AL-ZAWRAH NEW 10 MIGD SWRO DESALINATION PLANT

Authors: *Javier Arrieta, Borja Martinez, Raffi Shaffi*

Presenter: *Borja Martinez*
Desalination Technology and Water Supply Manager – CADAGUA, S.A. – Spain

Abstract

The rapid development of the Gulf Area over the last years implies a corresponding increase in the water demand. In order to respond to this demand, the Federal Electricity and Water Authority (FEWA) from UAE issued at the beginning of 2010 a tender invitation for proposals from the internationally reputed and experienced desalination plant manufacturers and EPC contractors to provide the new desalination unit and the associated auxiliary plants on turnkey basis.

FEWA is responsible for potable water and power supply in the Northern part of United Arab Emirates and namely in Ajman, UAQ, Ras Al Khaimah, Fujairah Emirates and remote parts of Sharjah Emirate.

After the evaluation of technical and commercial offers from different bidders, FEWA awarded in September 2010 the turnkey Contract of the Al-Zawrah New 10 MIGD SWRO Desalination Plant to the consortium formed by CADAGUA, S.A. from Spain and ESSA Engineering from UAE.

The Al-Zawrah New 10 MIGD SWRO Desalination Plant is located at Al-Zawrah Power Generation and Water Production Plant. Along with the existing 6 MIGD installation and the 3+7 MIGD SWRO Desalination Plants under construction, it will be the third RO desalination installation in the complex but the first one comprising advanced pre-treatment using dissolved air flotation (DAF) and ultrafiltration (UF) technologies.

This pre-treatment configuration (DAF+UF) was selected in order to provide the highest availability of the plant considering the variation in the seawater conditions over the year due to red tides associated to seasonal algae blooms and accidental oil spills, as well as to reduce the plant overall energy consumption.

At the same time, it is expected that the combination of DAF and UF processes will result in obtaining acceptable MFI and SDI values which will enhance the performance of the RO system.

The RO section will be formed by four (4) RO trains, each of 2.5 MIGD of net production capacity, designed to work at 40% recovery with low energy 440 ft^2 RO elements. With regard to the energy recovery, latest state-of-art energy recovery devices will be used to minimize the overall plant energy consumption.

This paper will present in detail all design aspects of Al-Zawrah SWRO Desalination Plant and discuss its advantages against other more conventional designs.

I. INTRODUCTION

The Al-Zawrah New 10 MIGD desalination plant is located at Al-Zawrah Power Generation and Water Production Plant in the Northern Emirate of Ajman (UAE) and will be the third seawater desalination plant by Reverse Osmosis (RO) in the complex.

In contrast to the existing and under construction desalination plants in the same complex, the new installation has been designed with an advanced pre-treatment to ensure a reliable and continuous daily output of potable water through the year and under the worst seawater conditions, i.e. during red tide and algae bloom events.

The essence of the design according to FEWA's requirements is robustness, simplicity and reliability in order to provide a long continuous service while obtaining the highest economy and lowest operation and maintenance cost.

According to the seawater quality records in the Gulf area high silt density index (SDI), as well as, total organic carbon (TOC) and total suspended solids (TSS) figures are expected.

Thus, having in mind FEWA's requirements and the seawater characteristics, ultrafiltration (UF) has been selected as seawater pre-treatment. Membrane based pre-treatments in comparison with conventional designs provide a saving in total water cost. In addition, this configuration reduces the plant footprint in comparison with conventional pre-treatment design, i.e., coagulation, flocculation and media filtration.

Apart from above mentioned criteria, the following design considerations have been adopted for Al-Zawrah SWRO plant:

- Operation of the plant by minimum number of personnel with full automatic control from the central control room
- Ease of access for inspection to all parts of the plant, as well as, for dismantling, maintenance and replacement of plant equipment
- Safe shutdown of the plant in sequential stages, if partial or complete loss of electrical power occurs

