Upgrading OF Tajura Seawater Reverse Osmosis Desalination Plant By Integrated Membrane Systems

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ABSTRACT

The Tajura seawater reverse osmosis desalination plant commenced operation in 1984 with only 50% of its production capacity (10,000 m^3/d). Feed water is supplied from an open intake located at Tajura on the Mediterranean coast and treated prior to RO using a conventional pre-treatment system. As time passed, numerous obstacles brought down the plant's production capacity to its lowest level. The operation problems with the coagulation-flocculation pre-treatment system led to an increase in the silt density index (SDI_{15}) and fouling of the RO membrane. In addition, a non-continuous plant operation increased differential pressure, salt passage, and decreased water production through the membranes. This paper describes the problems encountered in the existing conventional pre-treatment system and the conceptual Integrated Membrane System (IMS) design as a part of the plant rehabilitation process of the Tajura RO plant in Libya. The proposed design of the pre-treatment system for the Tajura RO plant utilizes Hydranautics IMS technology. The IMS design is based on long experience from the operation of the two separate RO pilots with different pre-treatment systems for a period of four months on the Mediterranean coast at Tajura city. The previously published data from those pilot plants confirmed the prior assumption that UF pre-treatment produced stable feed water quality, measured by reduced turbidity and by the SDI15. The upgrading of the Tajura RO plant by IMS was designed for full product capacity (10,000 m^3/day). The plant will employ dissolved air flotation pre-treatment followed by Hydranautics IMS membrane technology consisting of four UF racks with Hydranautics HydraCap80, the overall UF plant is designed for a continuous UF to permeate flow of 670 m^3/h. The nominal flux rate is 72.1 $L/m^2/h$ with all UF blocks in operation and downstream two seawater RO trains with SWC5 membranes working at 35% recovery.

Keywords: Conventional pre-treatment; Membrane pre-treatment; Desalination Reverse Osmosis; Integrated Membrane System.

1 Introduction

Pre-treatment is critical in RO applications because it directly impacts the fouling of the RO membranes. Fouling of the RO membranes results in increased operating costs from increased cleaning demands, increased feed pressures, and reduced membrane life. Additionally, fouling can result in reduced permeate water quality and permeate quantity, thereby impacting production from the RO facility.

The conventional pre-treatment system was applied to seawater RO plant from its early days and continues to be used today. Recently, UF has been recognized as competitive pre-treatment for RO systems [1,2]. A system designed with a UF as pre-treatment prior to a RO system has been referred to as an Integrated Membrane System (IMS). However, there are several of markets and regions where the use of IMS for brackish and seawater applications is growing [3]. Figure 1 shows the cumulative capacity of seawater RO plants with UF pre-treatment vs. time, which gives a clear indication of the overall fast adoption speed of IMS pre-treatment technology.

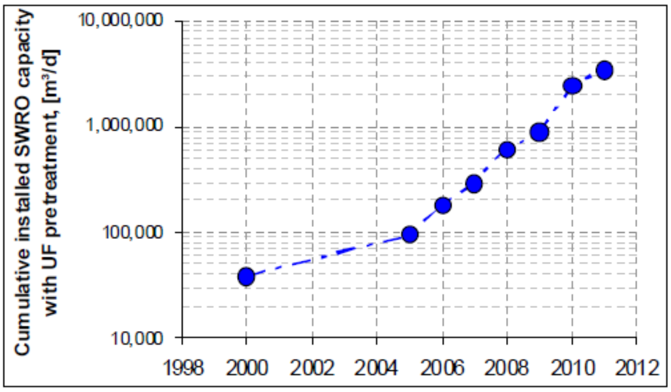

Figure 1 *Cumulative capacity of SWRO plants with UF pre-treatment [3]*

Examples of large seawater RO plants where the concepts of IMS have been implemented Table 1. The better-known plants with membrane pre-treatment are Addur, Bahrain Fukuoka, Japan, Kindasa, Saudi Arabia, and YuHan, China [4,5].

