness (as CaCO_3)

Example: 3.6 ml $\times 10$ = 36 ppm calcium hardness (as CaCO_3)

Magnesium hardness (as CaCO_3):

Total H ppm - calcium H ppm = ppm magnesium H (as CaCO_3)

8.2.3 Phenolphthalein alkalinity test (P)

Apparatus

Burette, 10 ml Automatic (for Standard Sulfuric Acid) (Item 5155)
Graduated Cylinder (Item 5150)
Bottle, with dropper (for Phenolphthalein Indicator) (Item 5154)
Porcelain Casserole (Item 5152)
Stirring Rod (Item 5153)

Reagents

Standard Sulfuric Acid (N/50) (1 ml = 1 mg CaCO_3) (Item 5021, 5022)
Phenolphthalein Indicator (Item 5033)

Method

- (1) Measure the amount of water to be tested in the graduated cylinder in accordance with:

<u>P Alkalinity</u> <u>(as CaCO_3)</u>	<u>Recommended</u> <u>size of sample</u>	<u>Factor</u>
Up to 25 ppm	100 ml	10
25-100 ppm	50 ml	20
100-400 ppm	20 ml	50
Above 400 ppm	10 ml	100

- (2) Pour into the casserole.
- (3) Add 2 drops of Phenolphthalein Indicator. If the water does not change to a red color, there is no phenolphthalein alkalinity present and the "P" reading is reported as "zero." If the water does change to a red color, phenolphthalein alkalinity is present and the test should be continued.
- (4) Squeeze the Standard Sulfuric Acid from the plastic bottle to just above the zero mark on the burette, then allow the excess acid to drain automatically to the bottle.
- (5) While stirring the water constantly with the glass rod, add Standard Sulfuric Acid drop by drop from the burette to the casserole until the red color disappears and the water resumes the color it showed before the Phenolphthalein Indicator was added. This is the endpoint. Read the burette to the nearest 0.1 ml.
- (6) Do not discard the sample, but save for other tests if M alkalinity or chloride tests are required.

Results

When testing a 100 ml sample:

Burette reading in ml $\times$ 10 = ppm P alkalinity (as CaCO_3)

Example: 7.0 ml $\times$ 10 = 70 ppm P alkalinity (as CaCO_3)

8.2.4 Total (methyl orange) alkalinity test (M)

Apparatus

Burette, 10 ml Automatic (for Standard Sulfuric Acid) (Item 5155)
Graduated Cylinder (Item 5150)
Bottle, with dropper (for Methyl Orange Indicator) (Item 5154)
Porcelain Casserole (Item 5152)
Stirring Rod (Item 5153)

Reagents

Standard Sulfuric Acid (N/50) (1 ml = 1 mg CaCO_3) (Item 5021, 5022)
Methyl Orange Indicator (Item 5029)

Method

- (1) Add 2-4 drops of Methyl Orange Indicator to the water in the casserole remaining from the phenolphthalein alkalinity test. If the water changes to an orange or red color, free mineral acid is present, there is no alkalinity, and the "M" reading is reported as "zero." The acidity may be determined by titration with standard alkali (Item 5111), as directed in 8.2.16. If the water changes to a yellow or straw color, methyl orange alkalinity is present and the test should be continued.
- (2) Do not squeeze the Standard Sulfuric Acid from the plastic bottle back to the zero mark on the burette, but leave it at the reading shown at the endpoint of the P alkalinity test.
- (3) While stirring the water constantly with the glass rod, add Standard Sulfuric Acid drop by drop from the burette to the casserole until the yellow or straw color changes to a faint orange or light pink. Read the *total burette reading to the nearest 0.1 ml*, including that used in the P alkalinity determination.
- (4) Do not discard the sample, if chloride test is required.

Results

When testing a 100 ml sample:

Total burette reading in ml $\times 10$ = ppm M alkalinity (as CaCO_3)

Example: 7.0 ml $\times 10$ = 70 ppm P alkalinity (as CaCO_3)

10.0 ml $\times 10$ = 100 ppm M alkalinity (as CaCO_3)

Note A: The endpoint may be difficult to see in artificial light. The most accurate results are secured if the test is conducted in daylight. Inexperienced operators generally add too much acid, thereby securing an incorrect endpoint of a definite red color. An alternative is to use the Mixed Indicator Method, described in 8.2.14.

Note B: If the sample tested is boiler water with a comparatively high concentration of phosphate, the M reading will have a tendency to fade.

8.2.5 Chloride test (Cl)

Apparatus

Burette, 10 ml Automatic (for Standard Silver Nitrate) (Item 5155)
Graduated Cylinder (Item 5150)
Bottle, with dropper (for Potassium Chromate Indicator) (Item 5154)
Porcelain Casserole (Item 5152)
Stirring Rod (Item 5153)

Reagents

Standard Silver Nitrate (1 ml = 1 mg Cl) (Item 5042)
Potassium Chromate Indicator (Item 5048)
Hydrogen Peroxide Solution (3%) (Item 5043)

Method

- (1) Measure the amount of water to be tested in the graduated cylinder in accordance with:

<u>Chloride (as Cl)</u>	<u>Recommended size of sample</u>	<u>Factor</u>
Up to 25 ppm	100 ml	10
25 to 100 ppm	50 ml	20
100 to 400 ppm	20 ml	50
Above 400 ppm	10 ml	100

- (2) Add 4-8 drops of Potassium Chromate Indicator to the water in the casserole remaining from the P alkalinity test. The water will turn a yellow color.
- (3) Squeeze the Silver Nitrate from the plastic bottle to just above the zero mark on the burette, then allow the excess silver nitrate to drain automatically to the bottle.
- (4) For waters that test above 100 ppm sulfite, add 2 ml Hydrogen Peroxide Solution (3%) to the sample and stir well before titrating with Silver Nitrate.
- (5) While stirring the water constantly with the glass rod, add Silver Nitrate drop by drop from the burette to the casserole until a faint red or dark orange color appears *throughout* the entire sample. This is the endpoint. Read the burette to the nearest 0.1 ml.

Results

When testing a 100 ml sample:

Burette reading in ml x 10 = ppm chloride (as Cl)

Example: 5.1 ml x 10 = 51 ppm chloride (as Cl)

Note A: The endpoint is the *first* appearance of a permanent faint red or dark orange color and *NOT* the deep red color that develops if Silver Nitrate is added past the endpoint.

Note B: Never make the chloride test directly on a sample. The P alkalinity test *must* be conducted first before determining the chloride.

8.2.6 pH (or hydrogen ion concentration) test

A pH measurement by the glass electrode meter is the most accurate method of determining pH; however, this equipment is expensive and is difficult to maintain. Therefore less accurate methods, which are better adapted to field usage, are recommended.

For pH values of 8.5 and below, method A, the colorimetric pH method, is recommended. For pH values above 8.5, determination of the P and M alkalinities and reference to Figure 2 shown in method B is recommended.

Method A - Colorimetric pH method

Apparatus

Taylor pH Slide Comparator, complete with pH Slides (Item 5160 Chlorphenol Red, Item 5161 Bromthymol Blue, Item 5162 Phenol Red, Item 5166 Thymol Red, Item 5167 Meta Cresol Purple)

Indicator Solutions, as follows:

<u>Name</u>	<u>pH range</u>	<u>Color change</u>
Chlorphenol Red, Item 5116	5.2-6.8	Yellow-Red
Bromthymol Blue, Item 5107	6.0-7.6	Yellow-Blue
Phenol Red, Item 5106	6.8-8.4	Yellow-Red
Thymol Red, Item 5108	8.0-11.2	Yellow-Red
Meta Cresol Purple, Item 5105	7.6-9.2	Yellow-Purple

3 Test Tubes, 5 ml (Item 5180)

Taylor Dalite Lamp, 110 v, 60 cycle (Item 5182)

Preparation of sample

The sample should be taken at room temperature, through a cooling coil if necessary, and in such a manner as to prevent contamination and contact with the air. The test should be made immediately after taking the sample, and the sample should not be filtered. The container in which the sample is taken and all three 5 ml test tubes used in the test should be rinsed repeatedly with the sample before making the determination.

Method

- (1) Fill three 5 ml test tubes exactly to the mark with the sample.
- (2) Place in the three center holes in the base of the comparator.
- (3) By means of the pipette in the indicator bottle, add 0.5 ml of the appropriate indicator to the middle tube only, and Stopper the tube.
- (4) Remove the middle tube from the base, mix the sample and the indicator by inverting the tube, and replace the tube in the middle hole.

- (5) Place the comparator base on the shelf of the Dalite lamp.
Turn switch ON.
- (6) Place the pH color slide corresponding to the indicator used on the comparator base.
- (7) Move the pH color standard slide to the right or left until the intensity of the color of the sample is matched by one of the color standards of the slide.

Results

The pH value is the number appearing on the slide, as indicated by the arrow on the base.

Note A: If the sample does not match one of the color standards of the slide, (1) the sample may not be in the pH range of the slide and the test should be repeated using a different indicator and the corresponding pH color standard slide, or (2) the sample may have become contaminated in handling, or (3) the indicator solution may have deteriorated or become contaminated by acid or alkali fumes, dust, etc. In case of contamination, repeat the test with a fresh sample and if necessary employ fresh indicator solution.

Note B: If the pH indicated is at the extreme low end of the pH range of an indicator, as for example, pH 6.8 when using Phenol Red, repeat the test using the lower range indicator, as Bromthymol Blue. If the pH indicated is at the high end of the indicator range, as pH 7.6 with the Bromthymol Blue, repeat the test using the higher range indicator, Phenol Red.

Method B - pH by P and M alkalinity

Method

- (1) Determine P and M alkalinity by methods 8.2.3, 8.2.4 or 8.2.14.
- (2) Now refer to the chart in Figure 2, noting the P alkalinity reading on the horizontal scale, then moving upward on the vertical scale to the M (methyl orange) alkalinity.
- (3) Note the position of the point on the graph; note position compared to the slanting lines labeled pH and estimate the pH.

