CHAPTER

7

Sand Removal, Sedimentation, and Dissolved Air Flotation

OUTLINE

7.1 INTRODUCTION

The purpose of sand removal, sedimentation, and dissolved flotation pretreatment systems is to minimize the content of coarse materials such as grit, debris, and suspended solids collected by the plant intake and protect downstream filtration facilities from solids' overload. The source water collected by onshore intakes and shallow open offshore intakes usually does not contain large quantities of sand but could have elevated content of floating and suspended solids. Well intakes typically have a very low content of suspended

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solids but depending on their design and the subsurface soil conditions they could produce source water of elevated sand content, especially when they are brought into service after a long shutdown.

7.2 SAND REMOVAL SYSTEMS

Well-designed desalination plant intakes usually produce source water of low sand and silt content. Therefore, most desalination plants do not have separate sand removal facilities. Small quantities or sand and coarse silt contained in the source water are typically retained by the plant sedimentation or filtration facilities. However, in locations where desalination plant's open intake is located adjacent to an area of significant ship traffic, of turbulent underwater currents, or in area where frequent dredging activities occur, a large amount of sand and silt may enter the desalination plant continuously and would need to be removed in separate facilities.

Sand removal facilities may or may not be followed by sedimentation basins. If the saline source water contains low level of turbidity but large amount of sand, than construction of grit removal facilities instead of clarifiers is more appropriate and cost-effective.

7.2.1 Settling Canals and Retention Basins

Some large onshore intakes are designed with long canal that delivers the source water into retention basin where the water is presettled and sand and large debris are accumulated. The source water from the retention basin overflows into the forebay of the screening facilities/intake pump station of the desalination plant from where it is conveyed into the main pretreatment system. Such canals and retention basins are dredged periodically or are equipped with sediment removal/flushing systems to minimize solids accumulation over time.

While such retention reservoir configurations are suitable for dampening the effect of heavy rain events, winds, currents, ship traffic, and other sources of elevated content of solids in the source water, they may present problems such as excessive algae accumulation, especially if the flow velocity is relatively low and the water remains in the reservoirs for a long time. Usually, it is more prudent and cost-effective to build an offshore intake with depth of at least 8 m (26 ft) below the water surface rather than to build an onshore open intake and settling canal/retention basin system to manage high sand and silt content in the source water.

7.2.2 Strainers

Depending on the size of the desalination plant, grit removal facilities most widely used in practice are 200–500-μm strainers (Fig. 7.1). Strainers of this size can remove sand and silt particles of 0.10 mm or larger.

Strainers are typically applied for small- and medium-size desalination plants [i.e., plants of capacity of 20,000 m^3/day (5.3 MGD) or less], which face large content of sand originating from shallow onshore open intake or intake wells with frequent failures.

FIGURE 7.1 Sand strainers.

7.2.3 Cyclone Separators

Cyclone separators have found application for removal of sand from groundwater, especially for small desalination plants. In such systems the inlet pressure from the intake well pumps drives the source water into the top of the separator chamber at a tangent, causing rotation and formation of vortex in the center of the separator. The vortex action forces the separation of heavy particles from the water. These particles accumulate at the bottom in a collection chamber from where they are periodically removed. In most recent desalination plant designs, cyclone separators and strainers are replaced by microscreens described in Chapter 5.

7.3 SEDIMENTATION TANKS

7.3.1 Introduction

Sedimentation is typically used upstream of granular media and membrane filters when the membrane-plant source water has daily average turbidity higher than 30 NTU or experiences turbidity spikes of 50 NTU or more which continue for a period of over several hours. If sedimentation basins are not provided, large turbidity spikes may cause the pretreatment filters to exceed their solids' holding capacity (especially if granular media filters are used), which in turn may impact filter pretreatment capacity. If the high solids load continues, the pretreatment filters would enter a condition of continuous backwash, which in turn would render them out of service and effectively will shut down the desalination plant operations.

Sedimentation basins for saline source water pretreatment should be designed to produce settled water with turbidity of less than 2.0 NTU and SDI_{15} below 6. To achieve this level of turbidity and silt removal, sedimentation basins are typically equipped with both coagulant (most frequently iron salt) and flocculant (polymer) feed systems. The needed coagulant and flocculant dosages should be established based on jar and/or pilot testing.

If the source water turbidity exceeds 50 NTU, then conventional sedimentation basins are often inadequate to produce settled water of the desired turbidity target level of less than 2 NTU. Under these conditions, sedimentation basins should be designed for enhanced solids removal by installing lamella plates (lamella settlers) or using sedimentation technologies that combine lamella and fine granular media for enhanced solids removal.