Table 1: *Summary Examples of large seawater plants with membrane pre-treatment are RO plants*

Location	Addur, Bahrain	Fukuoka, Japan	Kindasa, Saudi Arabia	YuHan, China
Membrane filtration capacity,m^3/day	140,000	96,000	90,0000	70,000
Operational status	Operational since May 2000	Operational since May 2005	Startup Mid 2006	Startup Early 2006
Membrane technology	Pressure- driven UF back washable Spiral wound	Pressure-driven UF back washable Spiral wound	Pressure-driven UF capillary	Submersible UF capillary
Pre-treatment Membrane Module manufacturer	Nitto Denko	Nitto Denko	Hydranautics	Zenon

The Tajura Nuclear Research Center (TNRC) operates an RO system with conventional pre-treatment at Tajura city in Libya on the Mediterranean shore. It was commissioned in 1984 with only 50% of its production capacity (10,000 m^3/d). The plant used the two-stage process of desalination in the period between 1984 and 1999. Since 1999 to date the utilized membranes have directly converted seawater to potable water with a conductivity of 500 micro Siemens. The second pass was kept to be utilized in cases when high-purity water was needed. The process design of the plant was influenced by long-term experiences of the deteriorating quality of seawater. This deterioration was particularly experienced with high levels of suspended solids and silt density index. In addition, problems with the facility's pre-treatment system, coupled with some operational difficulties have significantly reduced the plant's performance. The existing conventional pre-treatment system was considered unfit to deal with these seawater conditions throughout the seasons [6]. Following the recent experience in large RO plants and the continued cost reduction, on account of the technological improvements and worldwide competition by several membrane manufacturers, UF is now seriously considered for application in seawater systems [7,8].

Design hydranautics IMS technology has been employed, which incorporates Hydranautics HydraCap60™ ultra filtration modules and Hydranautics high rejection and energy saving SWC5 seawater RO membranes. The design is based on the previously published data from the operation of two different types of pilot plants with a period of four months, each pilot plant has different pre-treatment technologies for RO systems. These included: conventional pre-treatment and UF were installed at Tajura city in Libya on the Mediterranean Sea . The results from these pilots indicated that the UF membrane pre-treatment provided superior water quality for the RO plant, measured by reduce turbidity and SDI_{15}. The results have shown that the UF membrane system was able to consistently reduce SDI_{15} values to less than 3 and had turbidity values to less than 0.2 NTU, while over 70% of the conventional media filtration unit SDI_{15} values were over 3 and an average turbidity of 0.33 NTU [9].

The Tajura RO plant IMS designed for a production capacity of 10,000 m^3/day. The plant employ dissolved air flotation pre-treatment followed by Hydranautics IMS membrane technology consisting of eight UF racks equipped with Hydranautics

HYDRAcap80®elements and downstream two seawater RO trains with SWC5 membranes working at 35% recovery.
This paper describes the problems encountered in the existing conventional pre-treatment system and the conceptual proposed IMS design as a part of the plant rehabilitation process of the Tajura RO plant in Libya.

2 Pre-treatment for SWRO Desalination

RO seawater systems operating on surface feed water, originating from an open intake source, require an extensive pre-treatment process to control membrane fouling. Therefore, the main factor for the successful operation of SWRO is maintaining a constant high feed water quality. Two kinds of pre-treated seawater have fed the RO membrane: pretreated seawater by the conventional system and pretreated by the UF system.

2.1 Conventional Pre-treatment

Conventional RO pre-treatment has been widely applied in the past for seawater RO plants to lower the SDI_{15} and to remove suspended solids and excessive turbidity. Conventional pre-treatment includes coagulation, sedimentation, filtration using sand and/or multimedia filters, lime softening and activated-carbon adsorption, and cartridge filter. Whilst conventional pre-treatment technology can be effective, it needs to be carefully designed, and diligently operated. Up-sets, due to feeding variability or contamination, will be transferred to the RO. Most examples of RO system failure are down to pre-treatment failings, either in design or operation. Several major disadvantages of conventional pre-treatment treating surface seawater contribute to higher rates of RO membrane fouling and shorter RO membrane life expectancy including:

- Significant fluctuations in the quality of RO feed are caused by changing raw water conditions.
- Difficult to achieve a constant $SDI_{15} < 3.0$, especially during high turbidity feed water conditions.
- The low removal efficiency of particles smaller than 10–15 microns.
- Possibility of breakthrough during filter backwash.
- Carryover of high concentrations of colloidal particles immediately following the backwash filter.
- Coagulant impact on RO membranes.

In addition to the above, slow filtration velocities also result in large land footprint requirements for a conventional pre-treatment system [10-12].