Example 1

P alkalinity = 30 ppm
M alkalinity = 120 ppm
Estimated pH = 9.8

Example 2

P alkalinity = 49 ppm
M alkalinity = 150 ppm
Estimated pH = 10.1

- (4) Or, determine M/P by dividing the M alkalinity by the P alkalinity and refer to the following table:

<u>M/P</u>	<u>pH</u>	<u>M/P</u>	<u>pH</u>	<u>M/P</u>	<u>pH</u>
60	8.5	7	9.5	3.6	10.0
18	9.0	5.8	9.6	2.9	10.2
10	9.3	4.2	9.8	2.4	10.4

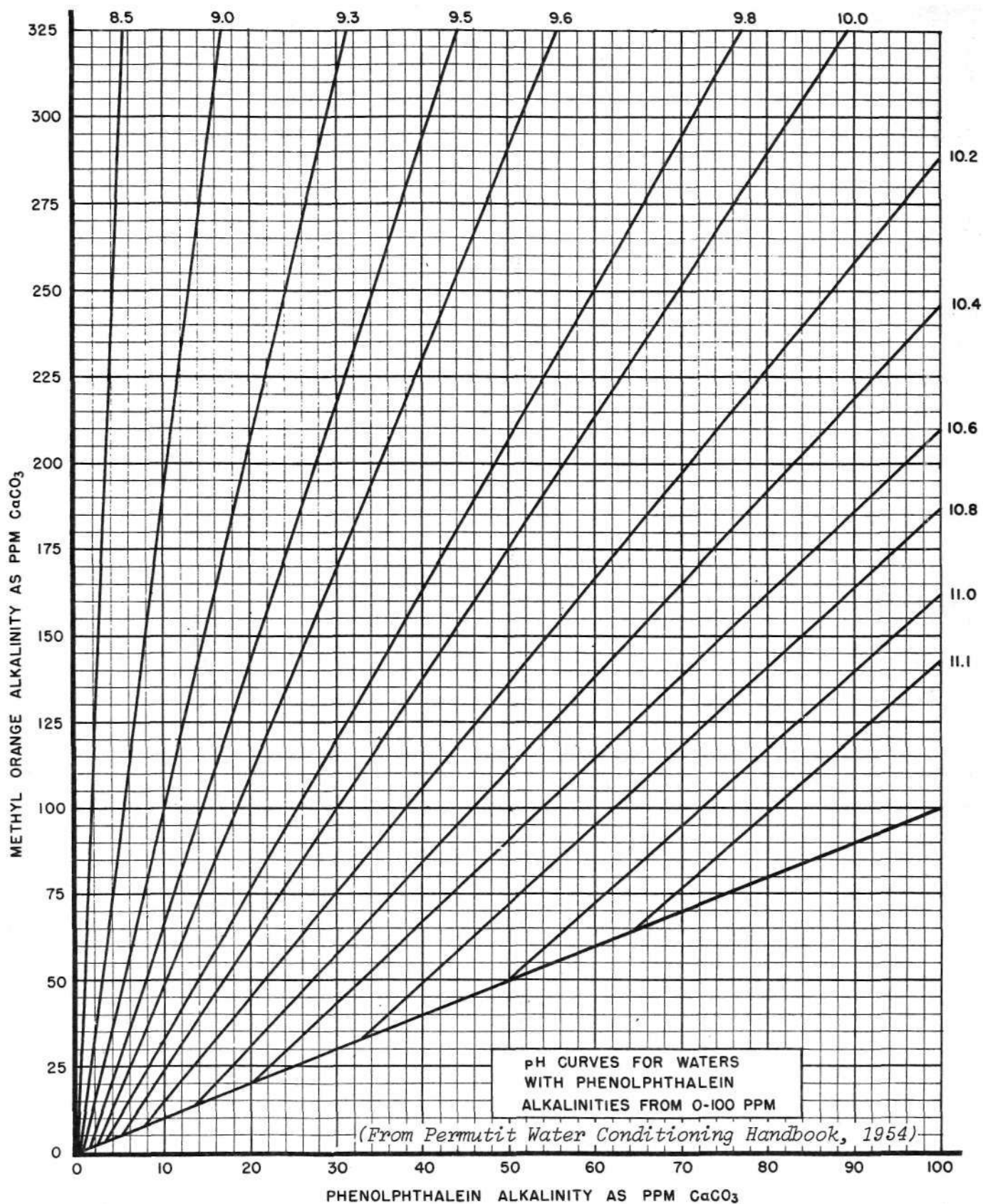


Figure 2. pH determination from P and M alkalinity

8.2.7 Sulfite test (SO₃)

Apparatus

- Burette, 10 ml Automatic (for Standard Potassium Iodide-Iodate) (Item 5155)
- Graduated Cylinder (Item 5150)
- Porcelain Casserole (Item 5152)
- Stirring Rod (Item 5153)
- 1 Plastic Dipper (for 1.0 gm Dual Purpose Starch Indicator) (Item 5198)
- 1 oz Bottle, with dropper (for Phenolphthalein Indicator) (Item 5154)

Reagents

- Standard Potassium Iodide-Iodate (1 ml = 0.5 mg SO₃) (Item 5068)
- Phenolphthalein Indicator (Item 5033)
- Dual Purpose Sulfite Indicator (Item 5072)

Method

- (1) Add 1 plastic dipper (1.0 gm) of Dual Purpose Starch Indicator to casserole.
- (2) Measure the amount of water to be tested in the graduated cylinder in accordance with:

<u>Sulfite (SO₃)</u>	<u>Recommended size of sample</u>	<u>Factor</u>
Up to 100 ppm	50 ml	10
100-500 ppm	10 ml	50

- (3) Pour into the casserole.
- (4) *Stir well.*
- (5) Add 3 drops of Phenolphthalein Indicator to the casserole.
- (6) If solution turns red, add more Dual Purpose Indicator, until the solution returns to its original color.
- (7) Squeeze the Standard Iodide-Iodate Solution from the plastic bottle to just above the zero mark on the burette, then allow excess solution to drain automatically back to the bottle.
- (8) While stirring the sample constantly with the stirring rod, add Potassium Iodide-Iodate drop by drop from the burette to the casserole until a faint but permanent blue color appears. This is the endpoint. Be careful not to over-titrate the endpoint. Read burette to nearest 0.1 ml (as 1.2 or 1.8).

Results

When testing a 50 ml sample:

Burette reading in ml $\times 10$ = ppm sulfite (as SO_3)

Example: 2.8 ml $\times 10$ = 28 ppm sulfite (as SO_3)

Note A: To insure the most accurate results, the sample should be collected without contact with the air, cooled below 120 F, and tested promptly.

Note B: The accuracy of this test is affected by any oxidizable substance in the water sample, such as organic matter or sulfides, which may cause the sulfite reading to be higher than the amount actually present.

8.2.8 Phosphate test (PO₄)

Apparatus

Taylor High Phosphate Comparator, complete, range 5 to 100 ppm (Item 5159)
High Phosphate Mixing Tube graduated at 5, 15, and 17-1/2 ml, with rubber stopper (Item 5183)
2 Test Tubes, 5 ml (Item 5180)
Dispensing Bottle, pint size (for Molybdate Reagent) (Item 5158)
Funnel (Item 5156)
Filter Paper, Whatman #5, 12-1/2 cm diameter (Item 5109)
Taylor Dalite Lamp, 110 v, 60 cycle (Item 5182)
Brass Measuring Cup, 0.1 gm size (Item 5197)
Test Tube Cleaning Brush (Item 5201)

Reagents

Phosphate Indicator Powder (Item 5075)
Molybdate Reagent Solution* (Item 5084)
 *[*Contains strong acids and should be handled with caution.]*
Distilled Water

Preparation of water sample to be tested

It is imperative that the water sample to be tested is free from suspended matter or sludge. Mere traces will cause serious errors. Filter the water through the same filter paper as many times as required to produce a clear sample. A new filter paper should be used for each test conducted.

Method

- (1) Fill the phosphate mixing tube to the 5 ml (bottom) mark with the filtered water sample.
- (2) Fill to the 15 ml (middle) mark with Molybdate Reagent.
- (3) Add two level measuring cups full of the Phosphate Indicator Powder to the phosphate mixing tube.
- (4) Insert the rubber stopper and mix. If a blue color does not develop in 5 minutes, there are no phosphates present, the PO₄ reading is reported as "zero," and the test is discontinued. If phosphates are present, a blue color will develop and the test should be continued.
- (5) Place the phosphate mixing tube in the middle hole of the comparator.
- (6) Fill two 5 ml test tubes with the filtered boiler water and place these test tubes in the holes on either side of the phosphate mixing tube.

- (7) Place comparator on shelf of the Dalite Lamp. Turn switch ON.
- (8) Move the color standard slide to the right or left until the intensity of the color of the sample is matched by one of the color standards of the slide.

Results

The phosphate in ppm is the number appearing on the slide as indicated by the arrow on the base. If the phosphate exceeds 100 ppm, discard the test. Repeat the test, using 2-1/2 ml of the filtered water sample (instead of 5 ml); dilute to the bottom mark (5 ml) with distilled water and repeat the test starting with step 2. Multiply the reading by 2 to obtain PO_4 in ppm.

8.2.9 Chromate test (CrO₄)

Apparatus

Burette, 10 ml Automatic (for N/40 Sodium Thiosulfate) (Item 5155)

Graduated Cylinder (Item 5150)

Porcelain Casserole (Item 5152)

Stirring Rod (Item 5153)

Reagents

NAO Sodium Thiosulfate (Item 5119)

Tri Purpose Chromate Indicator Powder, packets (Item 5121)

Distilled water

Method

- (1) Measure the amount of water to be tested in the graduated cylinder in accordance with:

<u>Chromate (asCrO₄)</u>	<u>Recommended size of sample</u>	<u>Factor</u>
0-100 ppm	50 ml	20
Above 100 ppm	20 ml	50

Dilute the 20 ml sample to 50 ml with distilled water in the graduated cylinder before pouring into the casserole.

- (2) Open one packet of Tri Purpose Chromate Indicator and pour its entire contents into the casserole and stir with the glass rod until the indicator is dissolved.
- (3) Squeeze the Sodium Thiosulfate Solution from the plastic bottle to just above the zero mark on the burette, then allow excess solution to drain automatically back to the bottle.
- (4) Titrate with N/40 Sodium Thiosulfate until the solution turns to a straw yellow. At this point the endpoint is near and the titration should be conducted slowly. The endpoint is when the yellow color disappears and the solution turns to a clear or a light blue color. Read burette to nearest 0.1 ml.

