**Lenox Institute Press**
Newtonville, NY, USA; Auburndale, MA, USA

**Evolutionary Progress in Science, Technology, Engineering, Arts and Mathematics (STEAM) Series**

# Operation and Performance of Clari-DAF® System for Water Purification

Authored by:

**Joseph M. Wong, P.E., BCEE**
Chief Engineer
Brown and Caldwell
201 North Civic Drive
Walnut Creek, CA 94596, USA
Tel: (925) 210-2555
Email: jmwong@brwncald.com

**James E. Farmerie**
Retired Business Development Manager
Xylem Water & Wastewater
227 S. Division St, Zelienople, PA 16063, USA

**Lawrence K. Wang, PhD, PE, BCEE**
Retired Acting President and Professor
Lenox Institute of Water Technology
1 Dawn Drive, Latham, NY 12110, USA
Tel: (518) 785-4843; Text (518) 250-0012
Email: lenox.institute@yahoo.com; lenox.institute@gmail.com

Wong, JM, Farmerie, JE, and Wang, LK. (2019). Operation and performance of Clari-DAF® system for water purification. In: "*Evolutionary Progress in Science, Technology, Engineering, Arts, and Mathematics (STEAM)",* Wang, Lawrence K. and Tsao, Hung-ping (editors). Volume 1, Number 8, August 2019; 63 pages. Lenox Institute Press, Newtonville, NY, 12128-0405, USA. No. STEAM-VOL1-NUM8-AUG2019; ISBN 978-0-9890870-3-2. US Department of Commerce, National Technical Information Service, 5301 Shawnee Road, Alexandria, VA 22312, USA.

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| **1. REPORT DATE** *(DD-MM-YYYY)* | **2. REPORT TYPE** | **3. DATES COVERED** *(From - To)* |
|---|---|---|
| 15-08-2019 | TECHNICAL PROGRESS REPORT | JAN 2011-AUG 2019 |

4. TITLE AND SUBTITLE

Operation and Performance of Clari-DAF® System for Water Purification

**5a. CONTRACT NUMBER** NA

**5b. GRANT NUMBER** NA

**5c. PROGRAM ELEMENT NUMBER** NA

6. AUTHOR(S)

Joseph M. Wong,
James E. Farmerie,
Lawrence K. Wang

**5d. PROJECT NUMBER** STEAM-VOL1-NUM8-AUG2019

**5e. TASK NUMBER** NA

**5f. WORK UNIT NUMBER** NA

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

1. Brown and Caldwell, 201 North Civic Drive, Walnut Creek, CA 94596, USA
2. Xylem Water & Wastewater , 227 S. Division St, Zelienople, PA 16063, USA
3. Lenox Institute Press, PO Box 405, Newtonville, NY 12128-0405, USA
Lenox Institute, 160 Pine Street, Suite 19, Auburndale, MA 02466, USA

**8. PERFORMING ORGANIZATION REPORT NUMBER**
STEAM-VOL1-NUM8-AUG2019

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

Wang, Lawrence K. and Tsao, Hung-ping (editors). "*Evolutionary Progress in Science, Technology, Engineering, Arts, and Mathematics (STEAM)",* Volume 1, Number 8, August 2019; Lenox Institute Press, PO Box 405, Newtonville, NY, 12128-0405, USA

**10. SPONSOR/MONITOR'S ACRONYM(S)**
LENOX

**11. SPONSOR/MONITOR'S REPORT NUMBER**
STEAM-VOL1-NUM8-AUG2019

**12. DISTRIBUTION / AVAILABILITY STATEMENT**
NO RESTRICTION

**13. SUPPLEMENTARY NOTES**
**REGISTRAT**ION ISBN 978-0-9890870-3-2

**14. ABSTRACT**

Xylem Water & Wastewater has provided Dissolved Air Flotation (DAF) systems to the municipal potable water treatment market since the early 1990s. This chapter will discuss the DAF process and the high-rate Clari-DAF® system design criteria. It will also present data from pilot studies and case studies of full-scale Clari-DAF® plants in operation showing expected performance through the system.

**15. SUBJECT TERMS** Dissolved air flotation, DAF, Rapid mix, Flocculators, Velocity gradient, Dispersion zone, Flotation cell, Collector header, Loading rate, Recycle rate, Hydraulic desludging, Mechanical desludging, Coagulant, Hydroxide floc, Micron size floc, Micron size bubbles, Clari-DAF, Water purification, Xylem

| **16. SECURITY CLASSIFICATION OF:** UNCLASSIFIED UNLIMITED (UU) | | | **17. LIMITATION OF ABSTRACT** | **18. NUMBER OF PAGES** | **19a NAME OF RESPONSIBLE PERSON** |
|---|---|---|---|---|---|
| **a. REPORT** UU | **b. ABSTRACT** UU | **c. THIS PAGE** UU | UU | 63 | Wang, Lawrence K. |
| | | | | | **19b TELEPHONE NUMBER** *(include area code)* (518) 250-0012 |

# Operation and Performance of Clari-DAF® System for Water Purification

**Joseph M. Wong, James E. Farmerie and Lawrence K. Wang**

ABSTRACTS
KEYWORDS
NOMENCLATURE

TABLE OF CONTENTS


1. INTRODUCTION

2. HISTORY OF PROCESS DEVELOPMENT AND APPLICATION

3. PROCESS DESCRIPTION

    3.1. Theory

    3.2. Process Components

    3.3. Alternatives for Sludge Withdrawal

        3.3.1 Hydraulic

        3.3.2 Mechanical

    3.4. Design Criteria

4. CASE STUDIES – OPERATIONS AND PERFORMANCE

    4.1 Pilot Testing

        4.1.1 Pilot Testing Case Study: San Luis Obispo County (California) Lopez Water Treatment Plant

    4.2 Full Scale Plants

        4.2.1 Case Study #1: Boulder Colorado – 63rd Street Plant

        4.2.2 Case Study #2: The Songjeon Water Treatment Plant (SWTP) - Wonju, South Korea

        4.2.3 Case Study #3: Greenville, South Carolina – Table Rock/North Saluda Plant

        4.2.4 Case Study #4: William R. Oliver Water Treatment Plant - Papillion, Nebraska

        4.2.5 Case Study #5: Evitts Creek Water Treatment Plant – Bedford, Pennsylvania

5. MARKETING OUTLOOK

GLOSSARY

REFERENCES

## List of Tables

Table 1. Clari-DAF® System Pilot Data

Table 2. Clari-DAF® System Pilot TOC Data

Table 3. Total Algae Counts at the Lake Lopez Intakes and Terminal Reservoir

Table 4. Chemical Costs for Treatment

Table 5. Turbidity Comparison of Pre- and Post Clari-DAF Installation (in NTU)

Table 6. Comparion of K-Water DBP Concentrations With Korean and U.S. Standards (in mg/L)

Table 7. Average DBP Concentrations With and Without PAC (in mg/L)

Table 8. Average Water Quality Data for Adkins and TR/NS Filter Plants

Table 9. Comparison of Process Design Criteria at Adkins and TR/NS Filter Plants

Table 10. Average Chemical Dosages in Adkins and TR/NS Filter Plants

Table 11. Comparison of Filter Performance at Adkins and TR/NS Filter Plants

Table 12. Comparison of In-Plant Water Usage Rate at Adkin and TR/NS Filter Plants

Table 13. Comparison of Production Costs at Adkins and TR/NS Filter Plants

Table 14. Performance Comparison Between Upflow clarification and Clari-DAF®

Table 15. USEPA TOC Removal Requirements by Stage 2 DBPR

## List of Figures

Figure 1. How the Leopold Clari-DAF System Works (courtesy of ITT, now Xylem)

Figure 2. Raw Water and Clari-DAF® Effluent Turbidity

**OPERATION AND PERFORMANCE OF CLARI-DAF® SYSTEMS FOR WATER PURIFICATION**

## ABSTRACT

ITT (now Xylem) Water & Wastewater Leopold Business Unit has provided Dissolved Air Flotation (DAF) systems to the municipal potable water treatment market since the early 1990s. This chapter will discuss the DAF process and the high-rate Clari-DAF® system design criteria. It will also present data from pilot studies and case studies of full-scale Clari-DAF® plants in operation showing expected performance through the system.

## KEY WORDS


| | | |
|---|---|---|
| Dissolved air flotation, | Rapid mix, | Flocculators, |
| Velocity gradient, | Dispersion zone, | Flotation cell, |
| Collector header, | Loading rate, | Recycle rate, |
| Hydraulic desludging, | Mechanical desludging, | Coagulant, |
| Hydroxide floc, | Micron size floc, | Micron size bubbles |
| Clari-DAF, | Water purification. | Xylem |

**NOMENCLATURE**

| | |
|---|---|
| MGD | Million gallons per day |
| MG | Miloion gallons |
| DAF | Dissolved air flotation |
| Clari-DAF® | ITT (now Xylem) dissolved air flotation |
| R&D | Research and development |
| TOC | Total organic carbon |
| DOC | Dissolved organic carbon |
| PAC | Powdered activated carbon |
| VFD | Variable frequency drives |
| TTHM | Total trihalomethane |
| HAA2 | Two different haloacetic acids |
| WTP | Water treatment plant |
| SDI | Silt density index |
| TR | Terminal reservoir |
| NTU | Nephelometric turbidity unit |
| IESWTR | Interim Enhanced Surface Water Treatment Rule |
| UFRV | Unit filter run volume |
| SWTR | Surface Water Treatment Rule |
| USEPA | US Environmental Protection Agency |
| $KMnO_4$ | Potassium permanganate |
| $ClO_2$ | Chlorine dioxide |
| LTESWTR | Long-Term Enhanced Surface Water Treatment Rule |
| TNRC | Texas Natural Resource Commission |
| DBPR | Disinfectant & Disinfection By-Product |
| MCL | Maximum contaminant level |
| TTHM | Total trihalomethane |
| FBRR | Filter Backwash Recycling Rule |

| | |
|---|---|
| I.M.S.® | Integral Media Support |
| HAA5 | Five different haloacetic acids |

## OPERATION AND PERFORMANCE OF CLARI-DAF® SYSTEMS FOR WATER PURIFICATION

### 1. INTRODUCTION

Potable water treatment plants process raw water from ground and surface sources to produce a product that meets all of the regulatory requirements for consumption. With few exceptions, surface water treatment plants are required to minimally have filtration, and usually will first remove suspended and colloidal solids to optimize filter performance.

The conventional design of surface water treatment plants include rapid mix, flocculation, clarification, filtration, clear well storage, and disinfectant contact. In the treatment process, a number of chemicals are used to produce the required water quality. The clarification process impacts the type and quantity of chemicals.

Where systems remove solids prior to filtration, the clarification unit process sets goals to (1-7):

1. Remove suspended and colloidal solids
2. Remove algae
3. Provide contact time for taste and odor control strategies
4. Remove naturally occurring organic matter
5. Remove Cryptosporidium and Giardia
6. Remove precipitated dissolved solids (e.g., Fe, Mn, As, Hardness)
7. Remove contaminants that demand disinfectant or oxidant
8. Produce and collect solids that are easily processed downstream
9. Provide consistent water quality to filters to maximize filter run time
10. Minimize the footprint for the unit process — obtain a high loading rate in $gpm/ft^2$ (m/hr)

The clarification equipment has a major impact on downstream processes. The effluent water quality affects the filter run time and also the cost with respect to quantity of backwash water, media breakdown, energy cost for backwash water pumps and air compressors, filter-to-waste quantity, and elimination or reduction of filter aids. The method used to remove solids from the process affects the volume of sludge to handle and the time required for dewating, which then affects the cost associated with energy usage, chemicals, cake solids and disposal.

