Recent Advances and Applications of Dissolved Air Flotation for Industrial Pretreatment

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Presented at

The Industrial Water/Wastewater Program
North Carolina AWWA/WEA Conference
November 17, 2003
Greensboro, North Carolina

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KEYWORDS

Dissolved air flotation, DAF, industrial wastewater, industrial pretreatment, water treatment, clarification

ABSTRACT

Dissolved air flotation (DAF) has gained widespread usage for the removal of contaminants and the recovery of by-products from wastewater and other industrial process streams over the last forty years. DAF systems are frequently used to provide wastewater pretreatment, product recovery, and thickening of biological solids in industries ranging from food processing to pulp and paper to petrochemicals. While considered a relatively simple technology, there have been significant improvements in the technology including changes in shape, whitewater production, and process design. There has also been an expansion of applications using DAF over the last several years in traditional and non-traditional areas of water and wastewater treatment.

ADVANCES IN DAF DESIGN

Rectangular Design

While there is still some debate as to the whether the rectangular-shaped DAF design outperforms the original circular design, the marketplace has clearly shifted to the rectangular design. Most of the DAF designs today are rectangular, even those from companies that used to or still do offer circular designs.

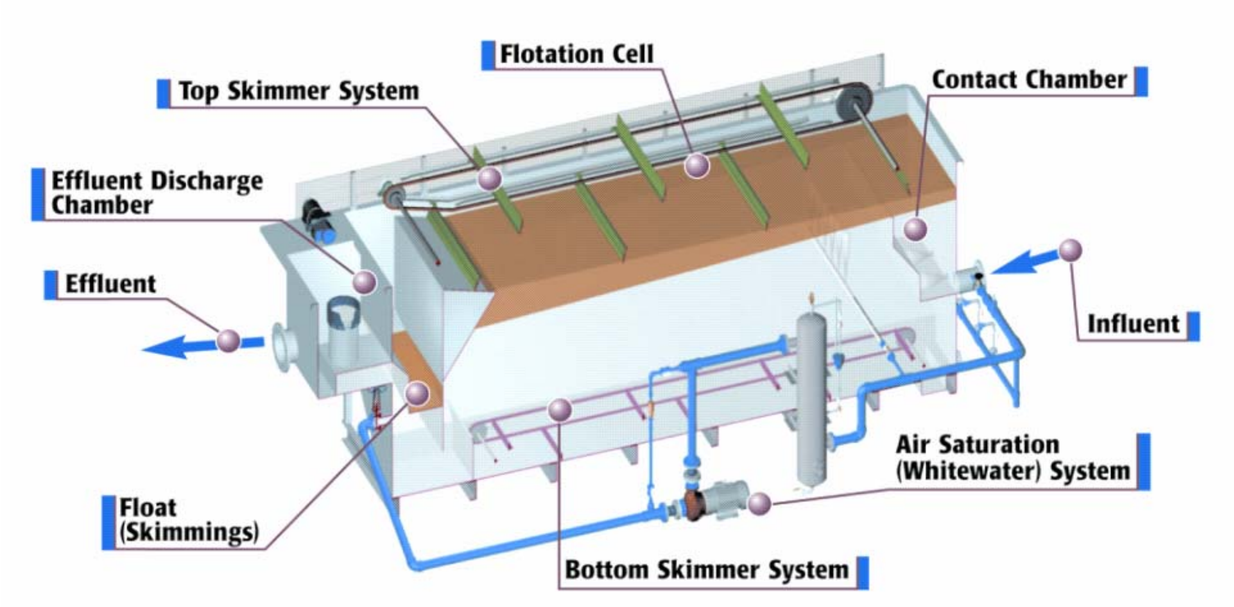
As illustrated in Figure 1, a rectangular DAF system may consist of the following primary components:

- Contact cell or coagulation chamber to provide contact of small air bubbles with flocculated particles.
- Flotation cell to provide surface area and a quiescent zone for the formation of float.
- Surface skimmer for the removal of surface float or skimmings.
- Bottoms skimmer or auger for the removal of settled solids.

- Effluent discharge baffle and chamber to separate the clarified effluent from the surface float and settled bottoms.

- Air saturation (whitewater) system which recycles a portion of the clarified effluent, forces air by pressure and mechanical action into solution with the recycle stream, and releases the high pressure on the stream to form microscopic bubbles for attachment to flocculated particles in the contact cell.