Results

When testing a 50 ml sample:

Burette reading in ml x 20 = ppm chromate (as CrO₄)

Example: 2.0 ml x 20 = 40 ppm chromate (as CrO₄)

8.2.10 Nitrite test (NO₂) (ceric sulfate method)

Apparatus

Burette, 10 ml automatic (for 0.1087 N Ceric Sulfate) (Item 5155)
Graduated Cylinder (Item 5150)
Porcelain Casserole (Item 5152)
Stirring Rod (Item 5153)
1 oz Bottle, with dropper (for Nitrite Indicator) (Item 5154)

Reagents

Ceric Sulfate (0.1087 N) (Item 5122)
Nitrite Indicator Solution (Item 5123)

Method

- (1) Measure 25 ml of the water to be tested in the graduated cylinder and pour into the casserole.
- (2) Add exactly 1 full drop of Nitrite Indicator to the water sample, which will turn red if nitrite is present.
- (3) Squeeze the Ceric Sulfate solution from the plastic bottle to just above the zero mark on the burette, then allow the excess Ceric Sulfate solution to drain automatically back to the bottle.
- (4) While stirring the water vigorously with the stirring rod, add Ceric Sulfate drop by drop from the burette until the red color changes to blue and remains blue for a 15 full seconds. This is the endpoint. Read the burette to the nearest 0.1 ml.

Results

When testing a 25 ml sample:

Burette reading in ml x 100 = ppm nitrite (as NO₂)

Example: 5.6 ml x 100 = 560 ppm nitrite (as NO₂)

8.2.11 Electrical conductivity test (boiler or cooling tower dissolved solids)

The electrical conductivity method is a simple and rapid way to determine the total dissolved solids content. It is based on the principle that ionizable solids in water cause the solution to conduct electricity. The higher the concentration of ionizable salts, the greater the conductance of the sample. Pure water, free from ionizable solids, possesses a very low conductance. The Electrical Conductivity Instrument used for this determination measures the total ionic concentration of the water sample, the value of which may be converted to ppm. Suspended solids or sludge content is not measured, since these solids are not in solution.

Apparatus

Electrical Conductivity Instrument (as Beckman Model RDR104F, RD1811 or older models) for 105-120 volt, 50-60 cycle (1-500 and 20-10,000 or 500-20,000 micromhos range) (Item 5190)

AC electrical outlet

Polystyrene Dip Cell, 2.0 cell constant (Item 5192)

0-220 F Dial Thermometer (Item 5194)

100 ml Capacity Cylinder, not graduated (Item 5193)

Brass Measuring Cup, 0.1 gm size (for Gallic Acid) (Item 5197)

Reagents

Phenolphthalein Indicator Solution (Item 5033)

Gallic Acid (Item 5057)

Method

- (1) Connect instrument to 110 v ac electrical outlet, connect dip cell and turn instrument switch to the "on" position.
- (2) Pour approximately 50 ml of sample into cylinder (sufficient to cover air vents in dip cell).
- (3) Add 2-4 drops of Phenolphthalein Indicator and sufficient Gallic Acid to change the solution from pink to colorless. (Usually 2 brass measuring cupfuls are sufficient.)
- (4) Determine temperature of sample with the thermometer, and set the pointer on the instrument temperature dial accordingly.
- (5) Now immerse the dip cell in the sample and move the cell up and down several times under the level of the water surface to remove air bubbles inside the cell shield. (Keep the dip cell at least 1/2 inch off the bottom of the cylinder when taking the following reading.)
- (6) Now adjust the upper instrument dial until the dark segment of the tube reaches its widest opening.

Results

Report the results in micromhos, as read from the dial. The results in ppm may be calculated by multiplying the dial reading by 0.9.

8.2.12 Electrical conductivity test (condensate dissolved solids)

The presence of mineral solids in condensate, caused by contamination of condensate by raw, softened water or other contaminants, may be determined by an electrical conductivity instrument having a range of measurement of 1-500 micromhos.

The detection of mineral solids in condensate is very important since the presence of raw or softened water in the condensate system will cause over-loading of the feedwater system, which will result in increased scale and corrosion and decreased efficiency of the entire power plant.

Apparatus

Electrical Conductivity Instrument (as Beckman Model RDR104F, RD181I or older models) (1-500 micromhos and 20-10,000 or 500-20,000 micromhos), 105-120 volt, 50-60 cycle, complete (Item 5190)

AC electrical outlet

Polystyrene Dip Cell, 0.1 cell constant (Item 5191)

Dial thermometer (Item 5194)

100 ml Capacity Cylinder, not graduated (Item 5193)

Reagents

None

Method

- (1) Allow condensate to flow for several minutes before sampling (see 8.1.2). Rinse container several times with the sample before collecting for analysis. Collect sample in a clean glass container (used specifically for condensate) and preferably cool by passage through small heat exchanger.
- (2) Connect instrument to 110 v ac electrical outlet, connect dip cell, and turn instrument switch to the "on" position.
- (3) Pour approximately 50 ml of sample into cylinder, rinse electrode and thermometer, take temperature reading and set temperature dial accordingly.
- (4) Cell should rest 1/2 inch or more off the bottom of cylinder when adjusting the upper instrument dial to its widest opening in the dark segment of the tube. Repeat rinsing until consistent reading is obtained.

Results

Report the results in micromhos, as read from the dial. The results in ppm may be calculated by multiplying the dial reading by 0.6.

Note A: Values above 20 micromhos are usually an indication that raw or softened water contamination is occurring.

8.2.13 Test to check conductivity instrument and electrode

The electrical conductivity instrument should be checked weekly for accuracy by testing the conductivity of a known solution (Item 5021, 5022, N/50 Sulfuric Acid),

Since all models of conductivity testers have not been standardized by the manufacturer at the same temperature, the conductivity of N/50 acid may be different. Originally conductivity testers were standardized at 18 C (64 F) and later at 25 C (77 F). Dependent on the model number of conductivity testers manufactured by Beckman Instruments, the conductivity of N/50 acid (Item 5021, 5022) should be as follows:

<u>Model number</u>	<u>Conductivity of N/50 acid (micromhos)</u>
Electrical Conductivity Instruments (Solu-Bridge 1-99; or 200-299; or all Betz Conducto Bridges) (Item 5190)	4300-5300
Electrical Conductivity Instrument (Solu-Bridge 100-199, or 300-399; dual range model RD1251, RDR104F or RD181I) (Item 5190)	5000-6200

Instructions for conducting the test are as follows:

- (1) Connect instrument to 110 v ac electrical outlet, turn on instrument switch, then connect dip cell and place in ungraduated plastic cylinder (Item 5193).
- (2) Pour sufficient N/50 Sulfuric Acid (Item 5021, 5022) into cylinder to cover air vents of dip cell, usually about 50 ml.
- (3) After immersing dip cell in the sample, move cell up and down several times under the level of the water to remove air bubbles inside the cell shield.
- (4) Determine the temperature of the sample with the dial thermometer (Item 5194) and set the temperature dial on the instrument accordingly.
- (5) When adjusting upper instrument dial to its widest opening of the dark segment of the "electric eye" tube, keep the dip cell at least 1/2 inch off the bottom of the cylinder.

Results

Report the result in micromhos shown on the large dial. The results should be reported weekly in the upper left hand corner of the boiler water control report.

In case the results are not within the specified ranges shown above, the electrode should be soaked in successive lots of N/50 Sulfuric Acid, or if a more rapid cleaning procedure is preferred, it may be immersed *for 1 minute only* in (1:1) Sulfuric Acid (Item 5062) or in (1:1) Hydrochloric Acid. After the cleaning procedure, the electrode should be

rinsed with water, then retested with a fresh lot of N/50 Sulfuric Acid. If the proper test is then not obtained, it is likely that the electrode requires replatinization, repair, or replacement. The electrode may be sent to the State Water Survey for replatinizing.

A spare electrode (Item 5192) should be kept on hand at all times. However if not available, the State Water Survey will be glad to loan an electrode or an instrument, or both, upon request.

8.2.14 Mixed indicator (total) alkalinity test

Apparatus

Burette, 10 ml automatic (for Standard Sulfuric Acid) (Item 5155)
Graduated Cylinder (Item 5150)
Bottle, with dropper (for Mixed Indicator) (Item 5112)
Porcelain Casserole (Item 5152)
Stirring Rod (Item 5153)

Reagents

Standard Sulfuric Acid, N/50, (1 ml = 1 mg CaCO_3) (Item 5021, 5022)
Mixed Indicator (Bromcresol Green - Methyl Red) (Item 5112)

Method

- (1) Add 2-4 drops of Mixed Indicator to the water in the casserole remaining from the phenolphthalein alkalinity test. If the water changes to a light pink or red color, free mineral acid is present. There is therefore no alkalinity present and the "M" reading is reported as "zero." If the water changes to a green or blue green color, "M" alkalinity is present and the test is continued.
- (2) Do not squeeze the standard sulfuric acid from the plastic bottle back to the zero mark on the burette, but leave it at the reading shown at the endpoint of the "P" alkalinity test.
- (3) While stirring the water constantly with the glass rod, add standard sulfuric acid drop by drop from the burette to the casserole until the green or blue green color changes to a light pink.

Results

When testing a 50 ml sample:

Burette reading in ml times 20 = ppm "M" alkalinity (as CaCO_3)

Example: 16.5 ml $\times$ 20 = 330 ppm "M" alkalinity (as CaCO_3)

When testing a 10 ml sample:

Burette reading in ml times 100 = ppm "M" alkalinity (as CaCO_3)

Example: 3.1 ml $\times$ 100 = 310 ppm "M" alkalinity (as CaCO_3)

8.2.15 Acidity

This test is generally required only for testing water treated with acid or for testing the effluent from a dealkalizing type ion exchanger, which is regenerated with acid. Water samples collected at these locations will usually test acid (pink) to methyl orange and must be titrated with a standard alkali solution in order to obtain an evaluation of acidity.

Apparatus

- Burette, 10 ml automatic (for Standard Sodium Hydroxide) (Item 5111)
- Graduated Cylinder (Item 5150)
- Porcelain Casserole (Item 5152)
- Two bottles with droppers (for Phenolphthalein Indicator (Item 5154 and Methyl Orange Indicator (Item 5154 or Mixed Indicator (Item 5112))
- Stirring Rod (Item 5153)

Reagents

- Standard Sodium Hydroxide (N/50) (Item 5111)
- Phenolphthalein Indicator (Item 5033)
- Methyl Orange Indicator (Item 5029) or Mixed Indicator (Item 5112)

Method

- (1) Measure a 50 ml sample and pour into casserole.
- (2) Add 2-4 drops of Methyl Orange Indicator or Mixed Indicator. If the water does not change to a pink or red color, there is no methyl orange acidity and the "M" reading is reported as "zero." If the water does change to a pink or red color, Methyl Orange acidity is present and the test should be continued.
- (3) Squeeze the Sodium Hydroxide from the plastic bottle to just above the zero mark on the burette, then allow the excess acid to drain automatically to the bottle.
- (4) While stirring the water with the glass rod, add Standard Sodium Hydroxide drop by drop from the burette to the casserole until the pink color changes to faint orange when using Methyl Orange or until the pink color changes to green or blue green when using Mixed Indicator. This is the endpoint. Read the burette to the nearest 0.1 ml and record after multiplying by 20 as the "M" acidity.
- (5) Do not discard the sample and do not squeeze the Standard Sodium Hydroxide from the plastic bottle back to the zero mark on the burette, but leave it at the reading shown at the endpoint of the Methyl Orange ("M") Acidity test.