In many cases, Dissolved Air Flotation (DAF) is an excellent choice for clarification process equipment (8-22). In the DAF process, raw water particles are flocculated and separated out of the water by floating to the surface rather than settle to the bottom of a basin. DAF was first used in this clarification application in water treatment plants in Finland in the early 1920s. There was renewed interest in the 1960s in Scandinavia, southern Africa, and the United Kingdom. The Clari-DAF® systems have been marketed by the F.B. Leopold Company (now a Business Unit of Xylem Water & Wastewater) since the early 1990s. This chapter will discuss the use of the Xylem Water & Wastewater Clari-DAF® System in water purification clarification applications and the evolution of design to its current offering.

## 2. HISTORY OF PROCESS DEVELOPMENT AND APPLICATIONS

In the 1990s, F.B. Leopold was owned by Thames Water International, with headquarters in Reading, England. At that time, as the United Kingdom's largest Utility, Thames Water had design, engineering, research and development (R&D), and operational groups. The R&D Group developed the DAF clarification system, which was later added to the Leopold portfolio of equipment that would be offered to the global municipal water and wastewater marketplace. Leopold not only added it to the filtration product line, but invested in intelligence to support the effort and develop new knowledge and designs to offer the next generation of high-rate DAF system — Clari-DAF® **system**. With the sale of Leopold in the early 2000s, the Dissolved Air Flotation product line remained with the company, and the continued product development was expanded under the ITT (now Xylem) umbrella. Leopold has a stable of Clari-DAF® pilot units that have performed tests on various global water sources to help determine optimum design criteria to achieve the target water quality from a variety of water sources.

The Clari-DAF® system is applicable where the source water is an impounded water source such as a lake, pond or reservoir, and contains low-density solids such as algae that are naturally buoyant or solids that are developed when inorganic coagulants are added and react with alkalinity to form hydroxide flocs. This hydroxide floc is formed when coagulants are added to enhance turbidity, color and organics removal.

Colloidal, highly-charged turbidity solids that require chemical charge neutralization and bridging are best removed by flotation rather than settling. Where true color requires excess coagulant, the hydroxide flocs that are formed are best removed by flotation. When Total Organic Carbon/Dissolved Organic Carbon (TOC/DOC) requires "enhanced coagulation" and pH is depressed with excess coagulant and/or acid, the chemical floc that is formed is better removed with the flotation rather than the settling process. Raw waters from rivers with rain run-off containing high-density silt solids are better served with setting processes unless they have a settling reservoir as pretreatment prior to entering the treatment plant. The Clari-DAF® system offers the Utility a high-rate clarification process (up to 20 gpm/ft$^2$ or 50 m/hr) at a significantly reduced footprint compared to conventional settling processes.

## 3.0 PROCESS DESCRIPTION

### 3.1 THEORY

The DAF process relies on removing floc particles from the water by decreasing their effective density to less than that of water by attaching micro bubbles to the floc. The process causes the flocs to rapidly float to the surface where they are removed periodically by either mechanical or hydraulic means. DAF is usually considered for the clarification process when the raw source water contains low-density contaminants or produces low-density solids. This includes solids formed by adding inorganic aluminum or iron-based coagulants that react with alkalinity and form hydroxide floc to remove turbidity, color or organics. In addition, DAF is the process of choice to remove algae in the source water as the flotation process takes advantage of algae's natural buoyancy.

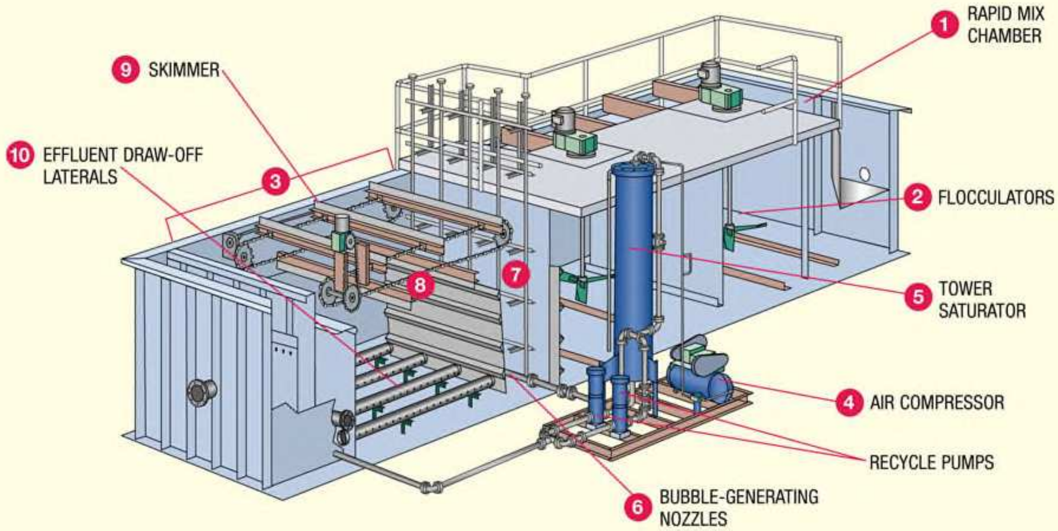
A second application in potable water treatment plants is to use DAF for wastewater that is clarified so that it can be recycled to the front of the treatment process rather than sent to waste. This would include filter backwash, sludge thickener overflow, or dewatering filtrate or centrate. Usually these recycle streams are sent to holding tanks where they are processed to remove the solids prior to pumping the effluent to the head of the treatment process. DAF is exceptionally good for removing these low-density solids so that the effluent stream that is put back into the plant influent does not contain concentrated contaminants that could eventually build up and get through the treatment train and foul the distribution system water quality.

### 3.2 PROCESS COMPONENTS

Figure 1 shows how the Clari-DAF® system works.[1] The DAF process starts with raw water being dosed with a coagulant in a rapid mix chamber, much like that of conventional sedimentation. Alum and ferric salts are typical choices for coagulant. Lower doses than sedimentation are needed because a pin floc is floated in lieu of a sweep floc, which is settled. Some of the reduction is also due to the fact that DAF is more efficient in removing smaller-diameter particles by floating them than by clarifiers attempting to settle them. Sedimentation requires large particles usually hundreds of microns in size to efficiently settle and remove them. The DAF uses an efficient contact of air bubbles and floc particles to achieve flotation and solids removal. To achieve this, floc particles that are only tens of microns in size are required; thus DAF typically uses significantly less chemicals than conventional gravity settling processes.

**Figure 1. How the Leopold Clari-DAF System Works (credit: ITT, now Xyleme)**

## How the Leopold Clari-DAF System Works




1. The Clari-DAF process starts with raw water being dosed with an aluminum or iron-based inorganic coagulant in a rapid mix chamber, much like that of conventional sedimentation. Lower doses than sedimentation are used because a pin floc is desired instead of a sweep floc.

2. Good coagulation is the most important factor affecting flotation. Two-stage tapered flocculation is standard. G values of 30 to 70 are typical for full-scale operations. Low tip speeds prevent the fragile floc from being sheared. Flocculation time is only one-fifth of that needed for conventional clarification.

3. Hydraulic loading rates based on collector area range from 8 to 15 gpm/sf (19.36 to 38.72 m/hr), although pilot testing has shown that rates up to 20 gpm/sf (48.4 m/hr) are not unusual. As a result, the Clari-DAF system requires a smaller footprint than conventional sedimentation.

4. After a pin floc is formed, the raw water stream is injected with water that has been saturated with air at 60 to 90 psi. The saturation process is accomplished by taking a fraction of the throughput, typically 10% of design flow, and recycling it back to a pressure vessel. VFDs control the recycle pumps to maintain a balance in the saturator. A compressor provides a constant pressure of oil-free air to the saturator.

5. The saturator, a packed tower for water or unpacked-tower for wastewater, mixes the water and air.

6. The aerated water is delivered to a distribution header that spans the width of the Clari-DAF cell. This distribution header has a series of specially designed orifices or nozzles. As the pressurized water exits the nozzles, the pressure drop produces a cloud of hundreds of millions of microbubbles that are approximately 40 microns in size.

7. The contact zone is given a milky appearance like that of a whitewater blanket. The tiny air bubbles rise through the coagulated water, capturing floc as they ascend to the surface. The tiny spherical bubbles rise under laminar flow at a rate following a modified Stokes Equation.

8. A blanket of sludge forms on the surface of the Clari-DAF cell. The blanket is supported from beneath by the microbubbles.

9. The sludge blanket that forms on the top of the Clari-DAF cell is removed periodically by either a mechanical scraper or by hydraulic means. Under certain conditions removal can be achieved using a combination of both mechanical and hydraulic processes.

10. The clarified effluent water is drawn off the bottom of the tank by a series of lateral draw-off pipes that allow for uniform distribution along the bottom of the Clari-DAF cell.

Good coagulation is an important factor affecting flotation. Two-stage tapered flocculation is standard. Typical G values of 30-120 $sec^{-1}$ are regularly seen in full-scale operations. Low tip speeds are preferred to prevent the fragile floc from being sheared. Flocculation times of 5 to 20 minutes are regularly designed, and pilot studies can determine what the optimum should be for the appropriate water. Temperature has less effect on the DAF process than it does on conventional sedimentation, since the number of 40-micro-diameter bubbles created in the saturator increases with lower temperature, which actually improves capture rate. Hydraulic loading rates normally range from 4 to 20 $gpm/ft^2$ (10 to 50 m/hr). As a result, the Clari-DAF® system process uses a smaller footprint than sedimentation and other clarification processes.

After a pin floc is formed, the raw water stream is injected with water that has been saturated with air at 80 psig (5.5 BAR). The saturation process is accomplished by taking a fraction of the throughput, typically 10 percent at design flow, and recycling it back to a pressure vessel. Variable frequency drives (VFDs) control the recycle pumps to maintain balance in the saturator. A compressor provides a constant pressure of air to the saturator. The packed tower vessel collects the aerated water for delivery to a distribution header that spans the width of the DAF cell. This distribution header has a series of specially designed orifices or nozzles. As the pressurized water exits the nozzles, the pressure drop produces a cloud of micro bubbles 20- to 80-micron diameters in size. The contact zone is given a milky appearance like that of a whitewater blanket. The tiny air bubbles rise through the coagulated water, capturing floc as they ascend to the surface. The tiny spherical bubbles rise under laminar flow at a rate following a modified Stokes Equation. A blanket of sludge, produced on the surface of the DAF cell, is supported from beneath by the tiny air bubbles. The clarified effluent water is drawn off the bottom of the tank by a series of lateral draw-off pipes that allow for uniform distribution along the bottom of the DAF cell; thus, the Clari-DAF® system can operate at surface loading rates as high as 20 $gpm/ft^2$ (50 m/hr).

### 3.3 SLUDGE WITHDRAWAL

The "float" is a sludge blanket that forms on the top of the DAF cell. It is removed periodically by either a mechanical scraper or hydraulic means. Under certain conditions, sludge removal can be achieved using a combination of both mechanical and hydraulic processes. Mechanical sludge withdrawal results in solids content typically in the range of 3 percent to 5 percent, while hydraulic sludge withdrawal results in solids content of 0.5 percent to 1 percent, similar to settling processes. The higher solids content achieved by the Leopold Clari-DAF® System reduces the quantity (volume) of sludge to be handled in dewatering or hauling, which significantly reduces the cost of sludge processing.