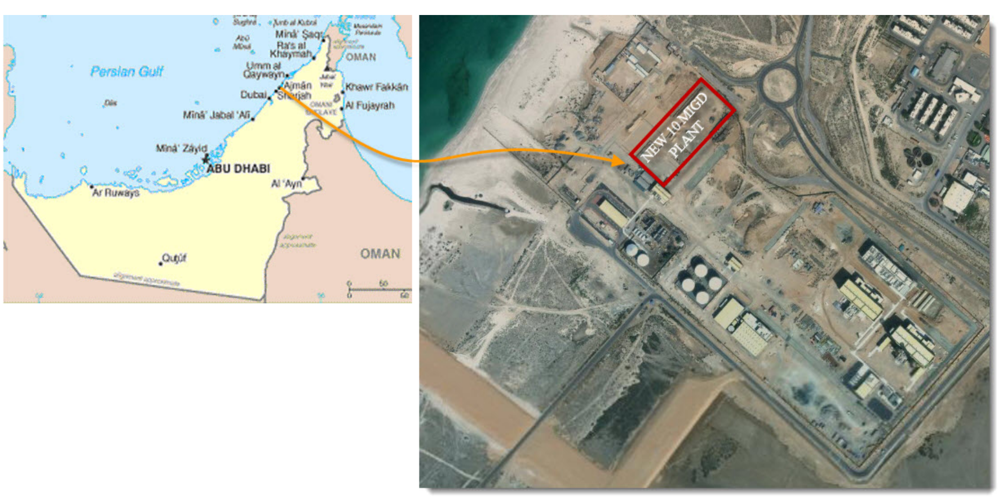

Figure 1. Plant Location

II. DESIGN CONDITIONS

2.1 Seawater Conditions and Analysis

The intake will be "an open sea intake" and the design conditions for the raw seawater considering this type of intake are the following:

- Temperature:

Maximum	35ºC
Minimum	18ºC
Design	28ºC

- Seawater analysis:

Seawater Salinity (TDS)	42,000 mg/l
pH	8.20

2.2 Product Water

For the seawater analysis and temperature range expressed above the RO Plant will be designed to produce 10 MIGD <> 45,460 m^3/d of desalinated water.

The quality of Product Water produced by the 10 MIGD SWRO Plant will meet the following values to be guaranteed at design conditions:

Permeate water TDS	≤ 450 mg/l
Post-treated Product Water TDS	≤ 500 mg/l
Chloride	≤ 200 mg/l
Boron	≤ 2 mg/l
pH range	7.5 – 8.5
LSI	Positive

III. PROCESS UNITS

The process configuration is shown in Figure 2 and consists of the following main process units:

- Seawater open intake (2 x DN 1100 HDPE pipes)
- Seawater intake pumps (5 x 25%)
- Flocculation and flotation cells (4 x 25%)
- Feed water pumps (5 x 25%)
- Self-cleaning filters (3 x 50%)
- UF racks (14 x 7.2%)
- Backwash & CEB pumps (2 x 100%)
- High pressure pumps (4 x 25%)
- RO trains (4 x 25%)

- Energy recovery devices (4 x 25%)
- Cleaning pumps (3 x 50%)
- Flushing pumps (3 x 50%)
- Product water transfer pumps (3 x 50%)
- Effluents treatment system

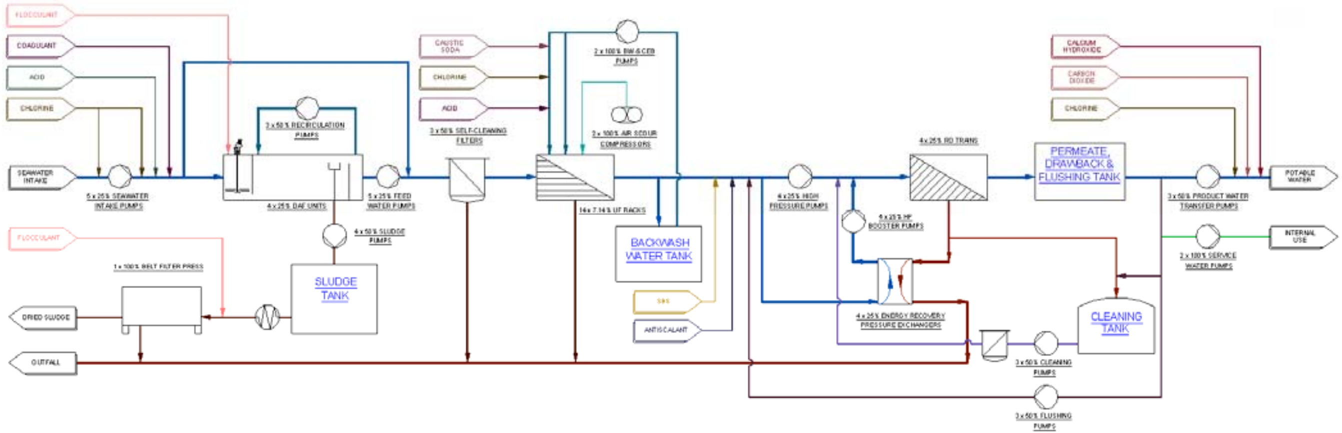

Figure 2. Process Scheme

IV. PLANT DESCRIPTION

The plant has a compact design as shown in Figure 3 below. All process and non-process related equipments and installations are located within the same area being the membrane processes (UF and RO) installed in a single building.