- (6) Add 2 drops of Phenolphthalein Indicator.
- (7) If the sample turns pink, report the "P" acidity the same as the "M" acidity.
- (8) If the sample does not turn pink, add a separate 50 ml sample to a clean casserole and add 2 drops of Phenolphthalein Indicator. Then, while stirring the water slowly with the glass rod, add Standard Sodium Hydroxide drop by drop from the burette to the casserole until a faint pink color appears (lasting at least 10 seconds). This is the endpoint. Read the burette to the nearest 0.1 ml and record after multiplying $\times 20$ as the Phenolphthalein ("P") acidity.

Results

When testing a 50 ml sample and using Methyl Orange or Mixed Indicator

Burette reading in ml times 20 = ppm "M" acidity

When using Phenolphthalein Indicator

Total burette reading in mls times 20 = ppm "P" acidity

8.2.16 Alkalinity in condensate

The purpose of this test is to determine the approximate amine content, so that the proper control of amine treatment may be maintained.

After collecting the condensate sample as directed in 8.1.2, the P and M alkalinity test is conducted.

Apparatus

Burette, 10 ml automatic (for Standard Sulfuric Acid) (Item 5155)
Graduated Cylinder, 100 ml (Item 5151)
Porcelain Casserole (Item 5152)
Two bottles with droppers (for Phenolphthalein Indicator (Item 5154) and Methyl Orange Indicator (Item 5154 or Mixed Indicator (Item 5112))
Stirring Rod (Item 5153)

Reagents

Standard Sulfuric Acid (N/50) (1 ml = 1 mg CaCO_3) (Item 5021, 5022)
Phenolphthalein Indicator (Item 5033)
Methyl Orange Indicator (Item 5029) or Mixed Indicator (Item 5112)

Method

- (1) Mark a 100 ml graduated cylinder and casserole to be used for condensate analytical purposes only.
- (2) After rinsing cylinder and casserole with the condensate sample several times, measure 100 ml sample and add to casserole.
- (3) Add 2-4 drops of Phenolphthalein Indicator. If the sample remains colorless, record "P" alkalinity as zero.
- (4) If sample is pink, add N/50 Sulfuric Acid until sample is colorless. This is the endpoint. Read burette to nearest 0.1 ml.
- (5) Do not squeeze the Standard Sulfuric Acid from the plastic bottle back to the zero mark on the burette, but leave it at the reading shown at the endpoint of the P alkalinity test.
- (6) Now add 2-6 drops of Methyl Orange Indicator or Mixed Indicator and continue titration with N/50 Sulfuric Acid to a pink endpoint. Read the burette to the nearest 0.1 ml.

Results

Burette reading to phenolphthalein endpoint $\times 10$ = ppm P alkalinity (as CaCO_3)

Total burette reading to methyl orange or mixed indicator $\times 10 =$
ppm M alkalinity (as CaCO_3)

Example: 0.8 ml required to phenolphthalein endpoint $\times 10 =$
8 ppm P alkalinity

Example: 1.6 ml required to methyl orange endpoint $\times 10 =$
16 ppm M alkalinity

Interpretation

Usually it is recommended that the P alkalinity be maintained at a slight positive value, but below 6 ppm and that the M alkalinity be maintained below 30 ppm.

9. REFERENCE MATERIAL

The following books may be referred to for further information on water testing methods and water treatment:

Annual Book of ASTM Standards, Part 23, Water; Atmospheric Analyses, 1971, American Society for Testing and Materials

Betz Handbook of Industrial Water Conditioning, 1962, Betz Laboratories, Inc., Trevose, Pa. 19047

Boiler-Water-Treatment Manual for Federal-Plant Operators, Handbook 5, Goldman, 1951, U. S. Government Printing Office, Washington, D. C. 20401

Cooling Water, It's Chemistry and Fundamentals, 1971 Wright Chemical Corp., Chicago, Illinois 60622

High Temperature Water Systems, Lieberg, 2nd Ed., 1963, The Industrial Press, New York 13, N. Y.

Introduction to Chemistry of Industrial Boiler Water, 1965, Wright Chemical Corp., Chicago, Illinois 60622

Industrial Water Treatment Practice, Hamer, Jackson, and Thurston, 1971, Butterworth Inc., Washington, D. C.

Manual on Industrial Water, STP442, 1969, American Society for Testing and Materials

Questions and Answers on Boiler-Feedwater Conditioning, Berk, 1962, U. S. Dept. of Interior, Bureau of Mines, U. S. Government Printing Office, Washington, D. C. 20401

Standard Boiler Operators' Questions and Answers, Elonka, 1969, McGraw-Hill, Inc., New York, N. Y.

Standard Methods for the Examination of Water, Sewage and Industrial Wastes, Thirteenth Edition, 1971, American Public Health Association

Water Treatment for Industrial and Other Uses, Nordell, Second Edition, 1961, Reinhold Publishing Corp.

Water is Everybodys ' Business, Behrman, 1968, Doubleday Book Co., Inc.

Water Quality and Treatment, 3rd Edition, 1971, McGraw-Hill, Inc., New York, N. Y.

APPENDIX A. PREPARATION OF WATER TEST REPORTS

The purpose of water testing and the reporting of tests is to attain proper water treatment by accurate and efficient control, and as a result, to eliminate serious operating outages and high maintenance costs. As the appropriate tests are made, the results are recorded on one of the five report forms discussed below. Reference to these water treatment records then shows clearly any changes in tests, chemical dosages, and operation, so the significance of such changes can be studied to determine the need for action.

The five water treatment reports are entitled Boiler Water Control Report, Cooling Water Treatment Report, Hot Water Treatment Report, Cold Process Softener Control Report, and Lime Soda Softener Control Report. The use of these forms will vary slightly from plant to plant because of differences in the equipment, and may vary from time to time because of changing problems. The completed report forms are sent each week to the State Water Survey.

The water treatment reports should be prepared neatly and in complete form. The name of the institution and the date should be included at the top of each report. Upon completion of testing, each operator should sign his initials on the report opposite his testing results. When the report is completed, it should be signed by the Chief Engineer and by the Superintendent or Warden of the institution or by the Director of the Physical Plant before mailing each week to the following address:

Illinois State Water Survey
Att: R. W. Lane
Box 232, Urbana, Illinois 61801

AI. Boiler Water Control Report (Fig. AI)

Complete and accurate boiler water test results should be reported daily. In the larger plants that operate more complicated water treating equipment, tests each shift are recommended. In plants employing direct acid treatment, tests of the make-up or feedwater alkalinity are recommended every 4 hours.

The electrical conductivity test (8.2.13) on N/50 sulfuric acid should be conducted weekly to determine whether the electrical conductivity instrument is performing correctly. The results are recorded in the space after *Electrode Test*, near the upper left hand corner under *Boiler Tests*.

All boiler water tests shown on the control chart should be recorded under the *Boiler Tests* columns. The control chart limits should be shown in the spaces provided above the test results.

A test for domestic hot water hardness need not be conducted unless blending or hot water treatment is applied, in which case it is recommended that a test be conducted once weekly or more often. Domestic cold water tests for hardness and P and M alkalinity should be conducted once weekly and reported only if a surface water supply that varies in hardness is being used.

Make-up hardness, feedwater hardness and alkalinity, and condensate hardness and dissolved solids or M alkalinity should be tested and reported at least once daily.

The pounds of chemical applied to all boilers daily (or when the chemical vat is charged) should be recorded under the chemicals listed under the *Treatment* columns. If the chemical applied is not listed, the name of the chemical should be written in the unlabeled column.

The number of manual blowdowns per day and the continuous blowdown valve setting should be listed in the *Blowdown* columns. This record is particularly helpful to subsequent shift operators to enable them to adjust the blowdown according to the test.

The pounds of steam produced by all boilers and the total make-up gallons should be recorded daily in the columns under *Total for All Boilers*. The pounds of steam produced is preferred to the amount of fuel burned unless flowmeters are known to be inaccurate.

A2. Cooling Water Treatment Report (Fig. A2)

The frequency of the *Water Tests* varies. In cooling towers employing acid treatment and in cooling towers for turbine condensers, *daily tests* should be conducted for hardness or dissolved solids, chromate, and for M alkalinity (if acid treatment is employed). Tests *once to three times weekly* are prescribed for towers employed for air conditioning. The number of tests conducted weekly should depend on the importance of the cooling installation and the difficulties of control.

The pounds of scale preventive (Item 63) employed daily or weekly (or when the chemical vat is charged) should be recorded in the *Organic* column under *Treatment*. The pounds of acid (as Item 20, 21, 27, 38, or 59) and chromate (as Item 34, 43, 61, or 64) employed daily or weekly (or when the chemical vat is charged) should be recorded in the *Acid* and *Chromate* columns. Under *Algae Preventives*, the pounds of Item 46 Calcium Hypochlorite or Item 60 Sodium Pentachlorophenate applied to the

Figure A2Figure A3

cooling tower daily or weekly should be recorded. The continuous blow-down valve setting or timer setting (if blowdown is individually timer controlled) should be recorded under *Blowdown*. The metered gallons of make-up water used daily or weekly (or between chemical vat charges) should be recorded in the *Make-up* column.

A3. Hot Water Treatment Report (Fig. A3)

Institutions applying caustic soda, sodium silicate, or carbon dioxide to the domestic hot water system to control corrosion and scale should prepare and mail this report weekly. The blending valve setting should be recorded in the upper left hand corner of the report, and the water temperatures should be entered on the center line near the bottom of the report.