Mechanical sludge removal is accomplished with a reciprocating skimmer. The sludge is collected and "thickened" on the surface of the flotation cell. Depending on the quantity, based on source water solids removed and coagulant dosage producing chemical sludge, the control system will actuate the skimmer to remove the sludge from the surface of the flotation tank, pushing the sludge up a beach and into a sludge collection trough where it is collected and sent to either a holding tank or directly to dewatering. Because of the solids content, the thickening process step can be eliminated. This sludge withdrawal typically occurs once every hour.

Hydraulic sludge removal is accomplished by the control panel sending a signal to lower a gate in the effluent channel, which in turn raises the level of water in the flotation cell and uses the water in the tank to carry the solids into the sludge collection trough. At the same time that the gate is being lowered, spray water along the edge of the tank pushes the sludge build up along the walls away from the wall surface so that all of the sludge can be hydraulically removed. Once the sludge has been removed, the gate is raised, the spray wash shut off, and the solids are again collected on the surface in the flotation cell. The solids remain in the unit until the next sludge removal event. Since water is used to carry the solids out of the tank, the solids content in the sludge is similar to settling processes. Some utilities prefer dilute sludge solids as they pump the sludge for a distance to a holding lagoon.

### 3.4 DESIGN CRITERIA

The optimum design for any potable water treatment plant would result from pilot studies of the source water. These pilot studies would not only develop design criteria, but also predict chemical requirements and dosages for specific contaminants, DAF effluent water quality, filter run times, filter effluent water quality, and sludge solids concentration. Many utilities will test during spring and fall so that they are able to review performance from seasonal changes of the source water.

The design criteria established during pilot studies are to achieve the optimum rapid mix, flocculator mixing time and energy (velocity gradient), loading rate ($gpm/ft^2$ or m/hr), and % recycle rate to achieve the optimum downstream equipment performance in the gravity media, pressure or membrane filters and solids handling processes. The rapid mix is typically 30 seconds of either mechanical or hydraulic mixing to achieve velocity gradients of 500 $sec^{-1}$, followed by two flocculators that will mix the water from 5 to 20 minutes. The mixing is reduced in each so that the floc that is formed will not shear; thus, velocity gradients are typically 100 $sec^{-1}$ in the first flocculator and 50 $sec^{-1}$ in the second flocculator. Each of the mixers in the flocculators is equipped with VFDs so that when the source water changes, the mixing energy can be changed to maintain the optimum mixing for flocculation and, consequently, contaminant removal. The loading rate can be based on the total of the cell in which the solids are captured and floated (reaction zone and flotation zone) or based on the collector area at the bottom of the flotation cell. This value is measured as flow per area and expressed as gallons per minute per square foot ($gpm/ft^2$) or cubic meters per hour per square meter (m/hr). The loading rate varies from location to location based on the source water contaminants, their concentration, and the target effluent water quality that is required.

The recycle rate is the percentage of DAF effluent that is recycled through the saturator system to eventually generate the small micron-size bubbles at the dispersion header to carry the flocculated particles to the DAF surface. The recycle rate is typically 10 percent, but can vary between 5 percent and 15 percent. The recycle rate is based on the contaminants, their concentration, the water temperature, and the dissolved oxygen in the source water. The recycle rate will determine the number of dispersion headers required in the reaction zone to achieve the quantity of water that is being recycled. A higher recycle rate will increase the operating cost of the DAF system.

In general pilot testing for each application is recommended to obtain process design critreria. Without pilot testing, the suppliers can provide a conservative design based on their experience with previous pilot test data and their own plant design for plants in operation over a period of time.

## 4.0 CASE STUDIES – OPERATIONS AND PERFORMANCE

### 4.1 PILOT TESTING

As of 2010, Xylem Water & Wastewater has conducted more than 100 pilots for potable water treatment studies using fresh water (impounded and river waters) and seawater for the source of supply. The studies were conducted with an ITT (now Xylem) pilot plant operator present for the entire study. The on-site pilot unit resides in a self-contained trailer that houses all of the equipment required to design a DAF system for the utility. The pilot unit has capabilities for multiple chemical additions in various locations in the treatment scheme, multiple basins with top entry mixers with VFDs to determine the optimum mixing scheme, and the ability to evaluate multiple loading and recycle rates. The unit contains filter columns that help determine the effect of the DAF effluent on differing media configurations. The unit is equipped with continuous analytical monitoring and recording to see realtime water quality changes in raw water, DAF effluent, and filter effluent when changes occur. Final reports recommend design criteria and present typical data such as pH, turbidity, iron (total and dissolved), manganese (total and dissolved), apparent color, true color, particle counts, algae, Total Organic Carbon (TOC), Dissolved Organic Carbon (DOC), total trihalomethane (TTHM) potential formation, and haloacetic acid (HAA5) potential formation as the changes in treatment strategy during the pilot are implemented. The typical performance of all Clari-DAF® system pilot studies collected for specific contaminants is listed in Table 1.

| Table 1. Clari-DAF® System Pilot Data | | | | |
|---|---|---|---|---|
| **Parameter** | **Raw Water** | **Average In** | **Average Out** | **% Removal** |
| Turbidity | 0-5 NTU | 3.71 NTU | 0.68 NTU | 82 |
| | 5-10 NTU | 7.24 NTU | 0.79 NTU | 89 |
| | 10+ NTU | 18.8 NTU | 1.68 NTU | 91 |
| Apparent Color | 0-50 Pt-Co | 28 Pt-Co | 14 Pt-Co | 50 |
| | 50-100 Pt-Co | 73 Pt-Co | 24 Pt-Co | 67 |
| | 100 + Pt-Co | 206 Pt-Co | 41 Pt-Co | 80 |
| True Color | 0-5 Pt-Co | 4.7 Pt-Co | 0.8 Pt-Co | 82 |
| | 5-10 Pt-Co | 8.5 Pt-Co | 2.8 Pt-Co | 67 |
| | 10+ Pt-Co | 15.1 Pt-Co | 3.9 Pt-Co | 74 |
| Iron | all | 0.22 mg/L | 0.047 mg/L | 79 |
| Manganese | all | 0.1 mg/L | 0.037 mg/L | 63 |
| Algae | all | 3469 counts | 831 counts | 76 |

The data for all pilots that obtained TOC removal are listed in Table 2. The data show the effect of pH where enhanced coagulation was practiced due to mandated removal rates in the United States based on raw water TOC and alkalinity.

| Table 2. Clari-DAF® System Pilot TOC Data | | | |
|---|---|---|---|
| **pH** | **Average In** | **Average Out** | **% Removal** |
| 8+ | 3.18 mg/L | 2.19 mg/L | 31.1 |
| 7 to 8 | 4.88 mg/L | 3.02 mg/L | 38.1 |
| 6 to 7 | 6.84 mg/L | 3.17 mg/L | 53.6 |

#### 4.1.1 Pilot Testing Case Study: San Luis Obispo County (California) Lopez Water Treatment Plant

The following pilot testing case study shows an example of excellent algae and turbidity removal in an existing water treatment plant using the Clari-DAF® system as the alternative pretreatment process. The Lopez Water Treatment Plant (WTP), operated by the San Luis Obispo County, supplies water to south San Luis Obispo County residents in the cities of Arroyo Grande, Pismo Beach, Grover Beach, Oceano and Avila Beach. Originally constructed in 1970, the Lopez WTP was a 6-MGD surface water plant that uses conventional treatment with gaseous chlorine and coagulant/cationic polymer pretreatment with conversion to chloramines prior to distribution. Plant source water originates from several tributaries that flow into Lopez Lake (lake). The lake is a full body contact recreational use reservoir formed by an earthen dam on

Arroyo Grande Creek. Raw water is piped from the lake approximately 17,000 feet to the Terminal Reservoir (TR), which provides a minimum 30-day retention period prior to treatment. This raw water is rather difficult to treat. Besides having problems of relatively high hardness, pH and TOC concentrations (4-8 mg/L), and relatively high manganese concentrations during certain periods of the year, the most challenging aspect of this raw water is the seasonal high algae counts. The TR promotes algae growth because of its shallow depth, which means the TR has higher algae counts than the lake intake. Table 3 shows the historical calculated total algae counts at the lake intakes and the TR. The lake's algae counts decrease proportionally to depth; however, for the TR, the algae counts at the three intakes from 6 to 18 feet are quite similar to each other.[2]

**Table 3. Total Algae Counts at the Lake Lopez Intakes and Terminal Reservoir**

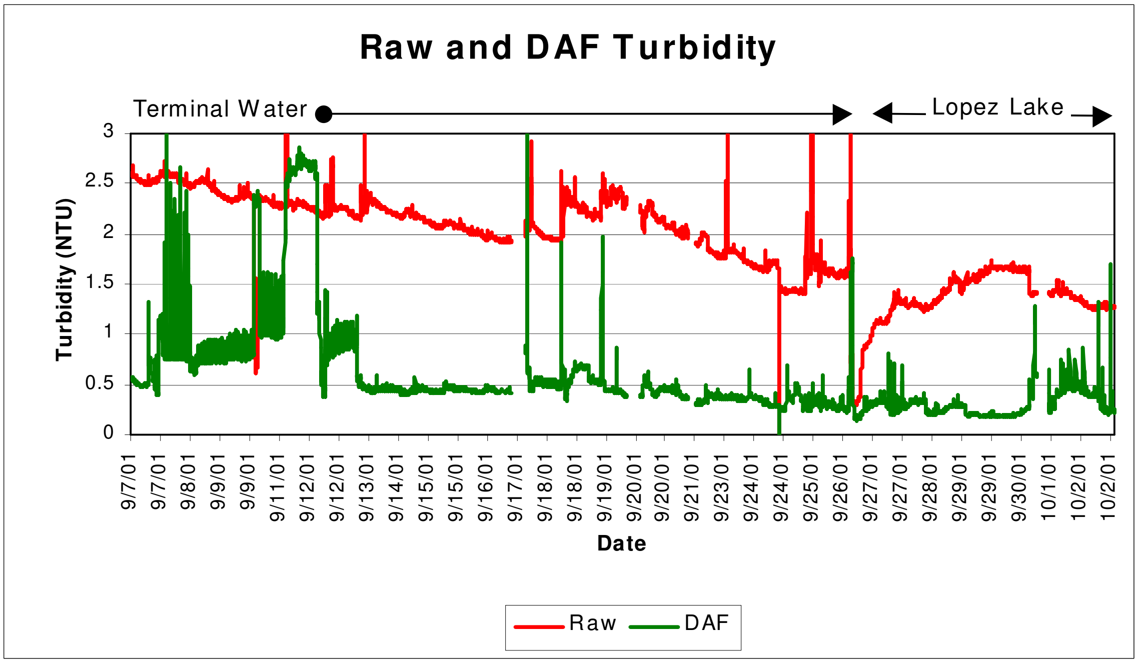
| Description | Minimum, c/mL | Maximum, c/mL | Median, c/mL |
|---|---|---|---|
| **Lopez Lake** | | | |
| Intake 1 | 0 | 24,000 | 1,403 |
| Intake 2 | 0 | 14,000 | 868 |
| Intake 3 | 0 | 6,000 | 354 |
| Intake 4 | 0 | 1,700 | 93 |
| Intake 5 | 0 | 1,200 | 50 |
| Intake 6 | 0 | 1,100 | 36 |
| **Terminal Reservoir** | | | |
| Intake 06' | 0 | 69,000 | 2,039 |
| Intake 12' | 0 | 71,000 | 2,056 |
| Intake 18' | 0 | 73,000 | 2,079 |

Algae episodes occur annually at both the lake and the TR. Algae counts usually peak from the end of summer through the fall season, and an algae bloom period can be quite long (four to five months). High filter effluent turbidity events occurred mostly during the algae bloom season in fall and relate directly to algae and silica-based submicron particles. Attempts to optimize the coagulation process with various chemical coagulants and polymers were unsuccessful for the existing WTP. It appeared that the existing conventional pretreatment scheme of coagulation-flocculation-sedimentation was not effective to treat this raw water consistently throughout the year. The consultant engineer evaluated three pretreatment alternatives—plate settling, Actiflo® and Clari-DAF® system—to replace the existing sedimentation process, and recommended DAF for pilot testing and further evaluation due to the occasional high algae counts in the raw water.