It is important to note that sedimentation tanks do not remove oil, grease, and other hydrocarbons to levels that protect downstream RO membranes from colloidal fouling. In addition, clarifiers do not settle well algae contained in the seawater because in most waters such algae are very small in size and are difficult to coagulate.

Typically, the use of enhanced sedimentation technologies is needed for treating source water from open shallow intakes that are under the strong influence of high-velocity currents, river water, or wastewater discharges of elevated turbidity. This condition could occur when the desalination plant intake is located in a river delta area, ship channel, industrial port, or is influenced by a seasonal surface water runoff.

For example, during the rainy season, the intake of the Point Lisas source water desalination plant in Trinidad is under the influence of the Orinoco River currents, which carry a large amount of alluvial solids. As a result, the desalination plant intake turbidity could exceed 200 NTU (Irwin and Thompson, 2003). To handle this high-solids load, the plant source water is settled in lamella clarifiers prior to conventional single-stage dual-media filtration. While this plant has lamella clarifiers, it does not incorporate separate sand removal facilities or strainers upstream of it (Fig 7.2).

FIGURE 7.2 Trinidad desalination plant.

7.3.2 Conventional Sedimentation Tanks

Conventional sedimentation tanks (clarifiers or settlers) are used for removal of suspended solids prior to filtration when the source water turbidity exceeds 20 NTU but is lower than 50 NTU. These clarifiers cannot produce water adequate for direct feed to the RO membranes and the clarified effluent will have to be filtered by granular media or membrane filtration prior to desalination.

Since conservatively designed membrane filtration systems can handle up to the same level of source water turbidity (e.g., 50 NTU) without presedimentation or other upstream treatment of the source water, in this case, it is preferable to use a conservatively designed single-stage membrane pretreatment system (e.g., MF or UF system with design flux of 40 lmh or less) instead of constructing a two-stage pretreatment which consists of clarification followed by higher rate granular media filtration or membrane filtration (e.g., MF or UF system with design flux of 65 lmh or less).

Conventional sedimentation tanks could be configured as rectangular or circular structures. To date, rectangular sedimentation tanks have found most common application for pretreatment of saline source waters because of their lower costs and slightly superior performance.

Key design criteria for this type of tanks are presented below:

Minimum number of tanks	Four
Water depth	3.0–4.5 m (10–15 ft)
Mean flow velocity	0.3–1.1 m/min (1.0–3.6 m/min)
Detention time	2–4 h
Surface loading rate (clarifier area)	1.0–2.0 m^3/m^2 h (0.4–0.8 gpm/ft^2)
Length-to-width ratio	Minimum of 4:1
Water depth-to-length ratio	Minimum of 1:15
Sludge collector speed	0.4–0.8 m/min (for collection path)

7.3.3 Lamella Sedimentation Tanks

Lamella sedimentation tanks (clarifiers or settlers) usually have superior performance and three to four times smaller footprint as compared to conventional clarifiers and they can handle up to four times higher source water turbidity (e.g., up to 200 NTU). Therefore, they have found wider application for saline water pretreatment than conventional sedimentation basins. These clarifiers contain plastic lamella plate modules installed in the upper portion of the clarifier tanks (see Fig. 7.3), which enhance the sedimentation process by shortening the path of solid particles to the bottom of the clarifiers.

Lamella clarifiers can be configured both as rectangular or circular structures. However, rectangular lamella clarifiers have found the widest application for pretreatment of saline

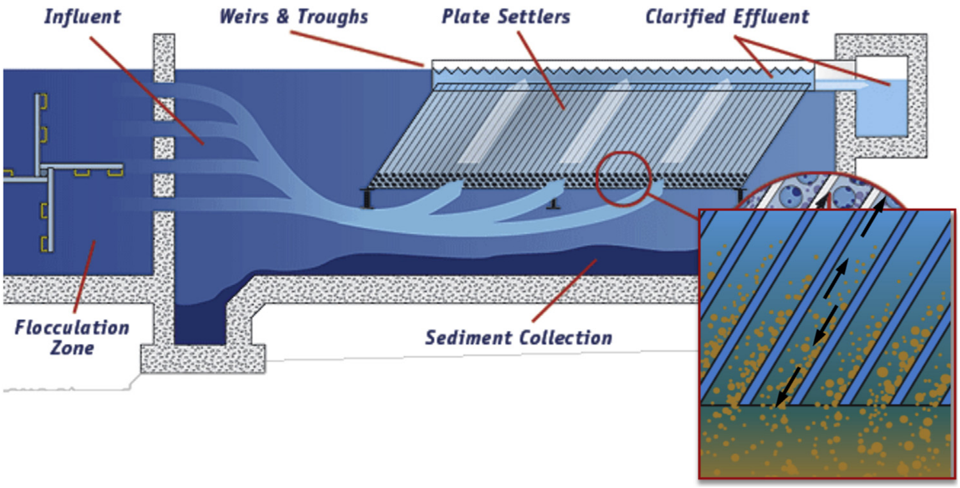

FIGURE 7.3 Schematic of lamella sedimentation tank.