Figure 1. Key Components of a Rectangular DAF System



There are some basic advantages to the rectangular design:

1. Space Efficiency. The rectangular shape presents a more space efficient footprint per square footage of surface area over a circular design. This means the unit can be placed in smaller, tighter spaces.

2. Packaged vs. Site Erected. This shape allows for large surface area DAF units (up to 500 ft^2) to be provided in a packaged or skid mounted form thus eliminating the need for field erection of tanks and piping typical of large circular DAF units. This typically results in lower capital costs and shorter delivery and installation times.

3. Float Removal. The top skimmer system of a rectangular unit operating allows for the removal of skimmings (float) away from the contact zone or coagulation chamber as the float is formed. This prevents the agitation caused by the incoming flow and whitewater (recycle) from breaking up the float which frequently happens in a circular unit.

4. Float Volume. In rectangular designs that have co-current flow (where the float is removed from the opposite end from where the influent enters the unit), there is a benefit to allowing the float to stay on the surface longer permitting free water to decant prior to removal which tends to promote higher solids float material and less float volume.

5. Performance. Combined, some of the process advantages mentioned above also allow for higher hydraulic loading per unit of surface area (gpm/ft^2 of surface area) in rectangular

DAF units. This means that the surface area requirement of a rectangular unit is typically smaller than that of a comparable circular unit.

The main disadvantage of the rectangular design is that it limits the size of a single DAF to handle a large flow. The limit on packaged, skid-mounted rectangular DAFs is roughly 500 ft^2 of surface area with a design capacity of 2,500 to 3,500 gpm of flow. Applications with flows larger than this would require multiple rectangular units compared to single or dual circular units with practical design capacities of up to 5,000 gpm.

There are a few variations in rectangular DAF designs in the marketplace:

1. Flow Direction. Some of the earliest rectangular designs remove float as soon as it is formed in the flotation cell and in the opposite direction of the main flow entering the unit (counter-flow). The designers of counter-flow units believe that the effluent quality is improved by removing the float material quickly before it has an opportunity to lose buoyancy and settle. Other designs either remove float from the effluent end of the unit or perpendicular to the perimeter (side) discharge of the effluent (co-current flow). This design is based on the theory of allowing the float to sit on the surface and decant free water back into the cell, creating a float with a lower moisture content and lower volume for handling. Some manufacturers also believe that it mitigates the potential of shearing the bubble-particle bond in the float by taking the float away from the agitation frequently present near the point of wastewater and whitewater introduction.

2. Plate Pack or Settlers. Some DAF designs employ the use of plate pack or settlers, similar to that used in Lamella clarifiers, to improve solid-liquid separation. The theory is that this increases the overall “available” surface area of the system while maintaining a smaller cross-section and footprint. Others discount the effect of these devices as doing little more than enhancing laminar flow through the unit. Most agree that there are limits on the solids loading (lb TSS/hr-ft^2) to DAF units with plate pack due to concerns with plugging the openings between the plate pack sheets and overloading the actual surface area of the unit with high concentrations of influent solids.

3. Shallow vs. Deep Units. There are significant variations in design philosophy regarding the water depth requirements for flotation. Design issues including particle rise rate, hydraulic retention time, and cross-sectional velocities all play a role in the many configurations of rectangular DAFs. This has resulted in a wide range of unit shapes and profiles ranging from the fairly shallow to the fairly deep. Essentially there is little documentation from either side of the debate to put this issue to rest.

Whitewater System Design

Improvements in whitewater systems have had perhaps the most dramatic effect on the design and specification of DAF systems over the past few decades. Most of the early DAF designs used low pressure (< 50 psig) centrifugal pumps to force flow into a pressurization tank where compressed air (at pressures 10 to 20 psi greater than the recycle pressure) was injected into the recycle stream somewhere between the pump discharge and the pressurization tank (post-pump air injection). The combined pressure and retention time of the tank forced the air into solution. Generally, these systems had low solution and volumetric efficiencies (Ross et al., 2000; Valentine et al., 1993). Improvements to this earlier design have included:

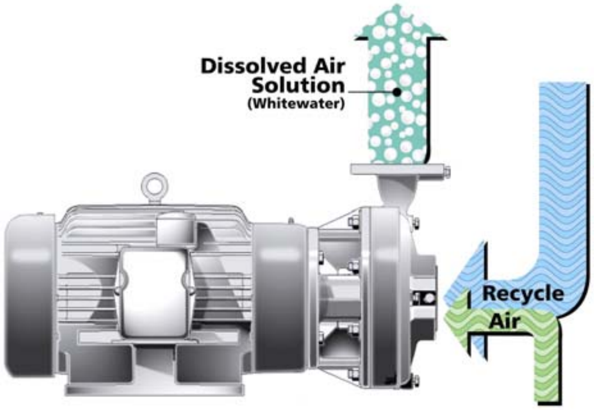
1. Recycle Pressurization. In recent years, a majority of DAF manufacturers have made a transition from full-flow pressurization to recycle-flow pressurization for the creation of a dissolved-air-in-water solution (whitewater) to promote flotation. Most of the full-flow pressurization systems operate at lower pressures (<50 psig), which limits the amount of

air going into solution per unit volume of recycle flow. Furthermore, full-flow pressurization exposes the wastewater floc to high shear forces and turbulence from the pumping system prior to entering the flotation cell and can destroy the floc formed prior to pressurization. In contrast, a recycle pressurization system involves pressurization of a sidestream of clarified effluent for return to the flotation cell. These systems can operate at higher pressures and minimize the destruction of floc formed in the process flow. The downside is increased hydraulic loading resulting from the recycle stream added to the influent flow. Generally, the benefits of higher air saturation and undisturbed floc formation outweigh the disadvantage of increased total hydraulic loading.

2. Higher Recycle Pressure. In addition to the transition from full-flow to recycle-flow pressurization systems, significant advances have also been made in methods for dissolving air into water. With a recycle-flow pressurization system, the recycle flow is a fraction of the full wastewater flow through the system; therefore, the pressurization pump is smaller. This allows the use of higher pressure pumps for the creation of a whitewater stream. More air is forced into solution with water at higher pressures (e.g., at 20^{o}C, the maximum amount of air that can be saturated in water at 80 psig is 46% greater than the amount at 50 psig). This increases both the volumetric efficiency of the pump (higher mass of air per unit volume of recycle flow) and improves whitewater quality (higher pressure systems generally create whitewater with smaller bubbles). With a smaller bubble size or diameter, more surface area is available for floc particle attachment, resulting in more efficient flotation. Smaller bubbles rising to the water surface also do not agitate and shear the forming floc bed as do larger ones.

3. Air-handling Pumps. Even with higher recycle pressures, systems that use post-pump air injection and large retention tanks have fairly low solution efficiencies (Valentine et al., 1993). In recent years, post-pump air injection systems have given way to the use of air-handling recycle pumps (regenerative turbine and special centrifugal “DAF” pumps) that can pressurize water with entrained air (10-20% v/v) without causing cavitation or vapor lock. Whitewater systems based on air-handling pumps draw air into the suction or volute of the pump, subjecting the mixture to the high shear forces of the pump impeller(s) to force air into solution more rapidly and efficiently (Figure 2).

Figure 2. Air-handling DAF Pump Schematic



In addition, studies on various DAF saturator configurations by Valentine et al. (1993) have indicated that mixing at higher pressures (>50 psi) significantly increases saturation efficiency over systems without mixing at lower pressures. Since air-handling pumps operate at higher pressures and achieve higher saturation efficiencies, they provide a higher mass of air per unit volume of recycle flow. In studies described by Ross et al.