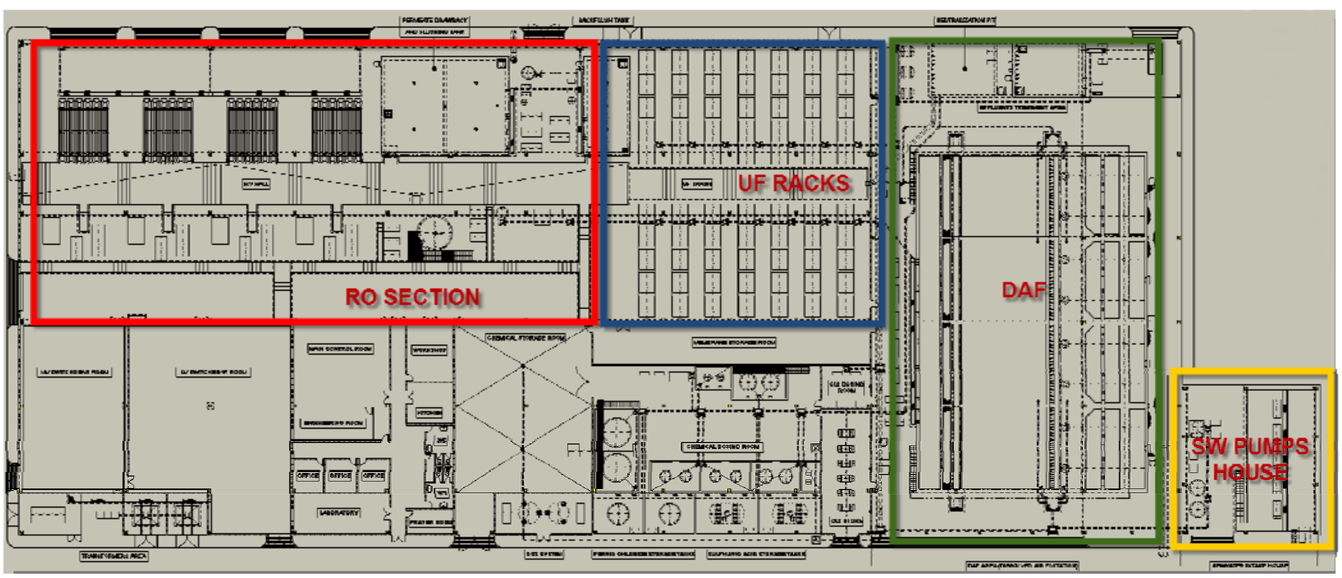

Figure 3. Plant Layout

4.1 Seawater Intake & Pumping

The seawater will be extracted from an independent open intake system serving the new 10 MIGD RO Desalination Plant. The plant is operated without continuous chlorination at the intake.

4.1.1 Seawater Screening – The off-shore seawater intake system consists on two (2) intake screens and a seawater intake pipelines made of HDPE laid and anchored to the seabed.

The screens are constructed in 70/30 Cu Ni stainless steel and with a slot clearance of 3 mm.

To perform the required backwash operation and injection of chlorine, the screens are equipped with built-in chlorine and backwash air diffusing headers.

The air backwash system is sized adequately for the backwashing of the screens and comprises the following equipments:

- 2 x 50% capacity air storage tanks
- 2 x 100% air compressors
- 2 x 100% backwash air delivery pipes of HDPE Class C - one (1) pipe per screen

The screens are connected to the off-shore intake headers (2 x DN 1100), made of HDPE class C. On-shore, both headers are unified into one single header (intake pumps suction header) made of GRP.

4.1.2 Seawater Intake Pumps – The seawater intake pumps are located in the seawater pumping house and will transfer the seawater to the pre-treatment system.

A set of 5 x 25% pumps made in duplex stainless steel with PREN> 40 are installed suitable sized to pump the total required feed flow to the RO section.

The pumps will be installed at a low level area, below ground level, to help the suction of the seawater from the intake structure. For evacuation of the air retained in the intake pipe a priming system is required.

The operation of this priming system is controlled by level switches installed in the intake header.