source waters, especially for removal of high turbidity spikes from seawater. Key design criteria for this type of sedimentation tanks are presented below:

Minimum number of tanks	Two
Water depth	3.5–5.0 m (11.5–16.4 ft)
Mean flow velocity	0.3–1.1 m/min (1.0–3.6 m/min)
Detention time (in the lamella module)	0.2–0.4 h
Surface loading rate (lamella module)	1.0–2.0 m^3/m^2 h (0.4–0.8 gpm/ft^2)
Surface loading rate (clarifier area)	4.0–8.0 m^3/m^2 h (1.6–3.2 gpm/ft^2)
Sludge collector speed	0.4–0.8 m/min (for collection path)

Lamella modules used in the high-rate settlers are proprietary products and design engineer should consult equipment manufacturers regarding lamella module configuration, number and size of modules as well as design surface loading rate and depth of the sedimentation tank.

7.3.4 Lamella Settler—Design Example

The example below illustrates general design criteria for a lamella settler for pretreatment of the source water for a 50,000 m^3/day (13.2 MGD) seawater desalination plant designed for a 43%-SWRO system recovery. The source water turbidity reaches levels of 80 NTU during storm events, which may last several days and therefore, the plant is equipped with a combination of lamella settlers followed by a single-stage-dual granular media filters. The source water quality is relatively low in terms of hydrocarbon content—with maximum concentration of 0.04 mg/L or less. The source water is not frequently exposed to algal blooms, and when such events occur periodically they are of low intensity—with algal content of the source water of 20,000 cells/L, or less.

The plant filter backwash flow is 8.5% of the intake flow and lamella clarifier waste stream (sludge) flow is 0.6% of the intake plant flow. The pretreatment system is designed to operate with addition of coagulant, flocculant, and pH adjustment of the source water flow.

The lamella settler system is designed to treat a total of 127,910 m^3/day (33.8 MGD)–[50,000 m^3/day/43%)/(100%–(8.5% + 0.6%) = 127,910 m^3/day]. Key design parameters of this system are shown in Table 7.1.

In Table 7.1 the sizes (width, length, and depth) and the net surface area per lamella module are provided by the lamella supplier. The surface loading rate is calculated by dividing the total feed flow to the lamella settlers by the total surface area of all lamella modules. This loading rate should be comparable to the loading rate used for design of conventional settlers [i.e., 1.0–2.0 m^3/m^2 h/(0.4–0.8 gpm/ft^2)].

However, if the surface loading rate is calculated by dividing the feed flow by the physical total surface area of the lamella settlers, this loading rate will be approximately five times higher in this example (7.7 m^3/m^2 h/1.42 m^3/m^2 h = 5). This comparison illustrates the fact that lamella settlers are significantly more space-efficient and economical than conventional settling tanks. Therefore, they have found wider implementation for desalination plant pretreatment than conventional clarifiers.

TABLE 7.1 Example of Lamella Settler Pretreatment System for 50,000 m^3/day (13.2 MGD) Desalination Plant

Component/Parameter	Specifications/Design Criteria
FEED WATER	
• Design flow rate, m^3/day (MGD)	127,910 (33.8 MGD)
• Turbidity, NTU	0.5–80
• $SDI_{2.5}$	6–16
• Algal content, cells/L	<20,000
DESIGN CHEMICAL DOSAGES	
• Ferric chloride, mg/L	15 (0.5–50 mg/L)
• Cationic polymer, mg/L	0.5 (0.0–1.0 mg/L)
• Sulfuric acid, mg/L—target pH—6.7	8 (0–30 mg/L)
• Number of settler tanks	4
• Number of lamella modules per tank	4
• Width of lamella modules, m (ft)	1.24(4.1 ft)
• Length of lamella modules, m (ft)	8.67 (28.4 ft)
• Depth of lamella modules, m (ft)	2.588 (9.8 ft)
• Net surface area per lamella module	235 m^2 (2528 ft^2)
• Surface loading rate/module area	1.42 m^3/m^2 h/(0.6 gpm/ft^2)
• Setter tank surface area	43 m^2 (463 ft^2)
• Settler tank surface loading rate	7.7 m^3/m^2 h (3.1 gpm/ft^2)
• Water depth	5.5 m (20.8 ft)

7.4 DISSOLVED AIR FLOTATION CLARIFIERS

7.4.1 Introduction

Dissolved air flotation (DAF) technology is very suitable for removal of floating particulate foulants such as algae, oil, grease, or other contaminants that cannot be effectively removed by sedimentation or filtration. DAF systems can typically produce effluent turbidity of <0.5 NTU and can be combined in one structure with dual-media gravity filters for sequential pretreatment of seawater.