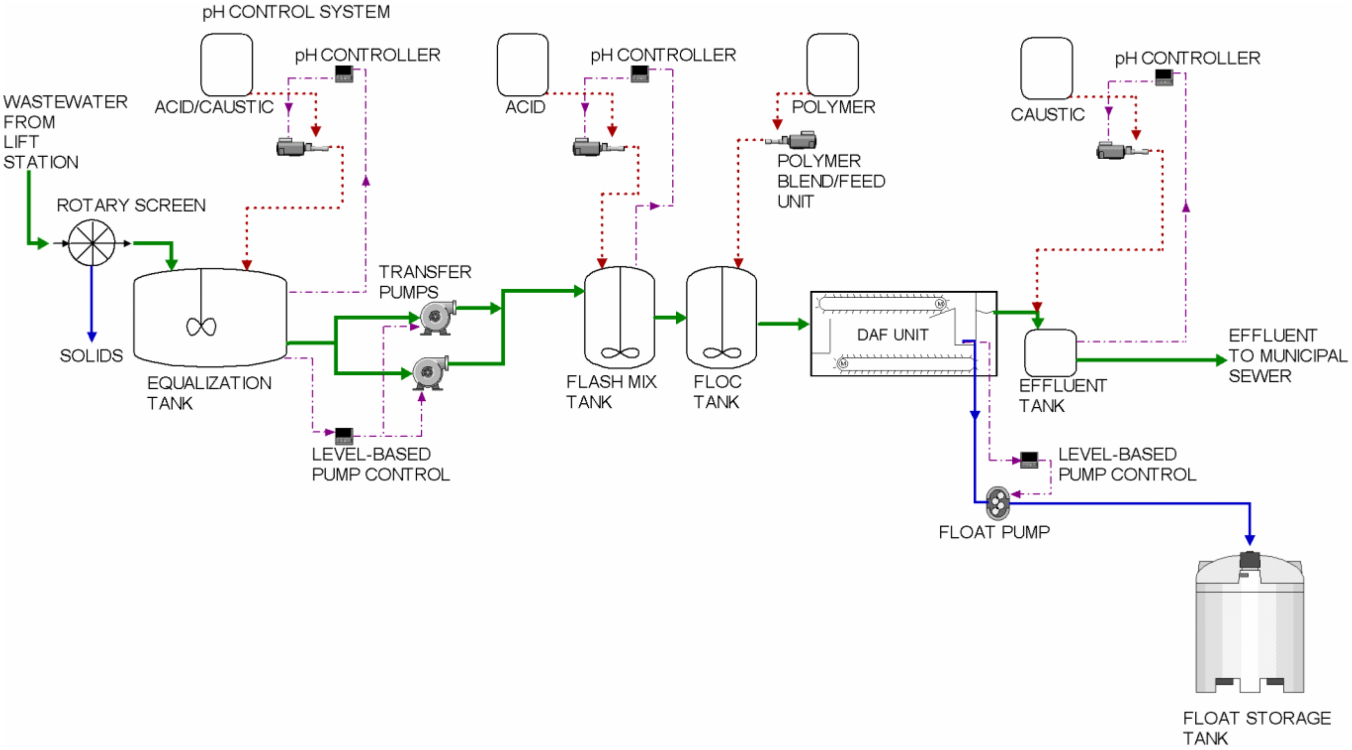
(200), regenerative turbine and centrifugal DAF pumps operating at 80 psig provided over 230% more dissolved air per unit volume of recycle (scfh air/gpm recycle flow) than a standard centrifugal pump operating at 50 psig. The combined effects of recycle pressurization and improved pumping systems allow the introduction of the same amount of dissolved air into the flotation cell of a DAF using 50 to 70% less recycle flow than earlier whitewater system designs.

Process Design

As more application experience has been gained, DAF has been integrated into more processes and more applications in the areas of industrial pretreatment, water treatment, and product recovery. This has led to significant improvements in developing process efficiency and process design criteria.

In terms of process design, the effective integration of support processes has led to improvements in DAF performance and reliability. An example of this integration is illustrated in a diagram of a typical DAF pretreatment process in Figure 3:

Figure 3. Process Diagram of Typical DAF Pretreatment System



1. Fine Screening. Fine screening is an effective but frequently overlooked pretreatment process prior to flotation. The removal of heavy solids prior to flotation generally reduces the load of heavy, non-floating solids going to the DAF. Not removing these solids can lead to fouling of transfer and recycle pumps and piping, more frequent bottoms blow-down from the DAF, and increased chemical requirements for coagulation and flocculation.

2. Equalization. Equalizing both flow and contaminant loads will improve the performance of a DAF system by providing a more constant, less variable load to the system. Adequate mixing is needed to both optimize the retention time of the equalization tank or basin and to keep solids from settling and oils and greases from collecting on the water surface.

3. pH Control. Most coagulation and flocculation chemistries perform optimally in a fairly narrow pH range. Equalization can help promote the control of influent pH; however, most wastewater streams require a pH control system to maintain this pH range. Furthermore, many chemical programs work well using pH to control coagulant dosing (e.g., the acidulation process in Figure 3).