Tests for hardness (not calcium), P and M alkalinity, and pH are required once daily. Tests *Before Treatment* are required only at the following institutions: Pontiac Penitentiary, Galesburg State Research Hospital, A. L. Bowen Children's Center, and Kankakee State Hospital. At the State Reformatory for Women at Dwight, these columns are used for recording the analysis of the distribution water near the point of chemical application and the *After Treatment* columns are used to record the analysis of the distribution system near the extremity of the system.

Under *Treatment*, the water meter readings, the gallons of water treated, and the pounds of chemical (in lb/10,000 gal) should be recorded by all the above institutions each time the chemical vat is charged. At institutions where only Item 32 Liquid Sodium Silicate is applied, 4/5 pint of Item 47 Sodium Hypochlorite (or 1 ounce of Item 46 Calcium Hypochlorite) per 100 gallons of the chemical vat should be applied and recorded each time the vat is charged.

A4. Cold Process Softener Control Report (Fig. A4)

Only institutions that have cold process softener equipment are required to make this weekly report. These include: Menard Penitentiary, Illinois State Farm, Vienna Penitentiary, Anna State Hospital, and Tinley Park Mental Health Center.

Daily complete analyses including calcium and magnesium of *Raw Water* (except Tinley Park), *Softener Effluent* or *Filter Influent*, and *Filter Effluent* should be conducted and reported. In cases of changeable raw water analyses, it may be necessary to make all of these analyses more frequently to provide proper control. At Tinley Park, only a weekly analysis of the raw well water is necessary, since this analysis should be relatively constant. The 2P-M value, calculated by multiplying the

phenolphthalein alkalinity by 2 and subtracting the M alkalinity, is a measure of excess lime treatment, which must be controlled to obtain proper softening as specified in the softener control chart. The M-H value, obtained by subtracting hardness from the M alkalinity, is a measure of the soda ash treatment which must also be controlled to obtain proper softening as specified in the softener control chart. Under *Chemical Dosage*, either chemical dosages or the feeder settings should be recorded in the labeled chemical columns.

The *Slurry Level* is the level of sludge below the water surface in the softened water outlet area of the cold process softener and should be determined by measurement and recorded. The *Draft Tube* sludge is sampled from the draft tube (center portion) of the cold process softener and is determined by collecting a 100 ml sample in a graduated cylinder and observing the percentage of settled sludge after 5 minutes. Under the *Concentrator* columns, the number of concentrators being operated, the timer setting of the concentrators, and the sludge volume of concentrator sludge samples should be recorded daily. The sludge volumes of the concentrator sludge samples are determined by the same method used for determining draft tube sludge.

The following also should be recorded daily: 1) the period of time that the main sludge valve is opened; 2) the propeller RPM of softener; 3) the temperature of the inlet water; and 4) the total volume of treated water.

A5. Lime Soda Softener Control Report (Fig. A5)

This report on hot process lime soda softener tests is required only from Pontiac Penitentiary, Illinois Soldiers & Sailors Children's School, and Peoria State Hospital, the only State institutions having this equipment.

The *Chemical Tests* are required each shift and are very similar to those required for the cold process softener, except that calcium and magnesium determinations are not required. The 2P-M results, which are a measure of the excess lime treatment, are obtained by multiplying the phenolphthalein alkalinity by 2 and subtracting the M alkalinity. The M-H results, which are a measure of the soda ash treatment, are obtained by subtracting the hardness from the M alkalinity. Recommendations are given in the softener control chart as to the 2P-M and M-H results for proper softening.

The *Middle Sludge Volume* is determined by sampling 100 ml of the sludge from the middle sampling valve in the bottom cone of the softener in a 100 ml graduated cylinder. The sludge volume in the cylinder after 5 minutes is recorded in the labeled column.

The *Setting* refers to the timer setting of the proportioning

Institution _____ week ending _____, 19____

Figure A5

equipment, which is actuated by the electriccontact water meter. This setting is raised or lowered to increase or decrease the amount of chemical to be applied.

The Chemicals Per Inch refers to the pounds of hydrated lime, soda ash, and sodium aluminate dissolved per inch in the softener chemical tank.

Inches Per Charge is the inches of chemical solution added to the chemical tank each time the chemical tank is charged. For example, if 4 lb lime, 2 lb soda ash, and 1/4 lb sodium aluminate are applied per inch, and a 6-inch charge of chemicals is applied, the operator should dissolve $6 \times 4 = 24$ lb lime, $6 \times 2 = 12$ lb soda ash, and $6 \times 1/4 = 1\text{-}1/2$ lb sodium aluminate in 6 inches of water in the tank and mix well before starting proportionate treatment.

The water meter readings are taken and recorded each time the tank is charged to give the gallons treated. Then the *Gallons of Water Treated Per Inch* is calculated by dividing the gallons treated by the inches of chemical charged. Comparing this value with the operating recommendations and with past records provides a measure of the accuracy of the chemical proportioning.

APPENDIX B. GRADING FEEDWATER TREATMENT EFFICIENCY

Each year the State Water Survey reviews the water treating operations at each of the State plants, grades these operations, and makes recommendations to the Award Committee that awards be made to institutions having certain grade levels. The Award Committee consists of the following personnel: R. J. Coleman, Chief Supervising Engineer, Department of Mental Health; Prof. E. F. Hebrank, Mechanical Engineering Department, University of Illinois; W. B. Manker, Chief Mechanical Engineer, Department of General Services; and R. W. Lane, Senior Chemist, Illinois State Water Survey.

Present recommendations are that institutions receiving a grade of 85 and above receive the Standard Certificate, and that institutions receiving a grade of 92 and above receive a Superior Certificate.

The following six classifications are included in calculating the final grade:

- (A) Adequacy of weekly water treatment reports
- (B) Observance of treatment control from monthly water sample analysis reports
- (C) Inspection of water testing facilities
- (D) Inspection of water treating equipment
- (E) Adequacy of water treating chemical supplies
- (F) Consideration for difficult water treatment control

Classification (A) on weekly water treatment reports (20 point total) is graded as follows:

Submission of reports:	All received	0
	1 not received	-1
	2 not received	-2
	3 not received	-3
	4 not received	-4
Submission of N/50 acid conductivity report:	100% reported during year	0
	75% reported during year	-1
	50% reported during year	-2
	25% reported during year	-3
	0% reported during year	-4

Submission of stored boiler water report:	100% reported during year	0
	67% reported during year	-1
	33% reported during year	-2
	0% reported during year	-3
Promptness in submitting reports:	On time	0
	Slightly late	-1
	Very late	-2
Legibility:	Good	0
	Fair	-1
	Poor	-2
Accurateness:	Acceptable	0
	Questionable	-5
Completeness:	Complete	0
	Incomplete	-1 to -2

The classification (B) on treatment control from monthly water sample analysis (total 30 points) is graded as follows:

Water analyses completed during the year are examined, and the degree of compliance with recommendations is evaluated. Analyses are graded as excellent (6 points), satisfactory (4 points), fair (2 points), and poor (0 points). The total points are averaged, and reference is then made to the following chart to decide the amount of the 30 points to be awarded.

<u>Average</u>	<u>Points Awarded</u>
6.0	30
5.0	28
4.0	25
3.5	18
3.0	15
2.5	13
2.0	10
1.0	5
0.0	0

An additional +2 points is added for excellent control, +1 for good control.

Grading for classification (C) is based on inspection of water testing facilities during plant visits (total 20 points). The test facilities should be properly designed for efficient testing, should be clean and neat, and should have all bottles and equipment properly labeled.

Comparisons of all testing facilities are made, and top grades are awarded to the most satisfactory facilities.

Classification (D) is based on inspection of water treating equipment during plant visits (total 10 points). The equipment should be proper, and should be kept continuously in good operating condition and in a cleanly condition.

Classification (E) on water treating chemicals (total 10 points) is based on whether chemicals are kept in adequate quantity and under proper storage conditions. If supplies become exhausted and reasonable efforts are not made to obtain replacement, the grade will be lowered.

In classification (F) for difficult water treatment control, a grade of 10 is awarded to institutions employing acid treatment or hot lime-soda treatment, and to institutions employing waters which are particularly difficult to treat. Lesser points are awarded to institutions employing the simpler zeolite-softened water treatment control.

APPENDIX C. INSTRUCTIONS ON FORMS AND PROCEDURES

The purpose of this section is to furnish instructions for clerical help entering the engineering division of the physical plant service for the first time. It establishes uniform procedures and instructions for the preparation and use of report forms prepared by the staff in the office of the Chief Engineer.

A list of all the necessary forms concerning the operation of the Engineering Section of the Plant Operations is set forth, together with procurement and distribution instructions. Procurement of forms is the responsibility of the Business Manager through a written request by the Engineering Section.

C. 1 List of Forms

These instructions pertain to the following report forms:

WM-1		Repair Requisitions
WM-4		Repair Order
WM-5		Work Request
WM-6		Job Order Summary
PH-175		Power Plant Daily Report - Generating and Heating
PH-175A		Power Plant Daily Report, High Temperature Hot Water System
PH-175B		Mechanical and Electrical Daily Log - Heating Plant Only
PH-175C		Mechanical and Electrical Daily Log - Low Pressure System
PH-176		Chief Engineer's Monthly Operation Report
PH-187		Annual Power Plant (Heat)
PH-188		Annual Power Plant (Water & Electricity)
SE-F		Monthly Fluoridation Report (Required only for activities having own source of supply)
SE-30C		Monthly Chlorination Report
SE-31A		Operations and Chemical Report on Water Purification (Surface Water)
SE-31B		Bacteriological Report on Water Supply
SE-31C		Operational and Chemical Report on Water Purification (Ground Water Supplies -- Lime or Zeolite Softened)
SE-SP2		Swimming Pool Report
SWB-Form	4	Trickling Filter Plant Sewerage Treatment Plant Report
SWB-Form	4B	Activated Sludge Plant Sewerage Treatment Plant Report

ISWS Boiler Water Control Report
 Lime Soda Softener Control Report
 Cooling Water Treatment Report
 Cold Process Softener Control Report
 Hot Water Treatment Report

C.2 Preparation of Forms

All forms are prepared by the staff of the chief engineer with the exception of WM-5 which is prepared by the supervisor of the specific activity and then forwarded to the assistant superintendent, for approval prior to submission to the chief engineer for preparation of the (WM-1) repair requisition.

C.2.1 Department of Mental Health. The following forms are prepared daily by personnel in the Power House.

PH-175
PH-175A
PH-175B
PH-175C

PH-176 is prepared monthly by office staff.