DAF process uses very small size air bubbles to float light particles and organic substances (oil, grease) contained in the source water (Fig. 7.4). The floated solids are collected at the top of the DAF tank and skimmed off for disposal, while the low-turbidity source water is collected near the bottom of the tank.

A typical DAF system consists of the following key components: coagulation and flocculation chambers; air saturation zone, flotation chamber, air saturation system, and clarified water recycling system (see Fig. 7.4).

As indicated in Chapter 6, coagulation and flocculation chambers are designed to enlarge the size of the particulate solids naturally contained in the saline source water in order to enhance their removal in the flotation chamber.

After coagulation and flocculation, the saline source water is mixed with clarified water, which is saturated with air to expose the particles in the saline source water in contact with the air bubbles that will carry them to the surface of the clarifier. The clarified water is recycled from the effluent end of the DAF units and is pumped through an air saturator at a rate of 10%–15% of the flow rate of the source water entering the DAF clarifier.

Typically, 8–12 g/m^3 of air has to be introduced for effective DAF process. As a rule of thumb, the air dosage is determined from the weight ratio of air to suspended solids of 0.12:1.0. The air is dissolved in the recycle water under pressure of 6–8 bars in pressure vessels (air saturators) equipped with an educator on the inlet side for adding air or with a packed column. In packed column saturators the depth of the packing is usually

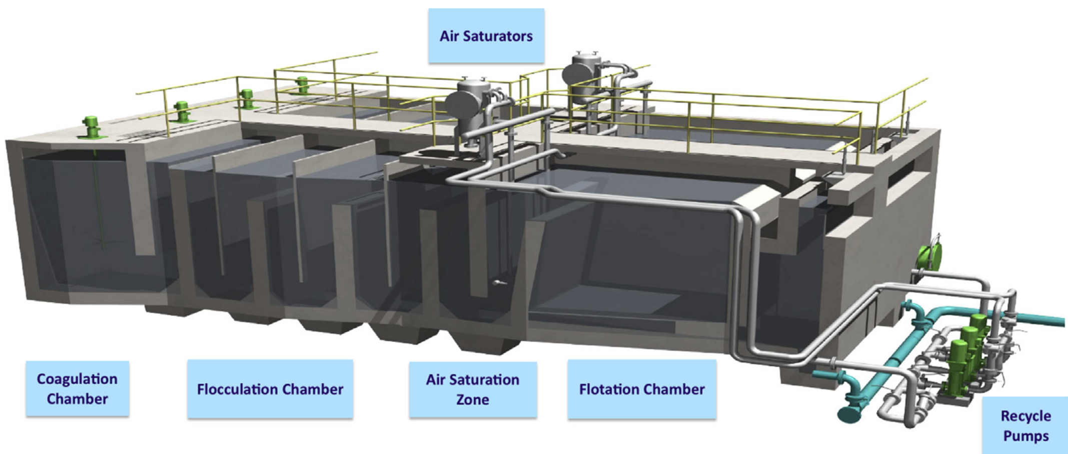

FIGURE 7.4 General schematic of DAF clarifier.

0.8−1.2 m of polypropylene rings. The design hydraulic loading rate of the air saturators is 60−80 m^3/m^2 h (25−33 gpm/ft^2). Saturator efficiency for educator systems is 65%−75% while for packed column units is 90%−95%. Air saturated water is recycled to the entrance of the flotation chamber through a series of nozzles to release the air bubbles unto the coagulated saline water in a white water curtain and maximize the contact of the air bubbles and the solid particles. Most DAF systems available on the market have air nozzles that deliver air bubbles in sizes of 10−100 μm and average between 30 and 50 μm. The diffusers are spaced at 0.1−0.3 m (0.3−1.0 ft).

The flotation chamber is a rectangular tank designed for a surface loading rate of 20−35 m^3/m^2 h (8−14 gpm/ft^2). Typical tank depth is 2−3 m (7−10 ft) and the preferred length to width ratio is 1.5−2.5:1. In the flotation chamber the air bubbles carry the solids attached to them to the surface of the chamber where they accumulate and form a sludge layer (see Fig. 7.5).