2.2 Advantages of membrane pre-treatment

As mentioned before, membrane processes are gaining importance for water applications as a result of the advances in membrane technology and increasing requirements on water quality. Pilots data are just recently available, documenting the benefits of membrane filtration to RO applications. For seawater applications, papers include[10-

12]; the benefits as described in these papers for membrane filtration as pre-treatment for RO are described below:

- Improved pretreated water quality, in terms of lower suspended solids and less biological content, resulting in improved RO operation
- Fewer RO membrane cleanings with resulting cost savings in cleaning chemicals
- Lower RO pressure drops from fouling, resulting in lower energy costs
- Longer RO membrane life associated with long-term improved pretreated water quality
- Increased flux rates in the RO system due to higher quality pre-treatment, resulting in a reduction in the size of the RO system with subsequent reduction in capital cost.
- Smaller plant footprint size (typically~ 30-60% of conventional) resulting in reduced capital investment
- Lower overall chemical and sludge handling costs if conventional technologies include coagulation, clarifiers, filtration, or other chemically intensive conventional pre-treatments
- Lower operator requirements due to complete automation
- Greater plant availability due to decreased downtime related to chemical cleanings
- Reduced environmental impact due to reduced chemical disposal requirements
- Membrane Integrity Testing provides a means to verify the removal of Giardia and Cryptosporidium-sized particles that are not available with granular media filtration.

2.3 Conventional vs. membrane pre-treatment

The comparison of conventional media filtration and low-pressure membrane (MF/UF) SWRO pre-treatment is presented in Table 2.

Table 2: *Comparison of conventional and MF/UF pre-treatment [10-12]*

Parameters	Conventional pre-treatment	MF/UF pre-treatment
Track record	Established	Rapidly developing
Feed water quality and removal efficiency	Lower removals possible	Better removals of organics, DBP's fine colloids, silt, and pathogens
Treated Water SDI_{15}	<4, 90% of the time	<2.5, 100% of the time, usually <1.5
Turbidity	<1.0 NTU	<0.1 NTU
Variable feed quality	Susceptible	Less sensitive
Post-treatment	Cartridge filters used	Optional ~ not usual
Filter replacement	Mean life ~20 years	Membrane life ~ 6 years
Energy usage	Less than MF/UF as it could be gravity flow	More energy for membrane TMP and backwash
Capital Costs	Cost competitive with MF/UF	Slightly higher than conventional pre-treatment. Costs continue to decline as developments are made
RO capital cost	Higher than MF/UF since RO operates at a lower flux	Higher flux is logically possible resulting in lower capital cost
RO operating costs	Higher costs as the fouling potential of RO feed water is high resulting in higher operating pressure. One experiences frequent cleaning of RO membranes	Lower RO operating costs are expected due to less fouling potential and longer membrane life

Chemical costs	High due to coagulant and process chemicals needed for optimization	Chemical use is low, dependent on raw water quality
Footprint	Larger, particularly if two-stage required	Significantly smaller footprint - Typically~ 30-60% (of conventional)

3 Brief Description of Tajura Seawater RO Plant

Tajura reverse osmosis desalination plant was designed to produce 10,000 m^3/d based on the Mediterranean seawater feed and was commissioned in 1984 with only 50% of its production capacity. Raw Water quality data for the Tajura seawater RO facility are shown in Table 3.

Table 3: *Raw water characteristics for the Mediterranean sea at Tajura coast [13]*

Component	Seawater Composition
Calcium Ca^{++}	455 mg/L
Magnesium Mg^{++}	1427 mg/L
Sodium Na^{++}	11600 mg/L
Potassium K^{+}	419 mg/L
Silica Si^{+1}	2 mg/L
Chloride Cl^{-1}	20987 mg/L
Biocarbonae HCO^{3}	163 mg/L
Sulphate SO^{4-}	2915 mg/L
Nitrate NO^{4-}	0 mg/L
TDS	38,000 mg/L
Conductivity	55 µS/cm
PH	8.3 standard units
Temperature	15-35 C°
Total Fe	0.55 mg/L