4. Flocculation Control. Many system designers overlook the need for providing a unit operation for the addition of coagulants and flocculants to promote the effective flocculation of contaminants prior to flotation. In some cases, chemical addition is an afterthought where the chemicals are simply dosed into the process piping going to a DAF. Without a flocculation tank or flocculation tube to provide the proper mixing and residence time, flocculation is often inefficient (excess chemical use) and ineffective (poor floc quality).

The unit process criteria for a DAF unit in industrial pretreatment are also often misunderstood. As described by Ross et al. (2000), most of the design criteria for DAF in the common literature are either grossly outdated or for unrelated (municipal) applications such as WAS thickening. Published design data for hydraulic and solids loading, recycle rates, and air-to-solids ratios are generally much more conservative than that established by practical experience in the field. While more applicable data are available in the literature, it is generally scattered and does not necessarily cover all of the applications for which the DAF process is currently being used. This has in many cases been offset by more frequent use of bench-scale and pilot-scale testing to better determine DAF design criteria.

APPLICATIONS

There has been an expansion in the use of dissolved air flotation as a unit process in a wide range of traditional and “non-traditional” applications:

- algae removal from facultative treatment ponds
- biological solids clarification from activated sludge and fixed film processes (in lieu of gravity clarifiers)
- recovery of plastics in plastics recycling processes
- removal of phosphorous through chemical precipitation
- recovery of wood fines from electrostatic precipitators at wood products facilities
- removal of metals from acid mine drainage (AMD)
- recovery of protein at rendering plants
- removal of suspended and colloidal solids from surface waters for potable use

To illustrate the range of applications for dissolved air flotation, listed below are five examples of recent DAF installations in both traditional pretreatment applications and non-traditional treatment or recovery processes:

Pretreatment of High O&G and TSS from Rendering Wastewater

In 1999, ETS provided an RT-180 (180 ft^2 surface area) for pretreatment of a screened wastewater discharge from a poultry by-product (rendering) facility. Prior to installation of the system ETS conducted an extensive treatability test using an on-site pilot DAF system to determine design parameters (Ross et al., 2000). The pilot testing was necessary because of the extremely high TSS and O&G loads in the wastewater as illustrated in Table 1. The pilot DAF test provided DAF design data (e.g., TSS surface loading, O&G surface loading, and air to solids ratios) that were far different than the standard design data found in the literature. This allowed the installation of a full-scale DAF system far smaller (roughly 90% smaller) than that suggested

by the standard design parameters found in the literature.
As shown in Table 1, the DAF system provided high TSS and O&G removals (>99%) and reduced the COD enough to allow further treatment by an anaerobic lagoon and aerobic SBR system downstream.

Table 1. Results from DAF Pretreatment at a Rendering Facility

Parameter	Influent mg/L	Effluent mg/L	Removal %
Flow, gpm	330	-	-
TSS	43,706	263	99.4
O&G	18,568	72	99.6
COD	113,864	9,400	91.7

Removal of Phosphorous from Poultry Further Processing Wastewater

In 2002, ETS provided a turn-key upgrade of a pretreatment system for a poultry further processing plant. In addition to meeting fairly stringent BOD, TSS, and O&G limits, the plant discharge also had to have a TP concentration less than 10 mg/L. The upgrade involved installing a new RT-140 DAF system (140 ft^2 of surface area) to replace an existing DAF to provide for the removal of production TSS and O&G prior to biological treatment in an aerated pond. The existing DAF was used later in the process to provide clarification of treated effluent from the aerated pond. The clarification DAF was also used to remove TP from the final effluent through the dosing of a metal salt. Flocculation tubes were used for both DAF units as the means for adding coagulants and flocculants to their respective streams.

As illustrated in Table 2, the system provided very good TSS, BOD, and O&G removals (>98%). TKN removal, including NH_3-N, averages 86.2%. TP removals average 98.8% with effluent concentrations (average 1 mg/L) well below the permit limit.

Table 2. Results from a Dual-DAF Pretreatment System at a Further Processing Plant

Parameter	Influent mg/L	Effluent mg/L	Removal %
Flow, gpm	400	-	-
TSS	5,450	103	98.1
O&G	2,860	<5	>99.8
BOD	7,910	18	99.8
TKN	160	22	86.2
TP	80	1	98.8

Removal of Metals from Acid Mine Drainage

Acid mine drainage (AMD) is a significant problem for coal mining regions of the country. Natural drainage or subterranean flows pass through surface and deep mine coal mining activities and are contaminated with metals and low pH. These flows eventually migrate into streams and rivers and negatively impact the quality of these bodies of water. The mining industry is required to mitigate these contaminants usually through the addition of lime in large sedimentation ponds. In many cases, this technology either does not work well, or the systems are not maintained.