A one-month pilot testing program was conducted in the fall of 2001 using the Clari-DAF® pilot system.[2] The treatment processes included pre-oxidation with various oxidants (chlorine dioxide and potassium permanganate), coagulation, flocculation, Clari-DAF® system, and dual media filtration. The Clari-DAF® pilot plant was operated from 27 to 72 gpm, which corresponded to DAF surface loading rates of 3 to 8 gpm/ft$^2$. Two dual-media filters with a surface area of 1.0 ft$^2$ were provided to filter Clari-DAF® system effluent.

The Clari-DAF® pilot system was very effective in lowering turbidity and algae counts from raw water. Figure 2 shows the raw water and Clari-DAF® system turbidity levels throughout the pilot testing period.[2] After chemical type and dose optimization during the first week of the testing, the Clari-DAF® system effluent turbidity readings were below 0.5 NTU most of the time, with readings as low as 0.2 NTU when Lopez Lake water was fed directly to the pilot plant. Clari-DAF® system surface loading rate variation tests conducted indicate that the there was no significant performance deterioration between 4 gpm/ft$^2$ and. 8 gpm/ft$^2$ (0.35 NTU vs. 0.40 NTU). Algae removal efficiency of Clari-DAF® system was higher than 95 percent when the algae count was higher than 2,000 c/mL. Most of the residual algae in the Clari-DAF® system effluent were diatoms. The average raw water particle count (2-20 micron) was approximately 10,000/mL. The average DAF effluent particle count was approximately 800/mL and was as low as 300/mL with 1.5 mg/L of chlorine dioxide as pre-oxidant. These results represent 92 percent and 97 percent particle removal, respectively.

**Figure 2. Raw Water and Clari-DAF® System Effluent Turbidity**




The filter effluent total particle count (2-20 micron) averaged 30/mL; it was as low as 10-12 /mL with 1.5 mg/L chlorine dioxide as a pre-oxidant. These are excellent results, given the log removal (Clari-DAF® system with filter) for total particles removal was above 2.8 log during the "best" period and 2.2-2.3 log during the "worst" period. This easily met the 2-log *Cryptosporidium* removal requirement of the Interim Enhanced Surface Water Treatment Rule (IESWTR). The filter runs of the pilot filters were at least 48 hours at a filtration rate of 4 gpm/ft$^2$. This is equivalent to a unit filter run volume (UFRV) of 11,200 gal/ft$^2$-run, which is excellent and indicates that Clari-DAF® system is a good pretreatment alternative.

Though the Clari-DAF® system process was later retrofitted into the existing sedimentation basins, the filtration was converted to membrane filtration due to the presence of submicron silica-based particles that could pass through granular media filters, which caused higher effluent turbidities. Membrane filtration effectively removes these particles, as well as protozoans. The Clari-DAF® system pretreatment adequately protects the membrane filters from potential algae fouling. Algae is known to cause fouling of membrane filters, which then require frequent chemical cleaning to recover operating flux.[3,4] The retrofit of Clari-DAF® system and membrane filtration into the full-scale Lopez WTP was implemented after a second successful pilot testing program was conducted in 2004, using Clari-DAF® system and Pall microfiltration units.

## 4.2 FULL-SCALE PLANTS

As of 2019, Xylem Water & Wastewater Leopold has more than 45 Clari-DAF® systems in operation globally. These systems are addressing specific needs of the individual plants based on the contaminants to be removed and the level of removal required for each location. In potable water treatment plants, they are being used for source water clarification prior to gravity media filters or low-pressure membranes, as well as for treating gravity media filter backwash or low-pressure membrane backwash waters prior to recycling the effluent to the headworks. Some case studies are presented below.

### 4.2.1 Case Study #1: Boulder Colorado – 63rd Street Plant, USA

**Overview**

DAF has been characterized as a clarification process limited to low-turbidity algae-laden waters. Pilot testing and actual plant operations at the 63$^{rd}$ Street Water Treatment Plant in Boulder, Colorado, has proven that this is not the case.

**Background**

The City of Boulder has two water treatment plants. The Betasso plant is the primary treatment plant which obtains raw water from high mountain snow melt that contains low turbidity, low hardness and low alkalinity. The raw water is gravity fed into the plant. The Betasso plant has an average flow of 14 MGD. The 63$^{rd}$ Street facility is the second treatment plant and operates at 4 MGD during the winter and 8 MGD during summer months. This facility uses more energy than the Betasso plant because pumping may be required to bring raw water into the plant or to pump treated water into the distribution system.

In 2002, Boulder experienced drought conditions that severely restricted its source water supply and necessitated that the City reduce its water production at the main Betasso plant to minimize the quantity of snow-melt source water used in producing water for its consumers. In addition, to maximize the City's water rights, it became evident that there was a need to expand the 63$^{rd}$ Street plant. With the high cost of anticipated construction, the City decided to look for a high-rate process that could be retrofitted into the existing clarification basins. The plant had a 12-foot-deep space that was 149 feet by 132 feet and contained a rectangular up-flow solids contact unit and a rectangular equalization basin where chlorine was fed prior to the filtration process. The Clari-DAF® System's small footprint and shallow depth provided the right clarification process to meet their needs for this application.

The raw water source for the 63rd Street plant is from the western slope basin. It forms Carter Lake before flowing through a canal to the Boulder Reservoir. The water in the Boulder Reservoir is higher in minerals than the Betasso water source, which comes from a shallow body of water used as a recreational lake for a large portion of the year. In the summer months, when the canal has peak flows, the plant uses this source because it is closer in water quality to the Betasso water source and allows easy blending of the two effluents in the distribution system. The turbidity of the Boulder Reservoir water is typically between 6 and 18 NTU, with occasional spikes as high as 100 NTU caused by high winds, heavy rains and spring thaws.

**Pilot Study**

For purposes of simulating high turbidity conditions during the pilot studies, the City dredged the bottom of the reservoir so sediment could be injected directly into the pilot unit's raw water piping. The concern with the ability of the DAF to handle high turbidity revolved around the fact that heavier solids are associated with higher turbidities and, thus, it would be difficult to keep them suspended and float them to the surface. By changing chemistry, it was found that higher turbidities could be handled efficiently and effectively. Data collected from the pilot unit's SCADA system showed that during the turbidity spike when raw water turbidities were as high as 275 NTU, the DAF effluent turbidity was kept below 2.0 NTU.

**Conversion from Solids Contact to DAF Clarification:**

The plan was put in place to retrofit the 63rd Street plant up-flow solids contact system and equalization basin rectangular tanks with the Leopold Clari-DAF® system during the low-demand season (November 2004 through February 2005). The plant was able to replace its filter pretreatment with an entirely new process scheme with only a five-month shut down. Both the guts of the up-flow clarifier, with the bottom of its tank filled in with concrete, and the reaction basin walls were removed so that a 149-ft x 132-ft rectangular space with 12-ft sidewalls remained. With the higher-designed loading rate of the Clari-DAF®

system than the up-flow clarifier, the capacity of the plant was doubled while using less than half of the rectangular space. Two 29-ft x 132-ft Clari-DAF® systems, each capable of processing 8 MGD, were installed. Each system was designed with hydraulic flash mix, 20-minute flocculation times, 4 gpm/ft$^2$ loading rate, and 10 percent recycle rate.

The plant has used a number of clarification treatment chemistries to obtain optimum clarified water quality. With conventional up-flow clarifier technology, plant personnel used ferric sulfate, Sumaclear 820B and caustic. On start-up of the Clari-DAF® system in March 2005, the City switched to alum, Sumaclear 820B, and caustic. The City initiated the feed of cationic polymer in April 2005. Since March 2006, plant personnel have been using Sumaclear 803B as the primary coagulant with the cationic polymer, and adding alum and caustic as needed. The cost of chemical treatment has declined and continues to drop since the installation of the Clari-DAF® system clarification process. Total unit treatment chemical costs before and after Clari-DAF® installation are listed in Table 4. The reduction in treatment chemical cost is about 29 percent.

**Table 4. Chemical Costs for Treatment**

| Clarification | Year | $/Million Gallons |
|---|---|---|
| Up-Flow Clarifier | 2004 | 153 |
| Clari-DAF® Start-up | 2005 | 151 |
| Clari-DAF® Operation | 2006 | 109 |

The average filter runs during up-flow solids contact clarification were 40 hours and have increased to 60 hours with Clari-DAF® clarification. The plant has achieved 70 hours between filter backwashes, but with fluctuations of demand, plant personnel prefer to use all of the filters and backwash at 60 hours rather than allow some of them to sit out of service for extended periods of time. These increased run times are due to the Clari-DAF® system providing better quality of water to the filters. Table 5 compares the turbidities of the two clarification technologies. Plant personnel have experienced turbidity spikes during the day from 20 NTU to 100 NTU, and only saw a turbidity increase in the Clari-DAF® system effluent from 0.4 NTU to

0.7 NTU during that three-hour time frame. In addition, daily pH swings from 7.5 to 8.5 have not had any affect on the Clari-DAF® system effluent turbidity quality.

**Table 5. Turbidity Comparison of Pre- and Post Clari-DAF Installation (in NTU)**

| | **Pre-DAF** | **Post-DAF** |
|---|---|---|
| **Average Daily** | **May, 2004** | **May, 2006** |
| Raw Water | 8.1 to 38.5 | 2.6 to 22.1 |
| Clarified Effluent | 0.72 to 3.13 | 0.23 to 0.47 |
| Filter Effluent | 0.04 to 0.09 | 0.02 to 0.08 |

A comparison of the sludge solids during the same time frames listed above indicated up-flow solids contact clarification yielding sludge solids concentrations of 0.70 percent and Clari-DAF® system yielding sludge solids concentrations of 4 percent. This increase in sludge solids has resulted in a significantly lower volume of solids that is pumped to the lagoon, and a significantly shorter period of time for the solids to dewater to a point where they can be removed.

Given the success of the new Clari-DAF® system technology, the utility added in 2010 an additional 8 MGD capacity in the remaining unused rectangular tank space. This allows the luxury of using the additional unused remaining space for equalization and chlorine contact tanks if desired.

### 4.2.2 Case Study #2: The Songjeon Water Treatment Plant (SWTP) - Wonju, South Korea

**Overview:**

The SWTP is operated by the Korean Water Resources Corp (K-Water). It obtains raw water from the Hoeng-Seong (HS) Lake. The lake water has algae blooms, high turbidity when there are rainfall events, and requires powdered activated carbon (PAC) to enhance organic removals and reduce formation of chlorinated by-products such as total trihalomethanes (THMs), dichloroacetic and trichloroacetic acid (HAA2), and chloral hydrate (CH), which are suspected carcinogens.