3.1 The process

Seawater is drawn through a 1.3 km long pipeline into a seawater basin with a capacity of 1920 m^3. The seawater is then pumped to mechanically filtered and then pumped into the pre-treatment section. Figure 2 illustrates the schematic process flow diagram of the Tajura plant. The pre-treatment consists of online coagulation-flocculation, 8- dual media filters (DMF), and 5-micron cartridge filters. The chemicals that can be injected into the seawater are copper sulfate solution ($CuSO^4$) for disinfection, sulfuric acid to reduce the pH, Ferric chloride sulfate solution ($FeClSO^4$) for destabilization, and agglomeration of the colloidal particles and a coagulant aid. The coagulated flocks are filtered off in the dual media filter (DMF) beds followed by filtration through 5-micron cartridge filters and de-chlorination by sodium bisulfate solution injection complete the pre-treatment of feed water. From the pre-treatment section, water is fed to the RO section. The RO system consists of two stages. The first RO stage consists of four parallel RO racks with 99 pressure vessels each. The system can be operated with either two racks 50% or four racks 100% of the total capacity with 30% recovery of product water. The product water of the first stage is collected in the buffer tank. Water from the buffer tanks is fed to two racks of the second stage using of two high-pressure pumps (for 50% operation one rack is operated). 85% of the first stage desalted water is recovered by the second stage. The product water is partially de-carbonated and post-treated with chlorine; stored in storage tanks. The major design parameters of RO membrane systems are presented in Table 4. The plant used the two-stage process of desalination in the period between 1984 and 1999. From 1999 up to date the membranes utilized were directly converting seawater to potable water with conductivity in the range of 500-micro. The second pass was kept to be utilized in cases when high-purity water was needed.

Table 4: *SWRO Plant main design parameter*

Parameters	Value
Product TDS	<500 mg/l
Recovery rate	30%
Feedwater TDS	38,000 mg/l
Feed temperature	15–35 °C
Membrane type	TFC spiral wound membrane
Total number of racks	4 racks
Number of RO stages	Two stages
Commissioning data	1984
plant capacity	10,000 m^3/h

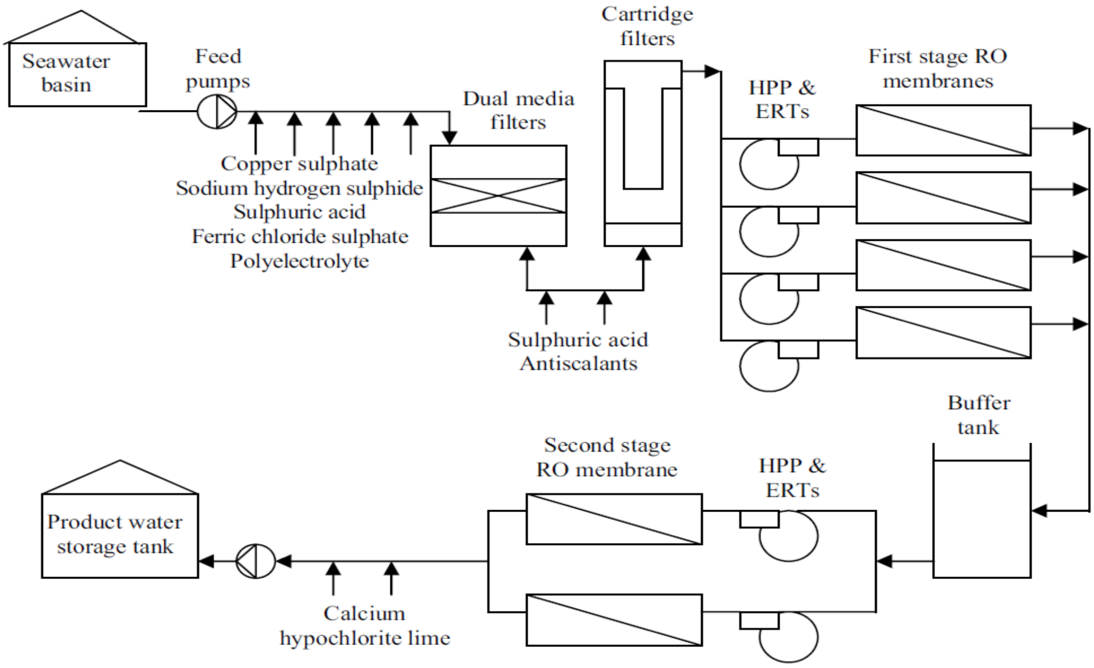

Figure 2 illustrates the schematic process flow diagram of the Tajura RO plant [13].

3.2 Operational experience with a conventional pre-treatment system at the Tajura plant

As it has been mentioned earlier that the Tajura plant is producing drinking water at a rate of less than 50% of its design capacity. Problems with the facility's pre-treatment system, coupled with some operational difficulties have significantly reduced the plant's performance [6].

3.2.1 Coagulation-flocculation unit

The coagulation-flocculation unit is out of operation, the tanks are corroded and leakage is noticed as in Figure 3. The mixers in the tanks are heavily corroded and destroyed, the condition of this unit is terrible and it can't be repaired. The nonexistence of this unit prevents the plant from working when the SDI_{15} of seawater is high.