The sludge layer (blanket) collected on the surface of the DAF tanks is removed by hydraulic means or by mechanical scrapers and directed for subsequent solids-handling system. Based on existing practices, the coagulation process is often enhanced by an acid feed that allows to adjust the pH of the source water to optimum level for formation of large, strong, and light flocs.

Some of the solids contained in the source water may settle rather than float during the DAF clarification process. Such solids accumulate at the bottom of the DAF tanks over time and are periodically removed from there via bottom sediment collection and evacuation system. Under normal operational condition, the sludge blanket level has solids concentration of 1%−3% and is 0.5−1.0 m (1.7−3.3 ft) thick.

Full-scale experience at SWRO desalination plants, to date, shows that DAF systems do not perform well if the source water turbidity is less than 5 NTU. In such low-turbidity conditions, the DAFs are shut down and bypassed. Typically below this turbidity level, the source water solids are very difficult to float and to form thick solids blanket. If solids blanket is not formed within 30−45 min, many of the air bubbles that have attached particles will burst and

FIGURE 7.5 Sludge layer on the surface of DAF clarifier.

the particles will settle down. Because clarified water is collected at the bottom of the DAF tanks, settling of solids is undesirable and often results in turbidity spikes in the clarified water higher than the turbidity of the source water entering the DAF clarifiers.

Practical experience, to date, shows that the most common problems associated with DAF clarifier performance are caused by:

1. Inadequate coagulation and flocculation of the suspended solid particles in the source water due to the low charge of these particles;
2. Mismatch between the size of the source water particles and that of the DAF air bubbles;
3. Low air bubble release pressure that does not provide adequate energy for the bubbles to overcome the drag forces of the dense saline water and results in bubble burst in mid-water column rather than carrying of the solids to the top of the DAF clarifiers;
4. Short-circuiting caused by lack of baffling devices inside most proprietary DAF systems available on the market at present;
5. Ineffective sludge removal—especially for DAF clarifiers where the sludge blanket is removed by hydraulic overflow rather than by mechanical sludge collection mechanism.

Overdosing of coagulant and flocculant are often the two most common operational challenges of DAF systems when the source water turbidity is low (<5 NTU). In such cases, DAF shutdown and bypass is a more desirable operational strategy than adding coagulant, because this coagulant does not have particles to react with and ultimately is conveyed to and captured by the downstream plant filtration facilities (filters, cartridges, and RO membranes) and causes their premature fouling.

The surface loading rate for removal of light particulates and floatable substances by DAF is several times higher than that needed for conventional sedimentation. Another benefit of DAF as compared to conventional sedimentation is the higher density of the formed residuals (sludge). While residuals collected at the bottom of sedimentation basins typically have concentration of only 0.3%–0.5% solids, DAF residuals (which are skimmed off the surface of the DAF tank) contain solids' concentration of 1%–3%.

In some full-scale applications, the DAF process is combined with granular media filters to provide a compact and robust pretreatment of source water with high algal and/or oil and grease content. Although this combined DAF/filter configuration is very compact and cost-competitive, it has three key disadvantages:

1. complicates the design and operation of the pretreatment filters;
2. DAF loading is controlled by the filter loading rate and, therefore, DAF tanks are typically oversized; and
3. flocculation tanks must be coupled with individual filter cells.

7.4.2 Planning and Design Considerations

The feasibility of DAF application for pretreatment of saline surface waters is determined by the source water quality and is governed by turbidity concentration and overall lifecycle pretreatment costs. The DAF process can handle source water with turbidity of up to 50 NTU. Therefore, if source water is impacted by high turbidity spikes or heavy solids (usually related to seasonal river discharges or surface runoff), then DAF may not be a suitable pretreatment option. In most algal bloom events, however, source water turbidity almost never exceeds 50 NTU, so the DAF technology can handle practically any algal bloom event.

Although DAF systems have much smaller footprint than conventional flocculation and sedimentation facilities, they include a number of additional equipment associated with air saturation and diffusion, and with recirculation of a portion of the treated flow, and therefore, their construction costs are typically comparable to these of conventional sedimentation basins and higher than lamella settlers of the same capacity.

Usually, the O&M costs of DAF systems are higher than these of sedimentation tanks due to the higher power use for the flocculation chamber mixers, air saturators, recycling pumps, and sludge skimmers. The total power use for DAF systems is usually 0.05−0.075 kWh/10,000 m^3/day of treated source water, which is significantly higher than that for sedimentation systems—0.01−0.03 kWh/10,000 m^3/day of treated water.