**Background:**

The raw water supply from Hoeng-Seong Lake had algae counts averaging 2455 cells/mL, low turbidity (average 6.1 NTU), low hardness (average 28 mg/L as $CaCO_3$), and low alkalinity (average 21.6 mg/L). Between 2000 and 2003, turbidity during and after rainfall events varied to spikes over 300 NTU. K-Water designed a system that would be flexible and handle a variety of raw water conditions. The plant was designed for flow rates of 100,000 $m^3$/hr (26.4 MGD). The process flow included a pre-sedimentation basin, a Leopold Clari-DAF® system, and Leopold gravity filters with Type S® Underdrain, I.M.S.® (Integral Media Support) Cap, sand (250 mm) and anthracite (1750 mm) media, and backwash troughs. The pre-sedimentation basin diverted flow during rain events to allow heavy turbidity to settle out prior to treatment through the Clari-DAF® system flotation process.

**Treatment Results:**

The plant was built and began operation in 2003. The coagulant chemical feed is polyaluminum chloride and lime, which averages 12 mg/L and 2 mg/L, respectively. The G value in the flocculators is 70 $sec^{-1}$ in the first stage, and 50 $sec^{-1}$ in the second stage. The loading rate is 16.3 m/hr (6.7 gpm/$ft^2$) based on collector area, while the recycle rate is 10 percent in the summer and 7 percent during the other nine months. Since the facility's start-up, the average raw turbidity has been 5 NTU, Clari-DAF® system effluent 0.3 NTU, and filter effluent 0.04 NTU. Rain events have resulted in raw water turbidities ranging from 64 NTU to 430 NTU. During those times, 2.3 to 16.5 NTU turbidity remained in the effluent from the pre-sedimentation process. This turbidity was reduced by the Clari-DAF system to 0.14 – 1.1 NTU, and then by the filter to 0.02 – 0.09 NTU, which produced a stable water quality.

When removing organics in the raw water, K-Water has managed to reduce the level of chlorinated by-products below the criteria mandated in Korea and the U.S. as listed in Table 6.

**Table 6. Comparion of K-Water DBP Concentrations With Korean and U.S. Standards (in mg/L)**

| Parameter | Korea | USA | K-Water |
|---|---|---|---|
| THMs | < 0.1 | < 0.08 | < 0.064 |
| HAA2 | < 0.1 | < 0.06 | < 0.048 |
| CH | < 0.03 | | < 0.024 |

To help the plant meet the goals, powdered activated carbon (PAC) was fed before adding the coagulant. Table 7 summarizes the average concentrations of chlorinated by-products in the effluent water with PAC addition from April 2005 to March 2006, and without PAC addition from April 2004 to March 2005:

**Table 7. Average DBP Concentrations With and Without PAC (in mg/L)**

| Parameter | w/o PAC | w PAC | Goal |
|---|---|---|---|
| THMs | 0.022 | 0.022 | < 0.064 |
| HAA2 | 0.029 | 0.020 | < 0.048 |
| CH | 0.006 | 0.007 | < 0.024 |

With PAC, the concentrations of THMs and CH were all but unchanged but the HAA2 was reduced by 9 μg/L. This is significant because, of the three chlorinated by-products, HAA2 has been the biggest problem in most Korean potable water treatment plants. While feeding PAC, and with raw water turbidity of 3.5 NTU, the pre-sedimentation basin average effluent went from 1.9 NTU to 2.8 NTU, and the Clari-DAF® system effluent yielded a slight increase from 0.15 NTU to 0.23 NTU. Plant personnel continue to investigate additional methods to further reduce chlorinated by-products.

### 4.2.3 Case Study #3: Greenville, South Carolina – Table Rock/North Saluda Plant, USA

**Overview:**

The Greenville Water System draws water from three sources—Table Rock Reservoir on the South Saluda River, Poinsett Reservoir on the North Saluda River and Lake Keowee. The Table Rock and Poinsett Reservoirs are both located in the foothills of the Blue Ridge Mountains in northern Greenville County. The source waters were so clear that for more than 70 years, the water from the mountain reservoirs was unfiltered and only treated with chlorine. In the mid 1980s, the Adkins Filtration Plant using conventional settling basin clarification technology for 30 MGD design capacity was built using Lake Keowee as its source water. This plant was expanded in 2003 to increase capacity to 60 MGD using the same settling basin clarification technology. Because increasing regulations required all surface water systems to be filtered, a new state-of –the-art filter plant was placed in service in July 2000 to provide filtration for all of the water drawn from the Table Rock and Poinsett reservoirs. This new Table Rock/North Saluda filter plant, designed at 75 MGD, uses the Clari-DAF® system for clarification in the treatment scheme.

**Background:**

The Adkins Filter Plant uses coagulation, sedimentation, filtration and disinfection to treat the source water. Alum is used as the coagulant, along with sodium hydroxide (caustic) for pH adjustment. Chlorine combined with ammonia is used for disinfection, while a zinc polyphosphate is added for corrosion control. Fluoridation is provided to prevent tooth decay. The Table Rock/North Saluda (TR/NS) Filter Plant uses the flotation process, rather than sedimentation, for particle removal. The remaining processes and chemicals used are similar to those at the Adkins Plant. The raw water quality of the two plants is very similar, with low turbidity, low hardness and low alkalinity. Listed in Table 8 are the average water quality data for raw, clarified and finished water for the two-year time period August 2003 thru July 2005:

**Table 8. Average Water Quality Data for Adkins and TR/NS Filter Plants**

| | Parameter | | Adkins | TR/NS |
|---|---|---|---|---|
| Raw | pH | | 6.55 | 6.55 |
| | Alkalinity | mg/L | 8.89 | 6.95 |
| | Temp | C | 21.70 | 19.20 |
| | Hardness | mg/L | 5.00 | 4.20 |
| | Turbidity | NTU | 1.20 | 0.49 |
| Clarified | Turbidity | NTU | 0.37 | 0.20 |
| | Chlorine | mg/L | 1.70 | 0.20 |
| Finished | pH | | 7.10 | 7.45 |
| | Alkalinity | mg/L | 10.70 | 8.70 |
| | Temp | C | 21.40 | 19.00 |
| | Hardness | mg/L | 5.25 | 4.40 |
| | Turbidity | NTU | 0.04 | 0.05 |
| | Chlorine | mg/L | 2.65 | 2.60 |

There is a significant difference in the footprint required for the processes at each facility while the energy requirement is similar for both processes. Table 9 compares the design criteria of the two processes.

| Table 9. Comparison of Process Design Criteria at Adkins and TR/NS Filter Plants | | |
|---|---|---|
| **Process** | **Adkins (Per Basin)** | **TR/NS (Per Train)** |
| **Rapid Mix** | | |
| Area ($ft^2$) | 95 | Inline Static |
| Flow (MGD) | 30 | |
| **Flocculation** | | |
| Area ($ft^2$) | 5664 | 3684 |
| Flow (MGD) | 15 | 25 |
| **Clarification** | | |
| Area ($ft^2$) | 28,438 | 3784 |
| Flow (MGD) | 15 | 25 |
| **Filtration (Per Filter)** | | |
| Area ($ft^2$) | 1,343 | 792 |
| Flow (MGD) | 11.25 | 6.87 |
| **Total Plant** | | |
| Area ($ft^2$) | 147,342 | 31,908 |
| Flow (MGD) | 60 | 75 |

The footprint for processing 60 MGD by the conventional settling basin system at Adkins is 147,342 $ft^2$. This results in a requirement of 2,456 $ft^2$ per million gallons of water processed when producing 60 MGD. The total area for processing 75 MGD through the DAF system at Table Rock/North Saluda is 31,908 $ft^{2.}$ This results in a requirement of 425 $ft^2$ per million gallons of water processed. By selecting the Clari-DAF® process, the land footprint requirement is reduced by 82.7 percent.

The average chemical dosages for the two-year time frame of August 2003 thru July 2005 are listed in Table 10.

**Table 10. Average Chemical Dosages in Adkins and TR/NS Filter Plants**

| Parameter | Adkins | TR/NS | Diff | % Diff |
|---|---|---|---|---|
| Alum mg/L | 14.1 | 11.4 | 2.7 | 19 |
| Caustic mg/L | 12.7 | 9.1 | 3.6 | 28 |
| Chlorine mg/L | 7.7 | 3.2 | 3.5 | 45 |
| Aq Ammonia mg/L | 1.4 | 0.6 | 0.8 | 57 |

Given the fact that the raw water turbidity was lower at TR/NS, it would be expected that the alum coagulant dosage would be higher. The lower the turbidity, the harder it is to clarify the water and, subsequently, the higher the inorganic coagulant dosage; however, the reduction at TR/NS is due to the fact that flotation can effectively remove smaller diameter solids. Some of the increased caustic feed at Adkins can be attributed to the higher alum feed that depresses the pH for coagulation. The increased chlorine and ammonia feed at Adkins is due to the fact that a higher clarified combined residual is maintained through the clarification process at Adkins to meet CT requirements.

Filter performance data listed in Table 11 were collected from one filter at Adkins and one filter/train at TR/NS (three total filters) for the August 2003 to July 2005 timeframe.

**Table 11. Comparison of Filter Performance at Adkins and TR/NS Filter Plants**

| Parameter | Units | Adkins | TR/NS |
|---|---|---|---|
| Surface Area | $ft^2$ | 1342 | 792 |
| Total Volume | MG | 21.59 | 16.817 |
| Average Filter Run | Hrs | 126 | 118 |
| Average Backwash | Gal | 294458 | 269125 |
| Unit Filter Runtime Vol. | $MG/ft^2$ | 17697 | 20984 |
| Backwash (%) Range | % | 0.77-2.41 | 0.88-2.42 |

The average in-plant water usage rates (water for filter backwash, water-to-waste after backwash, sludge removal, etc) for the same period are compared in Table 12.

**Table 12. Comparison of In-Plant Water Usage Rate at Adkin and TR/NS Filter Plants**

| Parameter | Adkins | TR/NS | Diff | % Diff |
|---|---|---|---|---|
| % In-Plant Use | 9.47 | 3.84 | 5.63 | 59.45 |

There is a major difference and, therefore, an associated cost savings, due to reduced in-plant water usage. The overall cost of water accelerates with higher figures because the in-plant usage is water that has already been processed and, therefore, has an associated multiplied cost. Some of the difference is the result of shorter filter runs and additional backwash water required to wash the filter. In addition, some of the difference is associated with the sludge content of the solids removed from the Adkins conventional settling basin (<0.5 percent) vs. the DAF unit solids thickening (to >2 percent) for removal from the TR/NS flotation clarification process. The Adkins submerged sludge collector consumes 2.6 million gallons of water per cycle per day. Table 13 compares the expenses incurred and the total water production at each treatment plant for the two-year timeframe August 2003 thru July 2005. There was a major reduction (56 percent) in cost per 1000 gallons treated at the TR/NS plant.

**Table 13. Comparison of Production Costs at Adkins and TR/NS Filter Plants**

| Parameter | Adkins | TR/NS | Diff | % Diff |
|---|---|---|---|---|
| Total Flow x $10^6$ (Gal) | 10,664 | 22,918 | +12,254 | +53 |
| Treatment Expense ($) | 1,892,941 | 1,727,882 | -165,059 | -8.7 |
| $/1000 gallons | 0.18 | 0.08 | -0.10 | -56 |

Given similar raw water conditions and the ability to produce effluent water below MCL (Maximum Contaminant Level), and given the potential of efficient sludge handling, selecting Clari-DAF® as a replacement for standard sedimentation technology has resulted in significant chemical and operating cost savings. The advantages include:

- The footprint required per million gallons was one sixth the size
- The chemical consumption was lower
- Unit Filter Runtime volumes were 18 percent longer
- In-plant water usage was 59 percent lower
- The total cost per 1000 gallons was 56 percent lower

#### 4.2.4 Case Study #4: William R. Oliver Water Treatment Plant - Papillion, Nebraska , USA

**Overview:**

The final US Environmental Protection Agency (USEPA) Filter Backwash Recycling Rule (FBRR) was promulgated on June 8, 2001. It stated that utilities with conventional or direct filtration processes were to have State approval for all return recycle flows within their treatment plants. If capital improvements were required to modify the recycle location, they were to be completed by June 8, 2006.The main objective of the FBRR was to improve performance at filtration plants by reducing the opportunity for recycle practices to adversely affect plant performance in a way that would allow microbes such as *Cryptosporidium* to pass through into finished drinking water. In addition, residual chemicals and other contaminants in the recycle stream could upset chemical feed processes in the main treatment train process, which would affect the coagulation process and contaminant removal in subsequent treatment processes.