Figure 3. Coagulation-flocculation tanks [6]

3.2.2 Multi-Media Filters

There are eight media filters, each having six automatically operated valves. Despite all the media filter vessels being in good condition but the problems with their valves have been experienced, Some of the valves failed shortly after the start-up under an actual pressure above the design value. These valves contribute largely to the complexity of the plant and increase the need for maintenance and repairs. Also, there is no yearly makeup for anthracite in the media filters. It is speculated that the quantity decreased due to the loss during the backwash process.

3.2.3 Silt Density Index (SDI_{15})

As a result, the existing pre-treatment system of the Tajura RO plant could not achieve1 an SDI_{15} value of less than 4.0 most of the time as shown in Figure 4, this was not meet with the SDI_{15} recommended by the manufacturer for the RO membrane which (< 4), this prevents keeping the plant in continuous operation. Non-continuous plant operation increased differential pressure, salt-passage and decreased the plant performance.

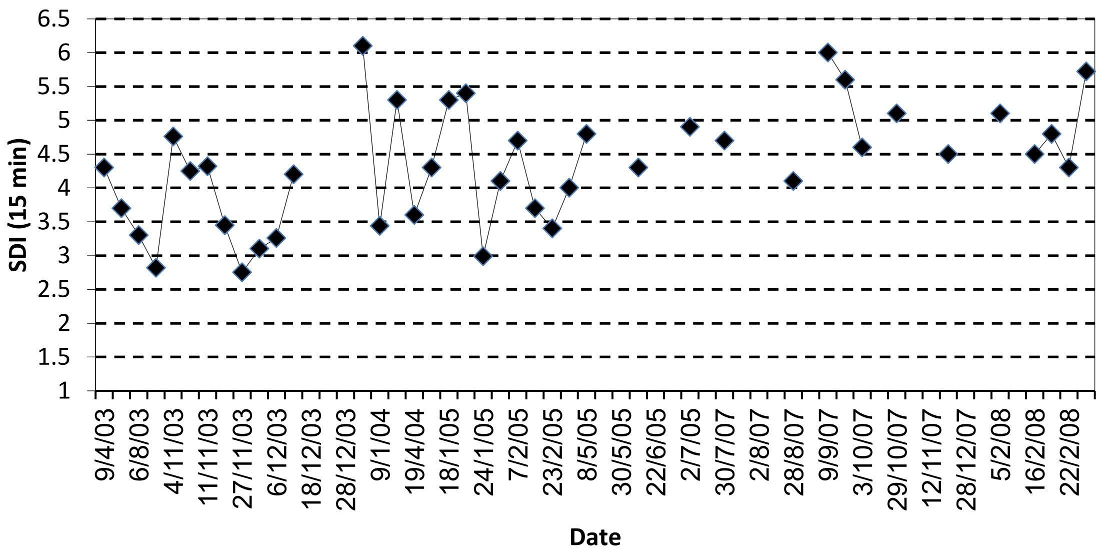

Figure 4. *SDI levels were obtained in the period between 2003– 2008.*

3.3 The UF system process conceptual design for the Tajura plant

Integrated Membrane System will be considered as an alternative option to conventional pre-treatment system for the Tajura RO plant. The proposed design of the pre-treatment system will utilize Hydranautics IMS technology. The IMS design is based on long experience from the operation of the two separate RO pilots with different pre-treatment units started in January 2013 for a period of four months on the Mediterranean coast at Tajura city. The results from those pilot plants confirmed the prior assumption that membrane pre-treatment will produce stable feed water quality, measured by reduced turbidity and by the SDI_{15}. The results have shown that the membrane filtration units were able to consistently produced SDI_{15} values less than 3 and turbidity values less than 0.2 NTU, while over 70 % of the conventional media unit SDI_{15} values were over 3 and produced an average turbidity of 0.33 NTU [9]. The membrane modules that have been selected for the pre-treatment unit of the Tajura RO plant are HYDRAcap80® UF modules made by Hydranautics. Each UF block consists of 44 UF elements of single-bore hollow fibre membranes with a bore size of 0.8 mm and a molecular weight cut-off (MWCO) of 150,000 Dalton. The overall UF plant is designed for a continuous UF to permeate flow of 670 m^3/h. The nominal flux rate is 72.1 $L/m^2/h$ with all UF blocks in operation. The UF system design parameters are presented in Table 5.