Figure 4. Seawater Pumping & DAF Area (3D-view)

4.2 Pre-Treatment

Successful long-term performance of reverse osmosis (RO) systems depends on three (3) factors:

- Pre-treatment
- System design
- Operation and maintenance

All three factors are important but proper pre-treatment is the basic foundation on which the successful design and operation of the RO plant are built.

The purpose of pre-treatment is to eliminate or minimize the fouling potential of the feed water to membranes to provide secure operation conditions for the RO plant.

The pre-treatment system comprises a chemical treatment (disinfection and pH adjustment) including in-line coagulation followed by 4 x 25% Flocculation and Dissolved Air Flotation units (only operative during red tide periods), 3 x 50% self cleaning security filters and 14 x 7.14% UF trains.

In normal operation DAF is not expected to be necessary, so this process is normally by-passed and seawater from the intake pumping is sent to self cleaning filtration and ultrafiltration units directly.

The pre-treatment stage is finalized with de-chlorination, antiscalant dosing and pH adjustment (if required).

4.2.1 Chemical Dosing Systems – The chemicals included in the pre-treatment chemical dosing systems are the following:

- Chlorine as disinfectant
- Ferric chloride as coagulation agent
- Coagulant aid
- Sulphuric acid for pH correction

- SBS for chlorine reduction
- Antiscalant

Figure 5. Chemicals Storage (3D-view)

4.2.2 Coagulation – To reduce the colloids concentration in the seawater (SDI) a coagulation process is installed.

An inorganic coagulant is used to coagulate any colloid and fine particulate matter in the seawater and to enhance the overall performance of the solids removal.

The coagulant considered for this application is Ferric Chloride ($FeCl_3$). To enhance the mixing of the coagulant and the seawater, a static mixer is installed. This mixing device will be capable of ensuring complete mixing of the anticipated chemical additives throughout any seasonal variations in feed-water flow rates or quality.

4.2.3 Dissolved Air Flotation – In order to allow the plant to continue working properly during red tide episodes, a Dissolved Air Flotation (DAF) system is required. This process unit is equipped with a by-pass line and will be out of service during normal operation.

The DAF technology uses micro-bubbles with a size in the range of 40-100 μm of diameter to attach to solid particles. The specific weight of the agglomerate (particle/air bubbles) is thus modified. The bubbles are simply floating up the particles to the water surface.

A security overflow to the brine outfall structure is provided in the inlet chamber of the DAF allowing the evacuation of seawater from intake pumps in the case of any eventual emergency situation.

From the inlet chamber the raw water will be transferred by gravity to the flocculation inlet channel. The flocculation process is carried out in the flocculation chambers properly designed for this purpose.

The installation is arranged in four (4 x 25%) lines with the same flow treatment capacity. For safety reasons 4 lines are designed allowing the possibility of working with 3 lines (one line out of service). Each line consists of two (2) flocculation chambers with four (4) electric mixers, two (2) per chamber and one (1) flotation cell.

As flocculant, a coagulant aid is added to improve the efficiency of the process flocculating any colloid and fine particulate matter in the seawater and enhancing the performance of Flotation Stage.

From the flocculation chambers the flocculated water enters into the flotation cells from the bottom of the inlet chamber. The pressurized water is added also in this chamber so as an intimate mixing with the flocculated water takes place.

The flocks created by the coagulant and the polymer float on the water surface in the flotation chamber. These solids are removed periodically with the surface scrapers and from floated sludge pits are pumped to the floated sludge storage tank.

The micro-bubbles are produced in the Air Dissolving Reactor. The process consists of dissolving air into recycled and pressurized clarified water taken from the outlet of the DAF Cell. This internal recycling loop represents approximately 10-15% of the raw water flow. The higher the pressure, the more air can be dissolved in the water. When this air saturated water comes back to the initial atmospheric pressure (after the pressure release), most of the dissolved air is immediately released as micro-bubbles, because the air solubility in the water is limited and depends mainly on the pressure.

Each flotation unit is equipped with two (2) air dissolving reactors where a stream of pressurized clarified water will be mixed with the dissolved air received from the air compressors.

The clarified water is collected by the clarified water extraction manifold located at the bottom of the tank.

4.2.4 Security Filtration – In order to protect the ultrafiltration modules three (3 x 50%) self cleaning filters with a 300 micron sieve opening are installed upstream the UF racks. These filters have an automatic cleaning which only occurs when the established head loss is reached.

4.2.5 Ultrafiltration Racks – After considering several different UF racks and modules configurations the design of the plant considers fourteen (14 x 7.14 %) UF racks.