Recycle streams could also be reintroduced in sufficient volumes to create a hydraulic surge or cause a plant to exceed capacity. All of these issues had the potential to impact finished water quality. The FBRR applies to all surface water or ground water systems in the United States under the direct influence of surface water that practice conventional (coagulation, flocculation, sedimentation and filtration) or direct filtration (coagulation, flocculation and filtration), and that recycle water within their process. Filters must be routinely backwashed to maintain proper treatment capability of the filter. The frequency of backwashing and the backwash method will vary from plant to plant. The backwash process fluidizes the filter media and removes particles that have been trapped within the media. The spent filter backwash will contain the removed particles.

**Background:**

The William R. Oliver Water Treatment Plant in Papillion, Nebraska, treats an average of 4 MGD with potassium permanganate ($KMnO_4$) and chlorine dioxide ($ClO_2$) to oxidize dissolved manganese. Sternpac coagulant and polymer coagulant help remove solids in the sand-ballasted clarification process. The effluent is processed through eight filters and then stored in a clear well where chlorine disinfectant is added. The filters have an average run time of 20 hours between backwashes and use air/water in their backwash sequence. Since the backwash water was recycled, the plant was required to install a treatment process to prevent potential contaminants from building up in their treatment process. It was decided to install a Clari-DAF® BWT (backwash water treatment) System to treat this stream to provide maximum protection of public health and to optimize the treatment processes.

**Performance:**

The Clari-DAF® BWT System was designed to handle a maximum flow of 1,310 gpm with one flocculator to provide 12 minutes mixing, a loading rate of 7 gpm/ft$^2$, and a recycle rate of 10 percent. Since start-up of the unit, the flow has ranged from a low of 400 gpm to a high of 1,000 gpm. Plant personnel have fed

Applied Specialties AS-1430PW acrylamide emulsion polymer at 0.2 mg/L. The influent turbidity has been as high as 800 NTU, and the Clari-DAF® BWT effluent has been consistently below 1 NTU.

#### 4.2.5 Case Study #5: Evitts Creek Water Treatment Plant – Bedford, Pennsylvania, USA

**Overview:**

The Evitts Creek Water Treatment Plant that is owned and operated by the City of Cumberland, Maryland is located in Bedford on the border of Pennsylvania near the Maryland panhandle. It provides potable water for Cumberland and other surrounding smaller communities in Maryland, West Virginia, and Pennsylvania. Both the states of Maryland and Pennsylvania have regulatory responsibility for this facility.

The raw water source for the treatment plant influent is Lake Koon, which has 2.2 billion gallon capacity and feeds into the 1.3 billion gallon Lake Gordon reservoir where the treatment plant intake structure is located.

**Background:**

The originally-designed 12 MGD plant had a treatment scheme with rapid mix, upflow solids clarifiers, filters, clear well, a contact tank and vacuum drying beds for sludge dewatering. Plant flow averaged 9 MGD, with peaks of 13 MGD. The influent turbidity averaged 3 NTU with influent soluble manganese levels averaging 0.1 mg/L, but peaking at 0.172 mg/L. Potassium permanganate ($KMnO_4$) was fed regularly at the intake for taste and odor control, and to oxidize manganese for removal in the clarification stage of the treatment process. The plant fed inorganic flocculant and polymer for clarification, caustic for corrosion control, fluoride for dental caries reduction, chlorine for disinfection, and ammonia to form chloramines to carry the residual throughout the large distribution system.

In 1998, in addition to the soluble manganese problem, increased agricultural runoff and a reduction in the surrounding forestry were causing progressively higher algae blooms during the summer months. These conditions created severe taste and odor problems, shortened filter run times, and led to discolored water that stained water consumers' laundry.

After investigating alternative clarification technologies, the City's consulting engineer recommended installing a DAF clarification system and replacing five filters to address increased algae and improve manganese removal.

**Pilot Study:**

In the summer of 1999, a Leopold state-of-the art Clari-DAF® system mobile pilot plant was brought in to determine its process effectiveness and develop design criteria. The six-week pilot study optimized the inorganic coagulant doses at 15-20 mg/L, while operating at a loading rate of 7 gpm/ft$^2$ based on total area with an efficient recycle flow of 7.8 percent. The pilot DAF indicated that it could effectively remove algae and manganese, as well as produce a consistent effluent quality for filter loading, thus maximizing the filter run times between backwashes. It would also produce 2 percent to 5 percent sludge solids in the float, which would reduce the sludge volume to handle and the cost of further processing by dewatering and hauling away the sludge solids. In addition, a smaller footprint allowed the water utility to handle a proposed 36 percent increase in ultimate plant capacity to 15 MGD in the same area for the proposed new expansion facility.

**Clari-DAF® System Design/Build Team:**

After evaluating the success of the pilot study and visiting several existing DAF installations, city of Cumberland officials were convinced that a DAF system was the best alternative for the Evitts Creek treatment scheme. A Design/Build Team formed between the City, F.B. Leopold, a local contractor, and the engineering firm accomplished the final design and installation in June 2002. The project was completed ahead of schedule and under budget. It consisted of three DAF systems (designed at 5 MGD apiece), each with dual flocculators, basins that are 22' wide x 32' long x 10' deep, and with all the required pumps, saturation tank, and controls. In addition, it involved replacing the existing filters with Type S® Underdrain, I.M.S.® (Integral Media Support) Cap, backwash troughs, sand and anthracite media, and three dual filter control consoles to provide automatic control and monitoring of the filter operation backwash sequence. The new filter system also included adding air scour to the backwash procedure.

**Pre and Post Clari-DAF System Performance**:

The DAF effluent turbidity is consistently below 0.2 NTU and has increased filter runs to the Pennsylvania state regulatory recommended maximum of 72 hours. Previously with the upflow clarifier, the filter runs were at 24 hours between backwashes. The taste and odor problems have been resolved, soluble manganese in the finished water is now below 0.02 mg/L, and the process obtains a minimum of 85 percent removal of the incoming algae.[5]

One of the big benefits from the DAF operation is the high solids content of the floated sludge. As it comes off the top of the unit, it is actually diluted to 2 percent for pumping purposes, and then sent to the belt press that has replaced the vacuum drying beds. The belt press, using anionic polymer as a sludge conditioner, produces sludge cake ranging from 16 percent to 22 precent solids. This compares favorably to the drying beds that produced 5 percent cake solids and required sawdust filler to be added to soak up water for hauling it to the landfill. The belt press processes a one-week accumulation of sludge in 10 to 14 hours rather than the 48 to 60 hours previously required using the drying bed. This has reduced the overall operating costs of the solids handling and disposal operation by more than 60 percent.

Table 14 compares the actual plant performance that has been achieved with the two clarification processes at the Evitts Creek Treatment plant.

**Table 14. Performance Comparison Between Upflow clarification and Clari-DAF®**

| Parameter | Upflow Unit | DAF |
|---|---|---|
| Raw Water Turbidity | 2.0 - 5.0 NTU | 2.0 - 5.0 NTU |
| Raw Water Manganese | 0.1 - 0.17 mg/L | 0.1 - 0.17 mg/L |
| Effluent Turbidity | 1.0 NTU | 0.2 NTU |
| Effluent Manganese | 0.05 mg/L | 0.02 mg/L |
| Filter Run Length | 24 hours | 72 hours |
| Filter Effluent Turbidity | 0.1 NTU | 0.04 NTU |
| Filter Effluent Manganese | 0.05 mg/L | 0.02 mg/L |

Today, the Clari-DAF® system's effluent water quality and subsequent filter run times are exceeding expectations. Also, the maintenance and operations requirements of the DAF units are less than anticipated, which gives plant operators extra time to accomplish more tasks during their regular shift.

## 5.0 MARKETING OUTLOOK

DAF offers utility operators an effective solution for high-rate clarification within the potable water treatment scheme. Compared to settling processes, the DAF system has many advantages that make it the clarification process of choice. With the capability to remove smaller particles and provide higher sludge solids content than settling processes, the Utility Operator gets multiple benefits.

In the USA, the Surface Water Treatment Rule (SWTR) requires 3-log *Giardia* removal or inactivation for municipal water treatment facilities. The Interim Enhanced Surface Water Treatment Rule (IESWTR) requires a 2-log removal of *Cryptosporidium*. Conventional water treatment plants receive 2.5-log removal credit for sedimentation and filtration, which leaves an additional 0.5-log removal credit for inactivation by disinfection.

The US Environmental Protection Agency (USEPA) assigns a 2-log *Cryptosporidium* removal credit for all water treatment plants with granular media filtration. The Long-Term Enhanced Surface Water Treatment Rule (LTESWTR) that was promulgated requires a 2-log *Cryptosporidium* removal credit by water filtration plants as outlined in the interim rule. The regulation requires additional log removals for raw water supplies with *Cryptosporidium* in excess of 0.075 oocysts/L.

The Xylem Water & Wastewater Leopold Group has developed pilot data that shows the impact of DAF clarification on the removal of *Cryptosporidium* and *Giardia* at 3.5- to 4-log removal. This test was conducted using the Lake Waco source water and spiking a quantity of inactivated *Cryptosporidium* and *Giardia* prior to the Xylem Water & Wastewater Leopold Clari-DAF® pilot system process. The pilot work will be submitted to the Texas Natural Resource Commission (TNRC) for verification of pathogen removal through the DAF.

The advent of the Stage 2 Disinfectant & Disinfection By-Product Rule (Stage 2 DBPR) has developed interest from potable water treatment plant personnel in learning about TOC removal at the treatment plant.

In the distribution system, the maximum allowable contaminant level (MCL) called out in the Stage 2 DBPR is 0.080 mg/L of total trihalomethane (TTHM) and combined residual of 0.060 mg/L of five different haloacetic acids (HAA5). Both are suspected carcinogens that are formed when chlorine is fed for disinfection purposes, and it combines with organics that are in the water. Treatment plants will attempt to remove the organics in the clarification and filtration processes so that the post-chlorination practices will not result in the formation of TTHMs and HAA5s.

All water treatment plants must complete an Initial Distribution System Evaluation (IDSE) to determine the water quality that is currently in the distribution system. Based on population, those reports were to be completed and submitted to the US Environmental Protection Agency (USEPA) by the following dates:

| Population | Complete Monitoring by |
|---|---|
| > 100,000 | 30-Sep-08 |
| 50,000 - 99,999 | 31-Mar-09 |
| 10,000 - 49,999 | 30-Sep-09 |
| < 10,000 | 31-Mar-10 |

The population served by the treatment plant distribution system determines the number of samples collected and the frequency of collection.[6]

To help meet the Stage 2 DBPR requirements, the USEPA developed guidelines for the level of Total Organic Carbon (TOC) removal based on the source water TOC and alkalinity. The TOC Removal mandated by the Stage 2 DBPR is shown in Table 15.