DAF clarifiers for seawater applications have several key differences as compared to these for fresh surface waters: (1) they have to remove smaller size algal cells and, therefore, have to have diffusers that create smaller size bubbles; (2) seawater has significantly higher density than freshwater and therefore requires operation at higher air pressures to provide adequate solids removal; (3) seawater particles and algae have lower charge than freshwater solids, which makes them more difficult to coagulate and flocculate and requires larger contact chambers than there of freshwater DAF systems. The differences between seawater and freshwater applications of DAF are discussed in greater detail in the following publication (Edzwald and Haarhoff, 2012).

Practical experience shows that DAF system design that is not adopted to the specific water quality challenges of seawater pretreatment often does not meet performance expectations of high algal content removal, especially during normal (non-algal bloom) source water conditions when the content of algae in the water is low (<500 cells/L) and source water turbidity is <5 NTU.

Smaller ocean water algal particles require smaller size air bubbles for effective removal. The optimum range of the size of the air bubbles is directly related to the predominant size of algal cells in the source water, which can be determined by the completion of algal profiles of this water.

Most existing commercially available DAF technologies have been created for wastewater and freshwater applications and, therefore, the majority of the bubbles generated by their diffuser systems are in a range of 30 and 100 μm. Often, the type of algae dominating during red tide events in the Persian Gulf for example have an order of magnitude smaller size than freshwater algae—i.e., they are pico-plankton (0.2−2 μm) and nano-plankton (2−20 μm). If such small size plankton is the main cause of algal blooms, conventional DAF systems designed to remove larger-size (40−100 μm) freshwater algal cells are likely to have limited removal efficiency. In addition, as indicated in a recent study (Zhu and Bates, 2012) commonly applied source water chlorination practice may result in algal cell destruction and further diminish the benefits associated with DAF pretreatment.

Because of its higher density and viscosity than fresh water, seawater requires 20%−30% higher air saturation and introduction of the air at higher pressures. As a result, while the required pressure of the feed water recycled to the DAF for freshwater is 4−6 bars, the actual pressure needed for seawater DAF operations to form large percentage of smaller size bubbles is typically 6−8 bars.

Low-charge particles in seawater as compared to high charge particles in fresh water require longer contact time and better mixing in the coagulation and flocculation chambers to form large-enough flocks for effective removal in the flotation zone of the DAF clarifiers. With freshwater particles and algae that carry strong negative charge, addition of coagulant (ferric chloride or sulfate) that carries positive charge will result in creation of large flocks in a very short time, based on strong opposite-charge attraction.

With fine uncharged seawater particles, the main mechanism of flock formation is direct physical contact with the coagulant particles, which requires more time, especially if the solids concentration is very low (i.e., at low feed water turbidity). As a result, a typical 5–7-min contact time used to design the flocculation chambers of DAFs for freshwater applications will be insufficient for adequate size flock formation of seawater particles—a contact time of at least 10–15 min is needed for DAF systems processing seawater. One proprietary DAF system designed for seawater pretreatment applications addresses this challenge by installing a device referenced as "the Turbomix," which increases particle collision and flocculation (Gaid, 2012).

The key design criteria for the coagulation and flocculation chambers, flotation chamber, and recycle system of typical DAF clarifier are presented below:

IN-LINE STATIC MIXER (OR COAGULATION CHAMBER)	
Velocity gradient ($G \times T$)	500–1600 s^{-1}
FLOCCULATION CHAMBER	
Contact time	10–20 min
Flocculation chambers in series	2–4
Water depth	3.5–4.5 m (11.5–15.0 ft)
Type of mixer	Vertical shaft with hydrofoil blades
Blade area/Tank area	0.1%–0.2%
Shaft speed	40–60 rpm
FLOTATION CHAMBER	
Minimum number of tanks	2 (same as filter cells if combined with filters)
Tank width	3–10 m (10–33 ft)
Tank length	8–12 m (26–39 ft)
Tank depth	2.5–5 m (8–16 ft)
Length-to-width ratio	1.5–2.5 to 1
Surface-loading rate	20–35 m^3/m^2 h (8–14 gpm/ft^2)
Hydraulic detention time	10–20 min
TREATED WATER RECYCLE SYSTEM	
Recycling rate	10%–15% of intake flow
Air loading	8–12 g/m^3
Saturator loading rate	60–80 m^3/m^2 h (25–33 gpm/ft^2)
Operating pressure	6.0–8.0 bars (87–116 psi)

Since most existing proprietary DAF systems were developed for removal of freshwater algae that usually are an order of magnitude larger in size than seawater algae, the air bubble systems of existing DAFs are designed to generate bubbles of size that are significantly larger than optimum. This flaw could be addressed by modification of the air-bubble nozzle system to produce smaller size bubbles and fit the size of the smallest size of algae, which occur in the ambient saline source water during the algal bloom season. The most appropriate bubble size could be determined based on source water particle size and algal speciation analyses.