Table 5: *The main design parameters of HYDRAcap80 UF membrane for the Tajura plant*

Parameter	Value
Number of racks	4
Total number of modules	176

Nominal Membrane Area	670 ft^2 (62.2 m^2)
Module type	HYDRACAP 80
Material	Hydrophilic Polyethersulfone
Fiber Dimensions	ID 0.8 mm, OD1.4mm
Maximum Applied Pressure	73 psig (5 bar)
Maximum Operating Temperature	104 °F (40 °C)
Feed water PH Range	4-10
Feed water Chlorine Concentration	100 ppm
Volume to be treated	17473 m^3/day
Volume to produce	16086 m^3/day
Waste water volume	1387 m3/day
Recovery	92.1%
Average rack flux	72.1 LMH

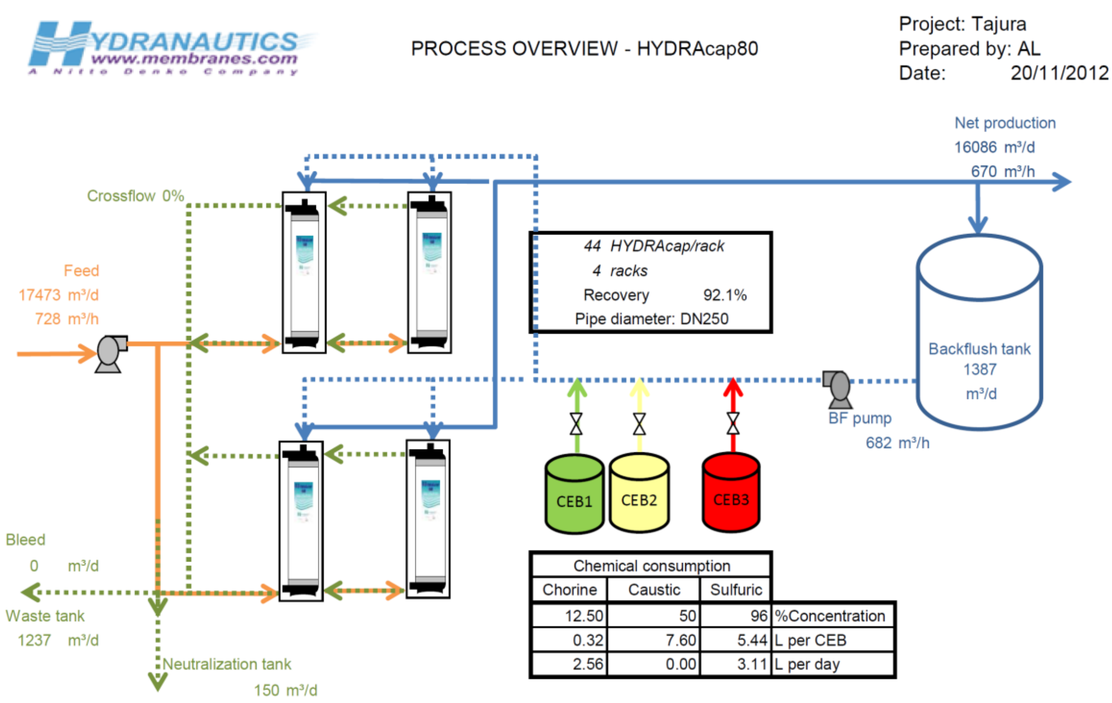

Figure 6 *UF Membrane Pre-treatment Process Flow Schematic*..

4 CONCLUSIONS

Seawater reverse osmosis desalination is a rather complex process when associated with fouling and scaling problems. It requires careful study to selected the proper pre-treatment systems for control membrane fouling and successful long-term performance of RO membrane. From the experiences it can be seen the RO plant at Tajura has an enormous problems encountered in the existing conventional coagulation-flocculation pre-treatment. UF membrane pre-treatment prove to be effective to provide superior water quality, and were able to handle wide swings in incoming water quality. The Integrated Membrane System had suggested as part of plant rehabilitation process of Tajura RO plant. The membrane modules that have been selected for pre-treatment unit are HYDRAcap80® UF modules made by Hydranautics company. The overall UF plant is designed for a continuous UF to permeate flow of 670 m^3/h. The nominal flux rate is 72.1 $L/m^2/h$ with all UF blocks in operation and downstream two seawater RO trains with SWC5 membranes working at 35% recovery.

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