**Table 15. USEPA TOC Removal Requirements by Stage 2 DBPR**

| | **Raw Water Alkalinity mg/L** | | |
|---|---|---|---|
| | **0 - 60** | **60 - 120** | **> 120** |
| **Source Water TOC mg/L** | **Percent Removal (%)** | | |
| > 2.0 - 4.0 | 35 | 25 | 15 |
| > 4.0 - 8.0 | 45 | 35 | 25 |
| > 8.0 | 50 | 40 | 30 |

Clari-DAF® Systems offer an excellent clarification process to help surface water treatment plants meet their requirements for TOC removal and subsequently meet the Stage 2 DBPRmaximum limits for TTHM and HAA5 in the distribution system.

Each raw water source contains TOC material that is a combination of insoluble and soluble (measured as DOC) components. To remove the soluble portion, they must be precipitated in some manner to create a particle that can be settled or floated out of the water. Many organic substances can be oxidized with ozone, potassium permanganate ($KMnO_4$), peroxide, etc. As an alternative, Utilities are evaluating the practice of "Enhanced Coagulation" where the pH is depressed to the optimum range to achieve the highest organic precipitation. The particles are small, colloidal in size and require coagulants to form floc that are large enough to remove them. Data was supplied in the pilot studies section of this chapter that shows the effectiveness of DAF to remove TOC at various pH levels.

Another potential use for DAF clarification is with desalination pretreatment systems. The reverse osmosis (RO) membranes typically have filtration pretreatment systems, but 'red tide' or algae events, as well as oil typically from ship ballast water, will foul the filters and shorten filter runs. This results in inadequate removal of the fouling material that leads to high Silt Density Index (SDI) numbers. DAF pretreatment will be part of the total pretreatment scheme, along with gravity media or UF membrane or cartridge filtration to protect RO membranes from fouling and reducing recovery.[7]

GLOSSARY

**Coagulant:** A chemical (alum or iron salts) added to water to destabilize particles, allowing subsequent floc formation and removal by clarification (flotation or sedimentation) and/or filtration.

**Coagulation:** A process of destabilizing charges of suspended and colloidal partices in water by adding chemicals (coagulants). In coagulatioh process, positively charged chemicals are added to neutralize or destabilize these negative charges and allow the neutralized particles to accumulate and be removed by clarification (flotation or sedimentation) and/or filtration.

**Collector:** A device or system designed to collect filter backwash water , or other treatment unit.

**Dispersion:** A uniform and maximum separation of extremely fine particles, often of colloidal size.

**Dissolved air flotation (DAF):** One of dissolved gas flotation (DGF) processes when air is used for generation of gas bubbles. See dissolved gas flotation (DGF).

**Dissolved gas flotation (DGF):** It is a process involving pressurization of gas at 25 to 95 psig for dissolving gas into water, and subsequent release of pressure (to one atm) under laminar flow hydraulic conditions for generating extremely fine gas bubbles (20-80 microns) which become attached to the impurities to be removed and rise to the water surface together. The impurities or pollutants to be removed are on the water surface are called float or scum which scooped off by sludge collection means. The clarified water is discharged from the flotation clarifier's bottom. The gas flow rate is about one percent of influent liquid flow rate. The attachment of gas bubbles to the impurities can be a result of physical entrapment, electrochemical attraction, surface adsorption, and/or gas stripping. The specific gravity of the bubble-impurity agglomerate is less than one, resulting in buoyancy or non-selective flotation (i.e. Save-All).

**Floc:** Collections of smaller particles that have agglomerated together into larger, more separable (floatable or settleable particlks as result of the coagulation process.

**Flocculation:** A water treatment unit process followibg coagulation that uses gentle stirring to bring suspended particles together so they will form largr, more separable (floatable or settleable) floc.

**Flocculator:** A process device to enhance the formation of floc in a water. Mixing energy can be provided by slow turning mechanical means or head loss.

**Rapid mixing:** A water treatment unit process of quickly mixing a chemical solution uniformly through the process water.

**Velocity gradient (G):** A measure of the mixinn intensity (in units of per second) in a water treatment process. Very high velocity gradients (greater than 300 per second) are used for complete mixing and dissolution of chemicals in a coagulation process, whereas lower values (less than 75 per second) are used in flocculation to bring particles together and promote agglomeragion.

REFERENCES


1. ITT Leopold Product Bulletin: The Leopold® Clari-DAF™ System – The Next Generation in Dissolved Air Flotation Clarification.
2. Corwin, B., J. Wong, J. Lodge, and C. Ferrara, "County of San Luis Obispo Selects an Innovative Approach to Solve Water Quality Problems," Proceedings of 2003 AWWA ACE (Poster), Anaheim, CA, June 2003.
3. Chevalier, M.R., et al., CIRSEE (Suez Environment), Lyonnaise des Eaux, 1994.
4. Montgomery Watson Applied Research Department Technology Transfer Note, No. 12, January 1997.
5. Marvin, R., "DAF Removes Algae, Eases Manganese Issues," Opflow, vol. 31, No. 2, February 2005.
6. USEPA, Stage 2 Disinfectants and Disinfection Byproducts Rule, Final Rule, 40 CFR Part 9, 141 and 142, January 4, 2006.
7. Farmerie, J. (2006). Eliminating Membrane Fouling. Membrane Technology, Vol 4, No. 1, November.
8. Krofta, M., and Wang, LK (1985). Application of dissolved air flotation to the Lenox, Massachusetts water supply: water purification by flotation, Journal of New England Water Works Association, 99(3), pp. 249-264.
9. Krofta, M., and Wang, LK (1985). Application of dissolved air flotation to the Lenox, Massachusetts water supply: sludge thickening by flotation and lagoon, Journal of New England Water Works Association, 99(3), pp. 265-284.
10. Forestell, W, and Wang, LK (1991). Air flotation and sand filtration : a success for innovation in Pittsfield, MA, Journal of New England Water Works Association, 105(3), pp. 223-243.
11. Wang, LK, Fahey, EM, and Wu, Z. (2005). Dissolved air flotation. In: Physicochemical Treatment Processes, (Wang, LK, Hung, YT, and Shammas, NK, editors), Humana Press, Totowa, NJ., USA, pp. 431-500.

12. Wang, LK, Shammas, NK, Aulenbach, DB, Selke, WA, and Guss, DB (2010). Pittsfield water treatment plant: once the world's largest flotation-filtration plant. In: Flotation Technology (Wang, LK, Shammas, NK, Selke, WA and Aulenbach, DB, editors), Humana Press, Totowa, NJ, USA, pp. 485-502.

13. Wang, LK (2018). Development and construction of the first two potable DAF-Filtration plant in Two America Continents. Journal of New England Water Works Association, pp.90-95, July 2018.

14. Wang, LK (2007). Emerging flotation technologies. In: Advanced Physicochemical Treatment Technologies (Wang, LK, Hung, YT, and Shammas, NK, editors), Humana Press, Totowa, NJ, USA, pp.449-484.

15. Wang, LK, Shammas, NK, Selke, WA, and Aulenbach, DB (2010). Flotation Technology. Humana Press, Totowa, NJ, USA. 680 pages.

16. Shammas, NK and Wang, LK (2016). Water Engineering: Hydraulics, Distribution and Treatment. John Wiley & Sons, Hoboken, NJ, USA. 806 pages.

17. Wang, LK, Hung, YT and Shammas, NK (2004) Physicochemical Treatment Processes. Humana Press, Totowa, NJ, USA. 723 pages.

18. Wang, MHS and Wang LK (2016). Glossary of land and energy resources engineering. In: Natural Resources and Control Processes. (Wang LK, Wang MHS, Hung YT, and Shammas NK , editors). Springer, New York, USA. 493-623.

19. Wang, MHS and Wang LK (2015). Environmental water engineering glossary. In: Advances in Water Resources Engineering. (Yang CT and Wang LK , editors). Springer, New York, USA. 471-556.

20. Edzwald, J.K.,(2007). Developments of high rate dissolved air flotation for drinking water treatment. Journal of Water Supply: Research and Technology –Aqua 56(6–7),399–409.

21. Edzwald,J.K., Tobiason,J.E., Parento,L.M., Kelley,M.B., Kaminski,G.S., Dunn,H.J., Galant,P.B., (2000). *Giardia*and*Cryptosporidium* removals by clarification and filtration under challenge

conditions. Journal of the American Water Works Association 92(12),70–84.

22. Wong, J (2013). Clarifying treatment: dissolved air flotation provides alternative for treating raw water with light particles. Water World, August 2013, pp. 41-45.

**List of Tables**

Table 1. Clari-DAF® System Pilot Data

Table 2. Clari-DAF® System Pilot TOC Data

Table 3. Total Algae Counts at the Lake Lopez Intakes and Terminal Reservoir

Table 4. Chemical Costs for Treatment

Table 5. Turbidity Comparison of Pre- and Post Clari-DAF Installation (in NTU)

Table 6. Comparion of K-Water DBP Concentrations With Korean and U.S. Standards (in mg/L)

Table 7. Average DBP Concentrations With and Without PAC (in mg/L)

Table 8. Average Water Quality Data for Adkins and TR/NS Filter Plants

Table 9. Comparison of Process Design Criteria at Adkins and TR/NS Filter Plants

Table 10. Average Chemical Dosages in Adkins and TR/NS Filter Plants

Table 11. Comparison of Filter Performance at Adkins and TR/NS Filter Plants

Table 12. Comparison of In-Plant Water Usage Rate at Adkin and TR/NS Filter Plants

Table 13. Comparison of Production Costs at Adkins and TR/NS Filter Plants

Table 14. Performance Comparison Between Upflow clarification and Clari-DAF®

Table 15. USEPA TOC Removal Requirements by Stage 2 DBPR

| Table 1. Clari-DAF® System Pilot Data | | | | |
|---|---|---|---|---|
| **Parameter** | **Raw Water** | **Average In** | **Average Out** | **% Removal** |
| Turbidity | 0-5 NTU | 3.71 NTU | 0.68 NTU | 82 |
| | 5-10 NTU | 7.24 NTU | 0.79 NTU | 89 |
| | 10+ NTU | 18.8 NTU | 1.68 NTU | 91 |
| Apparent Color | 0-50 Pt-Co | 28 Pt-Co | 14 Pt-Co | 50 |
| | 50-100 Pt-Co | 73 Pt-Co | 24 Pt-Co | 67 |
| | 100 + Pt-Co | 206 Pt-Co | 41 Pt-Co | 80 |
| True Color | 0-5 Pt-Co | 4.7 Pt-Co | 0.8 Pt-Co | 82 |
| | 5-10 Pt-Co | 8.5 Pt-Co | 2.8 Pt-Co | 67 |
| | 10+ Pt-Co | 15.1 Pt-Co | 3.9 Pt-Co | 74 |
| Iron | all | 0.22 mg/L | 0.047 mg/L | 79 |
| Manganese | all | 0.1 mg/L | 0.037 mg/L | 63 |
| Algae | all | 3469 counts | 831 counts | 76 |

| Table 2. Clari-DAF® System Pilot TOC Data | | | |
|---|---|---|---|
| **pH** | **Average In** | **Average Out** | **% Removal** |
| 8+ | 3.18 mg/L | 2.19 mg/L | 31.1 |
| 7 to 8 | 4.88 mg/L | 3.02 mg/L | 38.1 |
| 6 to 7 | 6.84 mg/L | 3.17 mg/L | 53.6 |