PH-187 and PH-188 are compiled monthly, and the yearly summary is forwarded annually, to reach the General Office not later than 30 days after the end of the fiscal year.

C.2.2 Department of Public Health. The following reports are compiled daily, and the monthly summary is forwarded once a month as set forth in C.4.

SE-F
SE-30C
SE-31A
SE-31B
SE-31C
SE-SP2
SWB-Form 4
SWB-Form 4B

C.2.3 Illinois State Water Survey. The following reports are compiled daily, and the weekly summary is forwarded to the Illinois State Water Survey. (See Appendix A for details on preparation.)

Boiler Water Control Report
Lime Soda Softener Control Report
Cold Process Softener Control Report
Hot Water Treatment Report
Cooling Water Treatment Report

C . 3 Procurement of Forms

C.3.1 From Printing Section. The following report forms are-
ordered from the Printing Section, Department of General Services,
and shall be ordered on Printing Requisition (Form F-5P) with cost
as noted.

WM-1 Repair Requisition (Cost: 18¢ per pad)
WM-4 Repair Order (Cost: 90¢ per pad)
WM-5 Work Request (Cost: 46¢ per pad)

C.3.2 From Central Stores. The following report forms are ordered
from the Department of Mental Health Central Stores on Form
DMH-508 at no charge.

PH-187
PH-188
WM-6
PH-175
PH-175A
PH-175B
PH-175C
PH-176

C.3.3 From Public Health. The following report forms are ordered
from the Department of Public Health, Division of Sanitary
Engineering, 535 West Jefferson, Springfield, Illinois
62706, at no charge.

SE-F
SE-30C
SE-31A
SE-31B
SE-31C
SE-SP2
SWB-Form 4
SWB-Form 4B

C.3.4 From Water Survey. The following report forms are ordered
from the Illinois State Water Survey, Box 232, Urbana, Illi-
nois 61801, at no charge.

Boiler Water Control Report
Lime Soda Softener Control Report
Cold Process Softener Control Report
Hot Water Treatment Report
Cooling Water Treatment Report

C.4 Distribution of Forms

Completed forms are distributed (at the time intervals specified in C.2) to the following locations.

WM-1-4	Original	- Shops (no copy)
WM-6	Original	- Chief Engineer Office (no copy)
PH-176	Original	- General Office
	Copy	- Office of the Supervising Architect 703 State Office Building Springfield
	Copy	- File
PH-187	Original	- General Office
PH-188	Copy	- Office of the Supervising Architect 703 State Office Building Springfield
	Copy	- File
SE-F	Original	- Division of Sanitary Engineering
SE-30C		Department of Public Health
SE-31A		535 West Jefferson
SE-31B		Springfield
SE-31C	copy	- General Office
SE-SP2	Copy	- File
SWB-Form4	Original	- Sanitary Water Board
SWB-Form4B		Department of Public Health
		535 West Jefferson
		Springfield
	Copy	- General Office
	Copy	- File
Water Survey Reports	Original	- Illinois State Water Survey Attention: R. W. Lane Box 232, Urbana, Illinois 61801
	Copy	- File

APPENDIX D. PREPARING ANNUAL POWER PLANT REPORTS

D.I Report PH 187, Heat (Fig. DI)

The methods for calculating and preparing the *Annual Power Plant Report* PH 187 were published November 1, 1972. These methods were reviewed and explained at the Twenty-Fifth Annual Short Course, October 23-27, 1972, and should be in accordance with the following procedures. Items are discussed and numbered here in the order of the columns in which they appear on the form.

- ① *Boiler Pressure Psig.* The boiler pressure is read directly from a gauge on the boiler in pounds per square inch (gauge) and is recorded on the mechanical daily log (forms 175B,C) at the given hour. The average boiler pressure for the month is recorded on the annual power plant report (form PH 187).

The Annual Data recorded on the bottom line is the average pressure for the 12 months.

- ② *Feedwater.* The feedwater temperature is read to the nearest degree Fahrenheit from the thermometer in the feedwater heater discharge line and is recorded hourly on the mechanical daily log (forms 175B,C). The average feedwater temperature for the month is recorded on the annual power plant report (form 187).

The Annual Data recorded on the bottom line is the average of the feedwater temperatures for the 12 months.

- ③ *Steam Generated.* The steam generated is read from each boiler steam flow meter, is totaled for all boilers, and is recorded on the mechanical electrical daily log (forms 175B,C). The total for the month is divided by 1,000,000. For example:

$$\frac{156,700,000}{1,000,000} = 156.7 \times 10^6 \text{ lb}$$

In this case, 156.7 is the figure to be recorded under item 3 (PH 187) for the appropriate month.

The Annual Data recorded on the bottom line is the summation of the 12 monthly readings of the steam generated per month.

Note: If the steam generated is not measured by a flow meter, this item should not be filled in.

Year - July 19 through June 19

Name of Institution

Item	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬
Month	Boiler Pressure Psig	Feed Water Temp °F	Steam Generated Lbs./10 ⁶	Total BTU's Output 4x10 ⁶ ③ x (A-B)*	Fuel Burned Lbs./10 ⁶ **	Heating Value of Fuel BTU's/Unit***	Total BTU's Input ⑤ x ⑥ X10 ⁶	Actual Evap. ③ / ⑥ ***	Unit Cost of Fuel \$	Fuel Cost for month ⑤ x ⑨ \$	Make Up Water Lbs./10 ⁶	Percent Make-Up ⑪ / ③	Boiler Efficiency ④ / ⑦ %
July													
August													
September													
October													
November													
December													
January													
February													
March													
April													
May													
June													
ANNUAL DATA													

* ③ x (A-B)

A is from Steam Table 2- Saturated Steam; Pressure Table - column h_g at a pressure equal to (① + 15). If superheated steam is generated, A is from Table 3- Superheated Steam - line headed h, at operating temperature and pressure equal to (① + 15).

B is (② - 32).

** = 1-Coal = $\frac{\text{Pounds}}{10^6}$

2-Oil = $\frac{\text{Gallons}}{10^3}$

3-Gas = Therms

*** 1-Coal = BTU's Per Pound

2-Oil = BTU's Per Gallon

3-Gas = 10⁵ BTU's

*** 1-Coal = $\frac{\text{Lbs. of Steam}}{\text{Lbs. of Coal}}$

2-Oil = $\frac{\text{Lbs. of Steam}}{\text{Gal. of Oil}}$

3-Gas = $\frac{\text{Lbs. of Steam}}{\text{Therm of Gas}}$

Figure D1

④ *Total BTU Output.* The total BTU output is equal to
 ③ x (A-B).

Item ③ is the total amount of steam generated
 expressed in pounds ÷ 10⁶.

A is found in Steam Table 2, Saturated Steam:
 Pressure Table, reading from the column headed hg
 at a pressure equal to (① + 15). Item ① is the
 boiler pressure read directly from the gauge.

B is (② - 32). Item ② is the boiler feedwater
 temperature.

Example:

① = Steam pressure = 245 psig + 15 = 260 psia
 ② = Feedwater temperature = 235 F
 ③ = Steam generated = 750,000 lb

$$A = h_g = 1201.5$$

$$B = (235 - 32) = 203.0$$

$$\begin{aligned} \text{Output} &= 750,000 \times (1201.5 - 203) \\ &= 750,000 \times 998.5 \\ &= 748,875,000 \text{ BTU} \\ &= 748.875 \times 10^6 \text{ BTU} \end{aligned}$$

(Also see Example on Page 28)

The Annual Data recorded on the bottom line is the
 summation of 10⁶ BTU output for the 12 months.

(5) *Fuel Burned.* If coal is the source of energy, it is
 measured in pounds. This item is recorded as the
 total pounds of coal burned for the month divided
 by 1,000,000 or:

$$\frac{19,500,000}{1,000,000} = 19.5 \times 10^6 \text{ lb}$$

In this case, 19.5 is the figure to be recorded in Item 5.

If fuel is other than coal, the units should be:

$$\text{oil} = \frac{\text{total gallons burned}}{10^3} \text{ or } \frac{32,620}{1,000} = 32.6 \times 10^3 \text{ gals}$$

Gas = therms burned

The Annual Data recorded on the bottom line is the
 summation of the fuel burned for the 12 months.

- ⑥ *Heating Value of Fuel.* The heating value of fuel is the BTU content per unit.

When coal is used, it is assumed that the coal as fired has 15% moisture in it, but plants having a moisture gauge will use the actual percent moisture that is determined from the coal sample. The BTU content as shown in the Moisture Free column of the Coal Analysis report is the figure to be used in calculating the average BTU content of the coal fired; an example of this is shown in Fig. D2 on page 101.

The heating values for oil or gas are the figures reported by the vendor.

The Annual Data on the bottom line is the average BTU content for the 12 months.

- ⑦ *Total BTU Input.* When coal is used, this value for each month is obtained by multiplying the total units of fuel burned (Item ⑤) by the BTU content per unit (Item ⑥).

When oil is used, this value for each month is obtained by multiplying the total units of fuel burned (Item ⑤) by the BTU content per unit (Item ⑥) and dividing by 1,000.

When gas is used, this value for each month is obtained by multiplying the total units of fuel burned (Item ⑤) by the BTU content per unit (Item ⑥) and dividing by 100,000.

The Annual Data on the bottom line is the total units of fuel (Annual Data of Item ⑤) times the average BTU content per unit (Annual Data of Item ⑥), as calculated above.

- (8) *Actual Evaporation.* The monthly actual evaporation (Item ⑧) of a boiler is determined by dividing the steam generated during the month (Item ③) by the total units of fuel consumed during the month (Item ⑤).

If coal is used: $\frac{10^6 \text{ pounds of steam}}{10^6 \text{ pounds of coal}}$, as an example

$$\frac{156.7}{19.5} = 8.04 \text{ lb steam/lb coal}$$

If oil is used: $\frac{10^6 \text{ pounds of steam}}{10^3 \text{ gallons of oil}} \times 10^3 = \text{lb steam/gal oil}$

If gas is used: $\frac{10^6 \text{ pounds of steam}}{\text{therms of gas}} \times 10^6 = \text{lb steam/therm gas}$

The Annual Data recorded on the bottom line is calculated by dividing the total steam generated (Annual Data of Item ③) by the total fuel burned (Annual Data of Item ⑤) as per above.

- ⑨ *Unit Cost of Fuel.* The fuel cost per unit is the average cost per unit of the fuel burned during the month. As an example, the average cost of coal (from the purchase order) during the month might be \$5.55 per ton; for oil, \$0.10 per gallon; or for gas, \$0.06 per therm.