In 1999, ETS provided an RT-180 DAF system (180 ft^2 of surface area) to provide treatment of an AMD stream in central Pennsylvania prior to discharge to a local stream. The unit was preceded by a flash mix tank for pH control followed by a floc mix tank for polymer addition and flocculation. The system has been in operation for over four years and has kept the site's owners in compliance with state regulations for their discharge.

As indicated in Table 3, concentrations of iron, manganese, and aluminum were reduced by 87-89% by the DAF system. The pH of the AMD was raised from a pH of approximately 3 to a pH of 7-9, which was well within permit limits.

Table 3. Results from DAF Treatment of Acid Mine Drainage (AMD)

Parameter	Influent mg/L	Effluent mg/L	Removal %
Flow, gpm	60-335	-	-
Iron	24.8	2.8	88.9
Manganese	10.5	1.3	87.5
Aluminum	25.0	3.3	86.7
pH, SSU	2.9-3.2	7-9.3	-

Pretreatment of High O&G Wastewater from Corn Dog Plant

In some design circles, it is believed that high concentrations of cooking oil require an oil/water separation step prior to DAF. The assumption is that the free oils will either overload the treatment capacity of the DAF or will not form a firm enough floc for the skimmer system to remove adequately. In 2003, ETS provided an RT-100 DAF system (100 ft^2 surface area) with a flocculation tube for coagulant and flocculent addition as part of a turn-key installation to provide pretreatment of wastewater generated by a corn dog plant. Initial concerns by plant and consulting personnel were that the high concentrations of cooking oil in the wastewater (O&G concentrations as high as 8,000 mg/L) would cause problems in the DAF.

As illustrated in Table 4, the system has performed well in providing O&G concentrations well below the 250 mg/L permit limit. TSS removals are 98% with an effluent consistently less than 100 mg/L, and the BOD removal was more than expected. Concerns over high cooking oil concentrations were proven unfounded.

Table 4. Results from DAF Pretreatment of Wastewater from a Corn Dog Plant

Parameter	Influent mg/L	Effluent mg/L	Removal %
Flow, gpm	250-300	-	-
TSS	4,300	86	98.0
BOD	4,867	903	81.4
O&G	4,200	<78	>98.1

Clarification of Biological Solids at a Citrus Plant

In recent years, DAFs have grown in popularity for use as clarifiers of biological solids from aerobic processes (i.e., activated sludge, moving bed biological reactors, etc.). DAFs are chosen for some of these applications because they provide the following advantages over traditional gravity clarifiers:

- have a smaller footprint
- are immune to the effects of filamentous or floating biomass
- provide better process control
- are capable of handling high mixed liquor suspended solids (>8,000 mg/L)
- generate thicker sludge (less volume)

In 1999, ETS provided an RT-500 DAF system (500 ft^2 surface area) for installation at a citrus processing plant in Florida. The system included a flocculation tank for the addition of a single polymer for flocculation prior to flotation. The system was installed primarily to provide for pretreatment of wastewater from the plant prior to activated sludge treatment (primary mode). However, it was also configured as an alternative to an existing gravity clarifier for biological solids clarification after the activated sludge process (secondary mode). The unit is operated in the secondary or clarification mode fairly often because of upsets in the gravity clarifier (e.g., bulking sludge, high mixed liquors, etc.). TSS removals have averaged well over 99% with very good effluent quality (8 mg TSS/L). Sludge total solids have averaged 2.85% which is considerably higher than that returned by the gravity clarifier.

Table 5. Results from DAF Clarification of Biological Solids at a Citrus Plant

Parameter	Influent mg/L	Effluent mg/L	Removal %
Flow, gpm	750	-	-
TSS	5,400	8	99.8
Sludge TS, %	-	2.85%	-

CONCLUSIONS

1. The applications for dissolved air flotation are expanding into more areas of industrial pretreatment, resource recovery and water treatment.

2. Improvements in DAF design, including shape and whitewater systems, have improved process performance and reduced the size and cost of DAF systems.

3. Improvements in DAF process design have improved DAF system performance and reduced the O&M cost for DAF operation.

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