The main considerations for this configuration selection have been to reach an acceptable flux increase when one or two lines are out of service and to properly arrange the UF area layout in combination with the RO system.

4.2.6 Backwash & CEB Systems – A portion of UF permeate is continuously sent to the backwash tank. From this tank the UF permeate will be pumped to the UF rack to be backwashed.

The tank is constructed in reinforced concrete and will have a capacity of 150 m^3 enabling the possibility of backwashing or doing a CEB for at least 4 trains.

For UF racks backwash operation two (2 x 100%) variable frequency drive controlled pumps are required. Depending on the cleaning operation (BW or CEB) this stream could be dosed with the appropriate chemical product.

The different membrane cleaning operations are:

- Backwash (without chemical addition): Once every 60 minutes per UF rack
- Chemical Enhanced Backwash (CEB): with chlorine, sodium hydroxide and sulphuric acid dosing.

In addition to the daily backwash and CEB operations when the membranes have lost permeability a clean in place (CIP) can be performed. In this case, a chemical solution is recycled during several hours through the membranes.

The backwash and CEB wastes will have the option to be sent to the brine pit (after being mixed with the RO first pass reject) or to the neutralization pit. In general and due to the large dilution factor in the seawater return channel they will be directly sent to the brine pit. However, the system has been designed to have the option of neutralizing the effluents before pumping them to the brine pit.

4.2.7 Effluents Treatment System **–** There are two main effluents that need to be treated before being evacuated to the existing brine outfall; (1) the floated sludge from the dissolved air flotation unit (to be dewatered and sent to disposal) and (2) the UF/RO chemical cleaning solutions (to be neutralized before being sent to the brine outfall).

During red tide periods Dissolved air flotation unit will be operative. Generated floated sludge will be delivered to the sludge storage tank from where two (2 x 100%) rotating positive displacement pumps will forward the sludge to one (1 x 100%) dewatering belt filter. At this point a polymer is added to the sludge to improve the efficiency of the dewatering process.

This equipment has been design to assume the maximum solids content expected during red tide periods.

On the other hand, liquid effluents with a high or low pH shall be neutralized before being delivered to the existing brine outfall. Effluents from UF-RO chemical cleanings with aggressive pH will be diverted to the neutralization basin where sulphuric acid or caustic soda can be added.

4.3 RO Plant

To produce desalinated water with TDS≤ 450 mg/l, Cl≤ 200 mg/l and Boron content less than 2 mg/l a single pass RO system is considered.

The RO system is projected with 4 independent permeate production units (HPG + ERS + RO Train) each one with a net design capacity of 2.5 MIGD (11,365 m^3/d).

Figure 6. General View (3D-view)

4.3.1 High Pressure Pumps – Seawater is pressurized using high pressure pumps and energy recovery devices and fed to the RO trains for desalination. The brine is returned to the energy recovery devices and thus excess energy is recovered before discharging to the sea.

Due to the fact that the designed energy recovery system is based on brine pressure exchangers, the high pressure pumps will not work with the total amount of seawater to be fed to the RO Trains. This fact reduces considerably the pump size and thus the energy required to feed the RO train.

The High Pressure Groups are formed by 4 x 25% high pressure pumps (HPP), centrifugal, horizontal, multistage, split casing.

4.3.2 Energy Recovery Devices – Energy is transferred by positive displacement from the high-pressure concentrate to feed water through direct, momentary contact.

The high-pressure flow rate through the energy recovery device or ERD's array is controlled by adjusting the booster pump speed with a variable frequency drive (VFD). Low-pressure feed water from the seawater intake pumps is supplied at a rate controlled with a throttle valve in the low-pressure concentrate discharge from the ERD's array. This valve also applies backpressure on the system required to prevent cavitations. The high and low pressure flow rates through the devices are completely independent and both are monitored with separate flow meters.

High-pressure and low-pressure flow rates through the ERD are normally set equally, a condition referred to as balanced flow.

4.3.3 RO Trains – Pressurized seawater is fed to the RO Trains and is desalinated by reverse osmosis. The produced permeate by each train is collected in the permeate, drawback and flushing tank with a capacity of 350 m^3. From this tank water shall be supplied to different services as flushing water system and forwarding water pumps.

The brine returns to the ERD and is then disposed to the sea by the brine collection system.