The Annual Data on the bottom line is the Annual Data of Item ⑩ divided by units of fuel burned from Annual Data of Item ⑤. If the fuel is coal, Item ⑤ should be multiplied by 10 and divided by 2,000 before making the division. If the fuel is oil, multiply by 10^3 and if the fuel is gas, division can be made directly.

- ⑩ *Fuel Cost for the Month.* When burning coal, the fuel cost for the month is calculated by dividing the total fuel burned by 2,000 and multiplying the fuel cost per ton. For example:

$$\frac{(\text{Item } ⑤) \times 10^6}{2,000} \times \text{Item } ⑨ = \text{Item } ⑩$$

$$\frac{19,500,000}{2,000} \times \$5.55 = \$54,112.50$$

This figure is carried to the nearest dollar, so the amount recorded would be \$54,113.

The cost of oil for the month will be the total number of gallons of oil multiplied by the cost per gallon.

$$\text{Item } ⑤ \times 10^3 \times \text{Item } ⑨$$

The cost of gas for the month will be the total amount as billed monthly by the gas company.

$$\text{Item } ⑤ \times \text{Item } ⑨$$

The Annual Data on the bottom line is obtained by totaling the 12 monthly costs.

- ⑪ *Make-up Water.* Make-up water as read from the water meter is usually measured in gallons, is recorded daily on the mechanical electrical daily log (forms 175B.C), is totaled for the month, and is converted to 10^6 pounds by multiplying gallons by 8.33 and by dividing by one million.

An example is:

$$\frac{885,000 \text{ gal} \times 8.33}{1,000,000} = 73.7$$

If the water meter reads in cubic feet, the multiplier is 62.4, rather than 8.33, to convert cubic feet to pounds.

The Annual Data on the bottom line is the summation of the total of the million pounds of make-up water used during the 12 months.

- ⑫ *Percent Make-up.* Percent make-up is calculated from the pounds of make-up water divided by the steam generated multiplied by 100 or:

$$\% \text{ make-up} = \frac{\text{pounds of make-up water}}{\text{steam generated}} \times 100 \text{ or}$$

$$\% \text{ make-up} = \frac{\text{Item } ⑪}{\text{Item } ③} \times 100$$

As an example:

$$\frac{74}{156.7} \times 100 = 47.2\%$$

Percent make-up is recorded to one decimal point; in this case, the percent make-up for the month would be recorded as 47.2%.

The Annual Data on the bottom line is calculated by dividing the total make-up water (Annual Data of Item ⑪) by the total pounds of steam generated (Annual Data of Item ③) and multiplying by 100.

- ⑬ *Boiler Efficiency.* The percent boiler efficiency is calculated as follows:

$$\text{boiler efficiency} = \frac{\text{heat output}}{\text{heat input}} \text{ or } \frac{\text{Item } ④}{\text{Item } ⑦}$$

The Annual Data on the bottom line is determined by the above formula using the Annual Data figures for Item ④ and Item ⑦ and is recorded to one decimal place.

See Example on Page 28.

(5568-7M-2-69) 14

STATE OF ILLINOIS
DEPARTMENT OF MINES AND MINERALS
Springfield

COAL ANALYSIS

Sample 1 of 1

AIR DRY LOSS		Sample Number Lab #4593	
Wt. of Pan + Sample		Date Received 11-17-69	
Wt. of Pan Empty		Data Sampled 11-8-69	
Wt. of Sample		Period Ending Weather-Clear Temp. 60	
Wt. after Air Drying		Date Reported 11-26-69	
Loss on Air Drying		Description P.O.#907177 3/4x10M 68 T.	
Percent Air Dry Loss		Dunn Bros/United Rec. #11 Fidelity	
		Ill Security Hospital/Chester, Illinois	
MOISTURE & ASH		As Received	Moisture Free
Factor			

SUMMARY			
P.O.#907177	As Received	Moisture Free	Ash—Moisture Free
TOTAL MOISTURE 10.20	12.04		
ASH 10.30	11.13	12.65	
B. T. U. 11,476	11,036	12,370	14,422
SULFUR 3.10	3.38	3.84	4.60
FUSION			

The BTU content as shown in the "Moisture Free" column is the figure to be used in calculating the "Heating Value of Fuel BTU's/Unit" for Item 6 of PH 187. If a composite sample report is received, the BTU's shown in the "Moisture Free" column of that report should be used.

Assuming that the coal as fired would have a moisture content of 15%, the heating value of coal is calculated as follows:

$$12,570 \times (1 - 0.15) = 12,570 \times 0.85 = 10,685$$

The figure 10,685 is to be recorded in column 6 of PH 187.

Figure D2. How to calculate heating value of coal

D.2 Report PH 187A, Heat (Fig. D3)

Since changing the *Annual Power Plant Report* PH 187 as reviewed and explained at the Twenty-Fifth Annual Short Course, October 23-27, 1972, it was decided to prepare an HTW System Annual Power Plant Report (form PH 187A), which would be similar to Form PH 187. Items are discussed and numbered here in the order of the columns in which they appear in the new form.

- ① *HTW System Pressure Psig.* The pressure is read directly from the HTW system pressure gauge in pounds per square inch (gauge) and is recorded on the mechanical daily log (form 175A) at the given hour. The average pressure for the month is recorded on the annual power plant report (form 187A).

The Annual Data recorded on the bottom line is the average pressure for the 12 months.

- ② *Supply Water.* The supply water temperature is read to the nearest degree Fahrenheit from the thermometer in the HTW supply line and is recorded on the mechanical daily log (form 175A) at the given hour. The average supply water temperature is recorded on the annual power plant report (form 187A).

The Annual Data recorded on the bottom line is the average of the supply water temperatures for the 12 months.

- ③ *Return Water.* The return water temperature is read to the nearest degree Fahrenheit from the thermometer in the return line and is recorded on the mechanical daily log (form 175A) at the given hour. The average return water temperature is recorded on the annual power plant report (form 187A).

The Annual Data recorded on the bottom line is the average of the return water temperatures for the 12 months.

- ④ *Water Circulated.* The water circulated is read from each generator water flow meter, is totaled for all generators and is recorded on the mechanical daily log (form 175A). The total for the month is divided by 1,000,000. For example:

$$\frac{395,800,000}{1,000,000} = 395.8 \times 10^6 \text{ lb}$$

In this case, 395.8 is the figure to be recorded under item ④ (form 187A) for the appropriate month.

Heat
PH 187A
(Rev. 11/72)

STATE OF ILLINOIS - DEPARTMENT OF MENTAL HEALTH
HTW SYSTEM
ANNUAL POWER PLANT REPORT

Year - July 19 _____ through June 19 _____

Name of Institution _____

Item	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭
Month	Pressure (Psig)	Supply Temp (°F)	Return Temp. (°F)	Water Circulated (Lbs/10 ⁶)	Total BTU's Output/10 ⁶ ④ x (A-B)*	Fuel Burned **	Heating Value of Fuel BTU's/Unit***	Total BTU's Input/10 ⁶ ⑥ x ⑦	Unit Cost of Fuel \$	Fuel Cost for Month ⑥ x ⑨ \$	System Capacity Lbs/10 ³	Make-Up Water Lbs/10 ³	Percent Make-Up ⑫ ⑪ x Days	System Efficiency ⑤ ⑧
July														
August														
September														
October														
November														
December														
January														
February														
March														
April														
May														
June														
ANNUAL DATA														

* ④ x (A-B)

A is from Table 1:Saturated Steam:Temperature Table

Column Headed h_f , at a Temperature Equal to ②.

B is from Table 1:Saturated Steam:Temperature Table

Column Headed h_f , at a Temperature Equal to ③.

** Coal = $\frac{\text{Pounds}}{10^6}$

Oil = $\frac{\text{Gallons}}{10^3}$

Gas = Therms

*** Coal = BTU's Per Pound

Oil = BTU's Per Gallon

Gas = 10⁵ BTU's

Figure D3

The Annual Data recorded on the bottom line is the summation of the 12 monthly readings of the steam generated per month.

- ⑤ *Total BTU Output.* The total BTU output is equal to ④ x (A-B).

Item ④ is the total amount of water circulated expressed in pounds $\div 10^6$.

A is found in Steam Table 1, Saturated Steam: Temperature Table, reading from the column headed h_f at the supply temperature (Item ②).

B is found in Steam Table 1, Saturated Steam: Temperature Table, reading from the column headed h_f at the return temperature (Item ③).

Example:

- ② = Supply temperature = 375°F
 ③ = Return temperature = 250°F
 ④ = Water circulated = 395,800,000 lb

$$A = h_f \text{ (for 375°F) } = 348.11$$

$$B = h_f \text{ (for 250°F) } = 218.48$$

$$\begin{aligned} \text{Output} &= 395,800,000 (348.11 - 218.48) \\ &= 395,800,000 \times 129.63 \\ &= 51,307,554,000 \text{ BTU} \\ &= 51,307.55 \times 10^6 \text{ BTU} \end{aligned}$$

The Annual Data recorded on the bottom line is the summation of 10^6 BTU output for the 12 months.

- ⑥ *Fuel Burned.* If coal is the source of energy, it is measured in pounds. This item is recorded as the total pounds of coal burned for the month divided by 1,000,000 or:

$$\frac{19,500,000}{1,000,000} = 19.5 \times 10^6 \text{ lb}$$

In this case, 19.5 is the figure to be recorded in Item ⑥

If fuel is other than coal, the units should be:

$$\text{oil} = \frac{\text{total gallons burned}}{10^3} \text{ or } \frac{32,620}{1,000} = 32.6 \times 10^3 \text{ gals}$$

Gas = therms burned

The Annual Data recorded on the bottom line is the summation of the fuel burned for the 12 months.

- ⑦ *Heating Value of Fuel.* The heating value of fuel is the BTU content per unit.

When coal is used, it is assumed that the coal as fired has 15% moisture in it, but plants having a moisture gauge will use the actual percent moisture that is determined from the coal sample. The BTU content as shown in the Moisture Free column of the Coal Analysis report is the figure to be used in calculating the average BTU content of the coal fired; an example of this is shown in Fig. D2 on page 101.

The heating values for oil or gas are the figures reported by the vendor.

The Annual Data on the bottom line is the average BTU content for the 12 months.

- ⑧ *Total BTU Input.* When coal is used, this value for each month is obtained by multiplying the total units of fuel burned (Item ⑥) by the BTU content per unit (Item ⑦).