| Table 3. Total Algae Counts at the Lake Lopez Intakes and Terminal Reservoir | | | |
|---|---|---|---|
| **Description** | **Minimum, c/mL** | **Maximum, c/mL** | **Median, c/mL** |
| **Lopez Lake** | | | |
| Intake 1 | 0 | 24,000 | 1,403 |
| Intake 2 | 0 | 14,000 | 868 |
| Intake 3 | 0 | 6,000 | 354 |
| Intake 4 | 0 | 1,700 | 93 |
| Intake 5 | 0 | 1,200 | 50 |
| Intake 6 | 0 | 1,100 | 36 |
| **Terminal Reservoir** | | | |
| Intake 06’ | 0 | 69,000 | 2,039 |
| Intake 12’ | 0 | 71,000 | 2,056 |
| Intake 18’ | 0 | 73,000 | 2,079 |

| Table 4. Chemical Costs for Treatment | | |
|---|---|---|
| **Clarification** | **Year** | **$/Million Gallons** |
| Up-Flow Clarifier | 2004 | 153 |
| Clari-DAF® Start-up | 2005 | 151 |
| Clari-DAF® Operation | 2006 | 109 |

| Table 5. Turbidity Comparison of Pre- and Post Clari-DAF Installation (in NTU) | | |
|---|---|---|
| | **Pre-DAF** | **Post-DAF** |
| **Average Daily** | **May, 2004** | **May, 2006** |
| Raw Water | 8.1 to 38.5 | 2.6 to 22.1 |
| Clarified Effluent | 0.72 to 3.13 | 0.23 to 0.47 |
| Filter Effluent | 0.04 to 0.09 | 0.02 to 0.08 |

| Table 6. Comparion of K-Water DBP Concentrations With Korean and U.S. Standards (in mg/L) | | | |
|---|---|---|---|
| **Parameter** | **Korea** | **USA** | **K-Water** |
| THMs | < 0.1 | < 0.08 | < 0.064 |
| HAA2 | < 0.1 | < 0.06 | < 0.048 |
| CH | < 0.03 | | < 0.024 |

**Table 7. Average DBP Concentrations With and Without PAC (in mg/L)**

| Parameter | w/o PAC | w PAC | Goal |
|---|---|---|---|
| THMs | 0.022 | 0.022 | < 0.064 |
| HAA2 | 0.029 | 0.020 | < 0.048 |
| CH | 0.006 | 0.007 | < 0.024 |

| Table 8. Average Water Quality Data for Adkins and TR/NS Filter Plants | | | | |
|---|---|---|---|---|
| | **Parameter** | | **Adkins** | **TR/NS** |
| Raw | pH | | 6.55 | 6.55 |
| | Alkalinity | mg/L | 8.89 | 6.95 |
| | Temp | C | 21.70 | 19.20 |
| | Hardness | mg/L | 5.00 | 4.20 |
| | Turbidity | NTU | 1.20 | 0.49 |
| Clarified | Turbidity | NTU | 0.37 | 0.20 |
| | Chlorine | mg/L | 1.70 | 0.20 |
| Finished | pH | | 7.10 | 7.45 |
| | Alkalinity | mg/L | 10.70 | 8.70 |
| | Temp | C | 21.40 | 19.00 |
| | Hardness | mg/L | 5.25 | 4.40 |
| | Turbidity | NTU | 0.04 | 0.05 |
| | Chlorine | mg/L | 2.65 | 2.60 |

| Table 9. Comparison of Process Design Criteria at Adkins and TR/NS Filter Plants | | |
|---|---|---|
| **Process** | **Adkins (Per Basin)** | **TR/NS (Per Train)** |
| **Rapid Mix** | | |
| Area ($ft^2$) | 95 | Inline Static |
| Flow (MGD) | 30 | |
| **Flocculation** | | |
| Area ($ft^2$) | 5664 | 3684 |
| Flow (MGD) | 15 | 25 |
| **Clarification** | | |
| Area ($ft^2$) | 28,438 | 3784 |
| Flow (MGD) | 15 | 25 |
| **Filtration (Per Filter)** | | |
| Area ($ft^2$) | 1,343 | 792 |
| Flow (MGD) | 11.25 | 6.87 |
| **Total Plant** | | |
| Area ($ft^2$) | 147,342 | 31,908 |
| Flow (MGD) | 60 | 75 |

| Table 10. Average Chemical Dosages in Adkins and TR/NS Filter Plants | | | | |
|---|---|---|---|---|
| **Parameter** | **Adkins** | **TR/NS** | **Diff** | **% Diff** |
| Alum mg/L | 14.1 | 11.4 | 2.7 | 19 |
| Caustic mg/L | 12.7 | 9.1 | 3.6 | 28 |
| Chlorine mg/L | 7.7 | 3.2 | 3.5 | 45 |
| Aq Ammonia mg/L | 1.4 | 0.6 | 0.8 | 57 |

**Table 11. Comparison of Filter Performance at Adkins and TR/NS Filter Plants**

| Parameter | Units | Adkins | TR/NS |
|---|---|---|---|
| Surface Area | $ft^2$ | 1342 | 792 |
| Total Volume | MG | 21.59 | 16.817 |
| Average Filter Run | Hrs | 126 | 118 |
| Average Backwash | Gal | 294458 | 269125 |
| Unit Filter Runtime Vol. | $MG/ft^2$ | 17697 | 20984 |
| Backwash (%) Range | % | 0.77-2.41 | 0.88-2.42 |

**Table 12. Comparison of In-Plant Water Usage Rate at Adkin and TR/NS Filter Plants**

| Parameter | Adkins | TR/NS | Diff | % Diff |
|---|---|---|---|---|
| % In-Plant Use | 9.47 | 3.84 | 5.63 | 59.45 |

**Table 13. Comparison of Production Costs at Adkins and TR/NS Filter Plants**

| Parameter | Adkins | TR/NS | Diff | % Diff |
|---|---|---|---|---|
| Total Flow x $10^6$ (Gal) | 10,664 | 22,918 | +12,254 | +53 |
| Treatment Expense ($) | 1,892,941 | 1,727,882 | -165,059 | -8.7 |
| $/1000 gallons | 0.18 | 0.08 | -0.10 | -56 |

**Table 14. Performance Comparison Between Upflow clarification and Clari-DAF®**

| Parameter | Upflow Unit | DAF |
|---|---|---|
| Raw Water Turbidity | 2.0 - 5.0 NTU | 2.0 - 5.0 NTU |
| Raw Water Manganese | 0.1 - 0.17 mg/L | 0.1 - 0.17 mg/L |
| Effluent Turbidity | 1.0 NTU | 0.2 NTU |
| Effluent Manganese | 0.05 mg/L | 0.02 mg/L |
| Filter Run Length | 24 hours | 72 hours |
| Filter Effluent Turbidity | 0.1 NTU | 0.04 NTU |
| Filter Effluent Manganese | 0.05 mg/L | 0.02 mg/L |

**Table 15. USEPA TOC Removal Requirements by Stage 2 DBPR**

| | Raw Water Alkalinity mg/L | | |
|---|---|---|---|
| | **0 - 60** | **60 - 120** | **> 120** |
| **Source Water TOC mg/L** | **Percent Removal (%)** | | |
| > 2.0 - 4.0 | 35 | 25 | 15 |
| > 4.0 - 8.0 | 45 | 35 | 25 |
| > 8.0 | 50 | 40 | 30 |

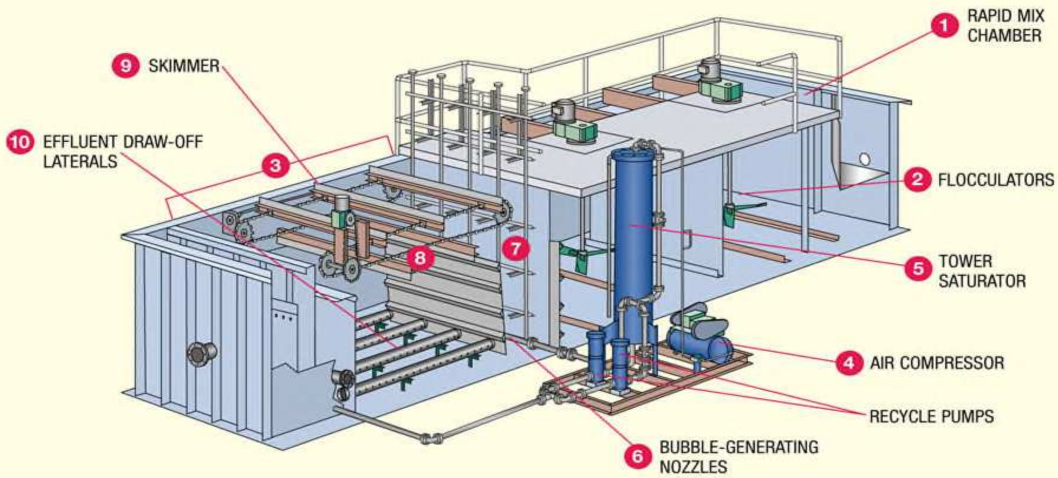
**List of Figures**

Figure 1. How the Leopold Clari-DAF System Works (courtesy of ITT, now Xylem)

Figure 2. Raw Water and Clari-DAF® Effluent Turbidity

**Figure 1. How the Leopold Clari-DAF System Works** (courtesy of ITT, now Xylem)

## How the Leopold Clari-DAF System Works




1. The Clari-DAF process starts with raw water being dosed with an aluminum or iron-based inorganic coagulant in a rapid mix chamber, much like that of conventional sedimentation. Lower doses than sedimentation are used because a pin floc is desired instead of a sweep floc.
2. Good coagulation is the most important factor affecting flotation. Two-stage tapered flocculation is standard. G values of 30 to 70 are typical for full-scale operations. Low tip speeds prevent the fragile floc from being sheared. Flocculation time is only one-fifth of that needed for conventional clarification.
3. Hydraulic loading rates based on collector area range from 8 to 15 gpm/sf (19.36 to 38.72 m/hr), although pilot testing has shown that rates up to 20 gpm/sf (48.4 m/hr) are not unusual. As a result, the Clari-DAF system requires a smaller footprint than conventional sedimentation.
4. After a pin floc is formed, the raw water stream is injected with water that has been saturated with air at 60 to 90 psi. The saturation process is accomplished by taking a fraction of the throughput, typically 10% of design flow, and recycling it back to a pressure vessel. VFDs control the recycle pumps to maintain a balance in the saturator. A compressor provides a constant pressure of oil-free air to the saturator.
5. The saturator, a packed tower for water or unpacked-tower for wastewater, mixes the water and air.
6. The aerated water is delivered to a distribution header that spans the width of the Clari-DAF cell. This distribution header has a series of specially designed orifices or nozzles. As the pressurized water exits the nozzles, the pressure drop produces a cloud of hundreds of millions of microbubbles that are approximately 40 microns in size.
7. The contact zone is given a milky appearance like that of a whitewater blanket. The tiny air bubbles rise through the coagulated water, capturing floc as they ascend to the surface. The tiny spherical bubbles rise under laminar flow at a rate following a modified Stokes Equation.
8. A blanket of sludge forms on the surface of the Clari-DAF cell. The blanket is supported from beneath by the microbubbles.
9. The sludge blanket that forms on the top of the Clari-DAF cell is removed periodically by either a mechanical scraper or by hydraulic means. Under certain conditions removal can be achieved using a combination of both mechanical and hydraulic processes.
10. The clarified effluent water is drawn off the bottom of the tank by a series of lateral draw-off pipes that allow for uniform distribution along the bottom of the Clari-DAF cell.

**Figure 2. Raw Water and Clari-DAF® System Effluent Turbidity**