The sizing of the 1st Pass RO Trains is as follows:

- 4 x 25% RO trains
- 100 pressure vessels per train
- 7 spiral wound elements per pressure vessel
- 700 spiral wound elements per RO train
- 2,800 spiral wound elements in total

The pressure vessels are arranged in 1 single stage. Each train works at 40% conversion and the maximum feed pressure to the pressure vessels will be less than 68 bar corresponding to a seawater temperature of 18ºC and after 3 years of element age.

The RO trains will be provided with an extra rack space up to 10% with the corresponding manifolds and sample panels for permeate (100% of the modules).

The seawater temperature variations will be mitigated by the adjustment of the feed pressure control valve installed downstream the HPP.

4.3.4 Flushing & Cleaning Systems – The flushing system of the desalination plant has the following functions:

- Subsequent to a stop or shut-down, seawater and brine water from high pressure groups (pumps and ERD's), RO trains and associated high pressure pipes of the RO system, must be swept away with permeate to protect the production units against corrosion (both pitting and crevice actions) caused by high chloride concentrations
- Cleaning solutions must be also swept away from the inside of the RO membranes during cleaning procedures

4.4 Post-Treatment & Product Water Transfer System

4.4.1 Remineralization – The permeate water obtained from the RO trains is sent to the Post-Treatment System for further remineralization to comply with the requirements of WHO with respect to the Drinking Water Quality.

The remineralization system is intended to augment the carbonate hardness in the potable water thereby minimising corrosion in the water distribution system thus eliminating to a great extend the so called "red water problem".

Permeate produced in desalination plants normally does not contain practically carbonate hardness, essential minerals, etc. and this product almost being unstable is considered to be very aggressive and accelerate corrosion in the materials normally used in the distribution system.

The remineralization of permeate is regarded as the best solution for the above mentioned problems, and recarbonation system is a part of remineralization system.

The recarbonation system using CO_2 and lime dissolution is considered to be very effective and economical to augment the carbonate hardness in the potable water thereby avoiding several problems.

4.4.2 Disinfection – The product water will be chlorinated in continuous basis by addition of chlorine gas.

The chlorine will be injected in the product water line downstream the post-treatment chemicals addition and will assure the required disinfection conditions in the product water line up to Ajman Water distribution centre.

4.4.3 Product Water Transfer System – The product water produced in the new 10 MIGD plant will be forwarded either to the under construction storage water tanks or direct pumped to water distribution centre located in Ajman WDC through DN 1200 existing pipeline.

For this purpose, a set of three (3 x 50%) pumps of 1,000 m^3/h at 3 bar are installed to pump the total production from the permeate, drawback and flushing tank to the mentioned storage and distribution centre in Ajman through an existing transmission line.

These pumps are equipped with VFD to adjust in every moment the required delivery conditions.

V. HIGHLIGHTS

5.1 Direct Feed Design

The Al-Zawrah New 10 MIGD plant has been designed considering a direct feed design concept. According to this design concept the water is directly fed from the seawater intake pumping to the RO section without breaking pressure at intermediate tanks which makes necessary to pressurize the seawater before sending to downstream processes.

This is achieved thanks to the fact that all process units downstream the DAF are pressurized.

This concept provides simplicity to the installation, at the same time it helps to optimize the power consumption of the whole installation. On the flip side, it is important to bear in mind when designing an installation under this concept that the process has to be fed continuously in order to avoid the stoppage of the plant.

5.2 Facing Up Red Tide Events

It is a well-known fact that red tides and algae blooms are more frequent year by year and become a serious problem for desalination plants using open sea intake systems. Usually, these events compromise the availability of the installation basically due to the impossibility to continue producing product water with such poor seawater quality.

Although red tides have not the same effect in all areas it is a fact that these events implies a considerable increase of total suspended solids and total organic carbon which have a direct impact on the performance on the plant.

It has been demonstrated that plants comprising conventional pre-treatments with single or dual stage filtration are not capable of facing up such increase of TSS and TOC and have to stop the production or reduce the production capacity.

In order to avoid these consequences and provide a reliable and continuous production of water the Al-Zawrah New 10 MIGD SWRO Plant has been designed considering a clarification by dissolved air flotation which is expected to reduce up to normal conditions the seawater quality prior to the entrance to UF.

VI. CONCLUSIONS

Al-Zawrah New 10 MIGD has been designed to become the largest SWRO plant in the Al-Zawrah Power Generation and Water Production complex. In addition to this and due to the fact that an advanced pre-treatment process (UF) is included, this plant is the most advanced SWRO plant using the latest state-of-art in seawater pre-treatment.

The use of highest design standards and high grade materials will lead the desalination plant to success for a minimum working life of 20 years.