When oil is used, this value for each month is obtained by multiplying the total units of fuel burned (Item ⑥) by the BTU content per unit (Item ⑦) and dividing by 1,000.

When gas is used, this value for each month is obtained by multiplying the total units of fuel burned (Item ⑥) by the BTU content per unit (Item ⑦) and dividing by 100,000.

The Annual Data on the bottom line is the total units of fuel (Annual Data of Item ⑥) times the average BTU content per unit (Annual Data of Item ⑦) as calculated above.

- ⑨ *Unit Cost of Fuel.* The fuel cost per unit is the average cost per unit of the fuel burned during the month. As an example, the average cost of coal (from the purchase order) during the month might be \$5.55 per ton; for oil, \$0.10 per gallon; or for gas, \$0.06 per therm.

The Annual Data on the bottom line is the Annual Data of Item ⑩ divided by units of fuel burned from Annual Data of Item ⑥. If the fuel is coal, Item ⑥ should be multiplied by 10^6 and divided by 2,000 before making

the division. If the fuel is oil, multiply by 10^3 and if the fuel is gas, division can be made directly.

- ⑩ *Fuel Cost for the Month.* When burning coal, the fuel cost for the month is calculated by dividing the total fuel burned by 2,000 and multiplying the fuel cost per ton. For example:

$$\frac{(\text{Item } ⑥) \times 10^6}{2,000} \times \text{Item } ⑨ = \text{Item } ⑩$$

$$\frac{19,500,000}{2,000} \times \$5.55 = \$54,112.50$$

This figure is carried to the nearest dollar, so the amount recorded would be \$54,113.

The cost of oil for the month will be the total number of gallons of oil multiplied by the cost per gallon.

$$\text{Item } ⑥ \times 10^3 \times ⑨$$

The cost of gas for the month will be the total amount as billed monthly by the gas company.

$$\text{Item } ⑥ \times \text{Item } ⑨$$

The Annual Data on the bottom line is obtained by totaling the 12 monthly costs.

- ⑪ *System Capacity.* The capacity of the system is the total volume of water in the system. This may be known from the amount of water required in the initial fill and after further building additions are made to the system. This can also be calculated from the known length and size of the distribution lines and the water volume of the heat exchangers and generators. The volume should be reported to the nearest thousand pounds.

Example:

683,060 lbs should be reported as 683,000 lbs

The Annual Data recorded on the bottom line is the average of the system's capacity for the 12 months. (The capacity of these systems is expected to be constant but sometimes building additions are made to these systems. This accounts for the need for calculating an average.)

- ⑫ *Make-up Water.* Make-up water as read from the water meter is usually measured in gallons, is recorded on the mechanical daily log (form 175A), is totaled for the month, and is converted to pounds by multiplying gallons by 8.33.

An example is:

$$4,430 \text{ gal} \times 8.33 = 36,900$$

If the water meter reads in cubic feet, the multiplier is 62.4, rather than 8.33, to convert cubic feet to pounds.

The Annual Data on the bottom line is the summation of the total of the pounds of make-up water used during the 12 months.

- ⑬ *Percent Make-up.* Percent make-up per day is calculated from the pounds of make-up water divided by the number of days during which the make-up was measured and then divided by the system capacity (Item ⑪) and then multiplied by 100 or:

$$\% \text{ make-up} = \frac{\text{pounds of make-up water}}{\text{days} \times \text{system capacity}} \times 100 \text{ or}$$

$$\% \text{ make-up} = \frac{\text{Item } ⑫ \times 100}{\text{days} \times \text{Item } ⑪}$$

As an example:

$$\frac{37,000 \times 100}{683,000 \times 31} = 0.17\%$$

Percent make-up is recorded to the second decimal place; in this case, the percent make-up for the month would be recorded as 0.17%.

The Annual Data on the bottom line is calculated by dividing the total make-up water (Annual Data of Item ⑫) by the number of days during which make-up was measured and by the average system capacity (Annual Data of Item ⑪) and multiplying by 100.

- ⑭ *Boiler Efficiency.* The percent boiler efficiency is calculated as follows:

$$\text{boiler efficiency} = \frac{\text{heat output}}{\text{heat input}} \text{ or } \frac{\text{Item } ⑤}{\text{Item } ⑧}$$

The Annual Data on the bottom line is determined by the above formula using the Annual Data figures for Item ⑤ and Item ⑧ and is recorded to one decimal place.

See Example on Page 28.

D.3 Report PH 188, Water and Electricity (Fig. D4)

The procedures for preparing form PH 188 are discussed below in the order of the numbers on the form.

- (1) *Gallons of Water Purchased.* The gallons of water purchased is taken directly from the monthly bill. If the billing is in cubic feet, it must be multiplied by 7.5 to obtain the total gallons. The cost is that shown on the water bill.
- (2) *Gallons of Water Pumped.* The gallons of water pumped is the total recorded from the water meter as having been pumped.
- (3) *Gallons of Water Softened.* This quantity is the total gallons of water recorded from the water meter as having been softened.
- (4) *Demand (KW and Pounds of Steam per Hour).* If electrical energy is purchased, the demand as shown on the monthly electrical bill should be recorded. If electrical energy is generated, the instantaneous maximum demand for the month is recorded.

For the demand pounds of steam, the maximum pounds of steam generated for any given hour for each month of the year should be recorded.

- (5) *Electrical Energy Purchased.* The electrical energy (KWH) is transferred directly from the electrical bill.
- (6) *Total Cost.* The total cost of electricity is taken directly from the electricity bill.
- (7) *Electrical Energy Generated.* The total generated electrical energy recorded on form PH 175 should be recorded.

Water & Electricity
PH. 188
(Rev. 1/69)

State of Illinois
Department of Mental Health
ANNUAL POWER PLANT REPORT

Year - July 19 _____ through June 19 _____

Name of Institution _____

Item	①		②	③	④		⑤	⑥	⑦
Month	Gallons of Water Purchased		Gallons of Water Pumped	Gallons of Water Softened	Demand		Electrical Energy Purchased KWH	Total Cost	Electrical Energy Generated KWH
	No. of Gallons	Cost			KW	Lib. of Steam Per Hr.			
July									
August									
September									
October									
November									
December									
January									
February									
March									
April									
May									
June									
ANNUAL DATA									

Chief Engineer _____

Figure D4

APPENDIX E. HOW TO CALCULATE DEGREE DAYS

Degree days are the number of degrees of temperature that have to be supplemented by some external means to maintain an average temperature of 65 degrees Fahrenheit.

Degree days are recorded from July 1 to June 30, or for the fiscal year. For example, degree days recorded for July 1, 1969, to June 30, 1970, normally would be referred to as the heating season of fiscal 1970.

Degree days are recorded daily on PH 175 and monthly on PH 176. The accumulative total degree days for the month are recorded on PH 176 thus:

Degree Days: This Month 1,119 To Date 3,176

To calculate degree days, you must know the highest temperature of the day and the lowest temperature of the day. Calculate as follows:

Example A: High temperature 62; low temperature 7

Add: $62 + 7 = 69$

Divide by 2: $69 \div 2 = 34.5$

Subtract from 65: $65 - 34.5 = 30.5$ degree days

Example B: High temperature 37; low temperature —15

Add: $37 + (-15) = 22$

Divide by 2: $22 \div 2 = 11$

Subtract from 65: $65 - 11 = 54$ degree days

Example C: High temperature —8; low temperature —22

Add: $(-8) + (-22) = -30$

Divide by 2: $(-30) \div 2 = -15$

Subtract from 65: $65 - (-15) = 80$ degree days

Example D: High temperature 68; low temperature 62

Add: $68 + 62 = 130$

Divide by 2: $130 \div 2 = 65$

Subtract from 65: $65 - 65 = 0$ degree days

APPENDIX F. HOW TO ESTIMATE AIR CONDITIONING LOADS

In order to approximate the tons of air conditioning required, the amount of the space (square feet, designated as A) to be air conditioned must be known. Then reference should be made to the following table which indicates the air conditioning requirements (designated B) for particular types of buildings employed for different uses.

<u>Buildings</u>	<u>Estimated requirement (B) in BTU's/hr/sq ft</u>
Apartment-Hotels	25
Department Stores	50
Offices	45
Doctor Offices	50
Libraries	60
Drug Stores	70
Barber and Beauty Shops	75
Food Stores and Taverns	80
Theaters	90
Restaurants	120

$$\text{Total tonnage requirements per hr per sq ft} = \frac{A \times B}{12,000}$$

As an example, 4000 sq ft of offices would require:

$$\frac{4000 \times 45}{12,000} = 15 \text{ tons}$$

Reference should be made to the following table to obtain a cost estimate:

	<u>Cost/ton</u>
Individual room window units	\$1000
Package unit, including cooling tower	\$1500
Central system, including duct work	\$2000

APPENDIX G. ELEVATED STORAGE TANK DATA

<u>Institution</u>	<u>Number</u>	<u>Capacity (gallons)</u>	<u>Year built</u>	<u>Cathodic protection</u>	<u>Year painted</u>
Adler Zone Center	N				
Alton State Hospital	1	250,000	1939	Yes	1966
Anna State Hospital	1	400,000	1948	Yes	1959
Bowen Children's Center	N				
Chicago State Hospital	1	500,000	1948	Yes	1954
Dixon State School	1	500,000	1916	No	1958
East Moline State Hospital	1	300,000	1949	Yes	1969
				(inside)	1949
Elgin State Hospital	1	500,000	1938	Yes	1954
	1	100,000	1931	Yes	1954
Fox Children's Center	N				
Galesburg State Research Hospital	N				
Jacksonville State Hospital	1	500,000	1953	No	1953
Kankakee State Hospital	1	500,000	1953	No	1958
Lincoln State School Annex	1	150,000	1930	No	1964
Lincoln State School Main	1	500,000	1968	No	1968
McFarland Zone Center	N				
Madden Zone Center	N				
Manteno State Hospital	1	250,000	1953	Yes	1967
Medical Center Complex	N				
Mental Health Center	2	1,000 (each)	1913	No	Unknown
Meyer Zone Center	N				
Murray Children's Center	N				
Peoria State Hospital	1	300,000	1964	Yes	1964
	1	500,000	1963	No	1963
Read Zone Center	N				
Security Hospital	N				
Singer Zone Center	N				
Tinley Park	1	500,000	1952	Yes	1961
Zeller Zone Center	N				
N = None					