Pressurizing the air-saturated clarified DAF stream to higher levels (8–10 bars vs. standard 6–8 bars) would improve DAF operation but typically would require the redesign of the DAF's air-saturation system.

Short-circuiting that occurs in some of the exiting proprietary DAF systems could be addressed by the installation of baffles within the DAF tanks, which break the flow pattern and increase the contact time between the air bubbles and source water particles.

If the DAF system has an ineffective sludge removal system, which does not allow easy evacuation of particles collected on the tanks' bottom, such tanks would need to be taken out of service and cleaned periodically. Otherwise, the solids accumulated at the bottom of the DAF tanks will begin to digest anaerobically and disintegrate into finer much more difficult to filter particles, which in turn, will deteriorate the performance of the downstream filtration facilities.

It is important to note that DAF clarifiers usually do not remove significant amount of alluvial organics and biopolymers, i.e., UV_{254} and DOC are not likely to be reduced by DAF. This flotation process removes some of the particulate organics, mainly contained in the source water algae and bacteria attached to them. Such removal rate would be highly dependent on the size of algae in the source water and could vary between 5% and 20%.

DAF process with built-in filtration (DAFF) is used at the 136,000 m^3/day (36 MGD) Tuas seawater desalination plant in Singapore (Kiang et al., 2007). This pretreatment technology has been selected for this project to address the source-water quality challenges associated with the location of the desalination plant's open intake in a large industrial port (i.e., oil spills) and the frequent occurrence of red tides in the area of the intake.

The source seawater has total suspended solids concentration that can reach up to 60 mg/L at times and oil and grease levels in the seawater that could be up to 10 mg/L. The facility uses 20 built-in filter DAF units, two of which are operated as standby. Plastic covers shield the surface of the tanks to prevent impact of rain and wind on DAF operation as well as to control algal growth. Each DAF unit is equipped with two mechanical flocculation tanks located within the same DAF vessel. Up to 12% of the filtered water is saturated with air and recirculated to the feed of the DAF units.

A combination of DAF followed by two-stage dual-media pressure filtration has been successfully used at the 45,400 m^3/day (12 MGD) El Coloso SWRO plant is Chile, which at present is one of the largest SWRO desalination plants in operation in South America. The plant is located in the City of Antogofasta, where seawater is exposed to year-round red-tide events, which have the capacity to create frequent particulate fouling and biofouling of the SWRO membranes (Petry et al., 2007).

The DAF system at this plant is combined in one facility with a coagulation and flocculation chamber. The average and maximum flow rising velocities of the DAF system are 22 and

33 m^3/m^2 h (9–14 gpm/ft^2), respectively. This DAF system can be bypassed during normal operations and is typically used only during algal bloom events.

The downstream pressure filters are designed for surface loading rate of 25 m^3/m^2 h (10.2 gpm/ft^2). Ferric chloride at a dosage of 10 mg/L is added ahead of the DAF system for source water coagulation. The DAF system reduces source seawater turbidity to between 0.5 and 1.5 NTU and removes approximately 30%–40% of the source seawater organics.

Another example of large seawater desalination plant incorporating DAF system for pretreatment is the 200,000 m^3/day (53 MGD) Barcelona facility in Spain (Sanz and Miguel, 2013). The pretreatment system of this plant incorporates 10 high-rate SeaDAF units equipped with flocculation chambers, followed by 20 first-stage gravity dual-media filters and 24 second-stage pressurized dual-media filters. The purpose of the DAF system is to mainly remove algae and to reduce source-water organic content. Because the plant intake is located near a large port area, the DAF unit is also designed to handle potential oil contamination in the source water.

The intake of the desalination plant is located 2200 m from the coast and 3 km away from the entrance of a large river (Llobregat River) to the ocean, which carries significant amount of alluvial/NOM reach organics. After coagulation with ferric chloride and flocculation in flash-mixing chambers, over 30% of these organics are removed by the DAF system.

7.4.3 DAF—Design Example

This example DAF clarifier is designed for seawater desalination plant with production capacity of 50,000 m^3/day (13.2 MGD) with SWRO system with 43% recovery—the same conditions used for sizing of the lamella settlers discussed in Section 7.3.2. The plant source water turbidity reaches levels of 80 NTU during storm events and up to 40 NTU during algal blooms. This source water is planned to be treated by a combination of DAF clarifier and granular dual media filter.

The plant filter backwash flow is 5% of the intake flow, and lamella clarifier waste stream (sludge) flow is 0.5% of the intake plant flow. Maximum algal count in the source water is 60,000 cells/L, and the hydrocarbon levels can reach levels of 0.5–1.0 mg/L. The pretreatment system is designed to operate with addition of coagulant, flocculant, and pH adjustment of the source water flow.

The pretreatment system will need to be designed to treat a total of 127,910 m^3/day. Source water coagulation will be completed by in-line static mixers. Design parameters of the DAF clarifier are summarized in Table 7.2.

7.5 CONSTRUCTION COSTS OF LAMELLA SETTLERS AND DAF CLARIFIERS

The graph of Fig. 7.6 depicts the construction costs of lamella settlers and DAF clarifiers. As can be seen on Fig. 7.6, lamella settlers are less costly than DAF clarifiers for the same volume of pretreated source water. However, lamella settlers do not remove algae and hydrocarbons well and, therefore, often DAF clarifiers are the preferred primary treatment step of choice for desalination plants using open intakes.

TABLE 7.2 Example of DAF Clarification System for 50,000 m^3/day (13.2 MGD) SWRO Desalination Plant

Component/Parameter	Specifications/Design Criteria
FEED WATER	
• Design flow rate, m^3/day (MGD)	127,910 (33.8 MGD)
• Turbidity, NTU	0.5–80
• SDI	6–16
DESIGN CHEMICAL DOSAGES	
• Ferric chloride, mg/L	15 (0.5–50 mg/L)
• Cationic polymer, mg/L	0.5 (0.0–1.0 mg/L)
• Sulfuric acid, mg/L – Target pH – 6.7	8 (0–30 mg/L)
FLOCCULATION TANK	
• Number per DAF tank	1
• Total number	6
• Width, m (ft)	4.85 (15.9 ft)
• Length, m (ft)	8.0 (26.4 ft)
• Depth, m (ft)	4.9 (16.1 ft)
• Number of mixers per tank	2
• Total retention time	13 min
DAF TANKS	
• Number	6
• Width, m (ft)	4.85 (15.9 ft)
• Length, m (ft)	10.0 (32.8 ft)
• Depth, m (ft)	4.9 (16.1 ft)
• Total surface area	291 m^2 (3132 ft^2)
• Surface contact zone area	57 m^2 (620 ft^2)
• Surface flotation area	234 m^2 (2548 ft^2)
• Surface loading rate @ 15% recycle	26.2 m^3/m^2 h (10.7 gpm/ft^2)
CIRCULATION PUMPS	
• Number	6 + 1
• Capacity	133 m^3/h (680 gpm)
• Delivery head	7 bars (100 psi)
AIR COMPRESSOR	
• Number	6 + 1
• Capacity	15 m^3/h (66 gpm)
• Delivery pressure	10 bars (142 psi)
DAF SATURATOR TANKS	
• Number	6
• Capacity per tank	100 m^3/h (440 gpm)
• Net volume per tank	4 m^3 (1060 gallons)

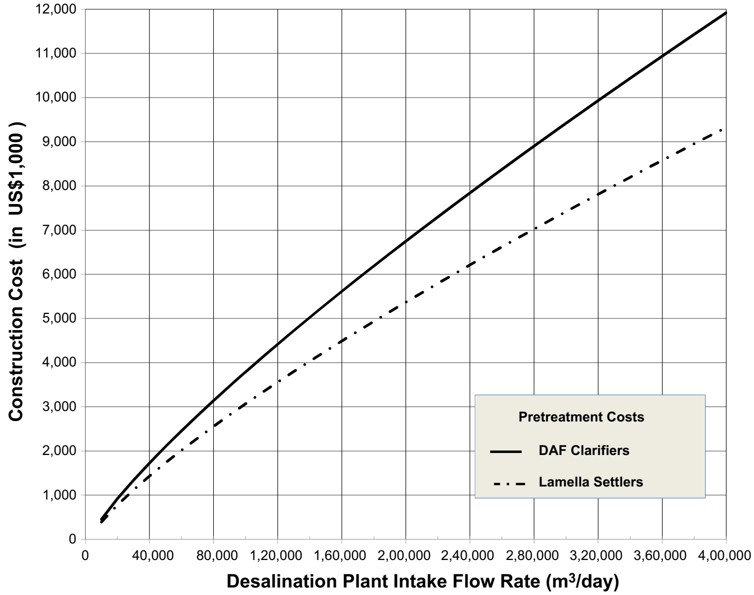

FIGURE 7.6 Construction costs of lamella settlers and DAF clarifiers.

Based on readings from Fig. 7.6, the estimated costs of the example lamella settlers and DAF clarifiers for 50,000 m^3/day SWRO desalination plant (127,910 m^3/day of intake water), described in Sections 7.3.2 and 7.4.3, are US$3.7 and 4.7 million, respectively. These costs are in US$2017 dollars.

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