Comparative Performance of UF vs. Conventional Pretreatment for SWRO: Pilot Studies

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Abstract

Surface seawater intended for desalination by reverse osmosis (RO) need extensive pretreatment to control membranes fouling. Proper pretreatment is the most critical factor for successful long-term performance of seawater reverse osmosis (SWRO) membrane. Two types of technologies are using for pretreatment, Conventional Multimedia Filtration (MMF) and Ultra Filtration (UF). Both of these treatments are currently applied in SWRO plants in the world. In this study, two pretreatment techniques have been compared, a conventional filtration and an UF membrane, both followed by separate RO pilot systems. The project was implemented at Tajoura Libya on the Mediterranean Sea. Both pilots were using raw feed water from basin of Tajoura desalination plant intake, for a period of four months. The preliminary results indicate that the membrane filtration pretreatment provided superior water quality for the RO, measured by reduced turbidity and silt density index (SDI_{15}). The results have shown that the membrane filtration units were able to consistently reduced SDI_{15} values to less than 3 and 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.

Keywords: Conventional pretreatment; membrane pretreatment; desalination; reverse osmosis.

1. Introduction

Libya is located in North Africa, with a long coastline on the Mediterranean Sea. Water resources are limited and depend mainly on ground water which exploited beyond the save limit leading to seawater intrusion. Water shortage has existed since the year 1995 [1]. In order to meet the increasing demand on potable water the only non-conventional source to supply the demand is desalination, reverse osmosis RO is the most convenient technique for brackish and sea water desalination [2, 3]. RO membrane is very sensitive to the quality of the feed water therefore pretreatment is a measure task. The major obstacles to the successful use of membrane separation processes are phenomena know as membrane fouling; Membrane fouling refers to the deposition of rejected particles, colloids, macromolecules, bacteria, salts, etc. on the membrane surface or in the pores of the membrane. Fouling of the RO membranes results in increased operating cost 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 [4, 5].

In order to more fully understand and compare the performance differences between conventional pretreatment and UF pretreatment for seawater desalination processes. In this study, two pretreatments have been compared, a conventional filtration and a UF membrane, both followed by separate RO pilot systems. The project was implemented at Tajura on the Mediterranean Sea in Libya. Both pilots were using raw feed water from basin of Tajura desalination plant intake system for a period of four months.

2. Material and Methods

2.1. Source Water Quality

In this study, the source water of Tajura Desalination Plant (Tripoli, Libya) was used as feed water for the pilot systems. The intake head was placed at a distance of 1.3 km into the sea 7 m below the sea level and 6 m above the sea bottom. From the intake head seawater by gravity goes through two submersed pipelines into a seawater basin with a design capacity of 1920 m^3. The seawater is then pumped from the basin to the pilot systems (UF and MMF). Raw water characteristics are presented in Table 2.1.

Table 2.1: Raw water characteristics of Mediterranean sea in Tajura

Component	Units	Seawater Composition
Calcium, Ca^{++}	mg/L	455
Magnesium, Mg^{++}	mg/L	1427
Sodium, Na^{++}	mg/L	11600
Potassium, K^{+}	mg/L	419
Silica, Si^{+}	mg/L	2
Chloride, Cl^{-}	mg/L	20987
Bicarbonate, HCO_3^{-}	mg/L	163
Sulphate, SO_4^{-}	mg/L	2915
Nitrate, NO_4^{-}	mg/L	0
TDS	mg/L	38,000
Conductivity	mS/cm	55
PH	standard units	8.3
Temperature	°C	17.9
Total Fe	mg/L	0.55

2.2. Pilot Equipment Description

The pilot plant was composed of multiple pretreatment units and a skid containing two identical and independent seawater RO systems, the first received conventionally pretreated seawater and the second received water pretreated with UF membrane. Each SWRO is capable of producing up to 0.8 m^3/hr permeate flow.

2.2.1. Multi Media Filter (MMF) Pilot

A single media filtration system that is comprised of two 24-inch diameter pressure vessels with Turbidex filtration media is placed in 40 feet shipping container. The system utilizes a number of treatment steps. During service, feed water is pressurized by the system feed pump. The pressurized feed water is fed through the disc filter for the removal of particles > 130 microns. The discs filter backwashes automatically and require no expendables. Effluent from the disc filter is fed to the media filter vessels for further removal of suspended particles (nominally > 5 - 10 microns). Effluent from the media filter vessels is fed to the filtrate storage tank and then fed to SWRO1. A process flow diagram of the MMF system with chemical dosing points is presented in Figure 2.1.

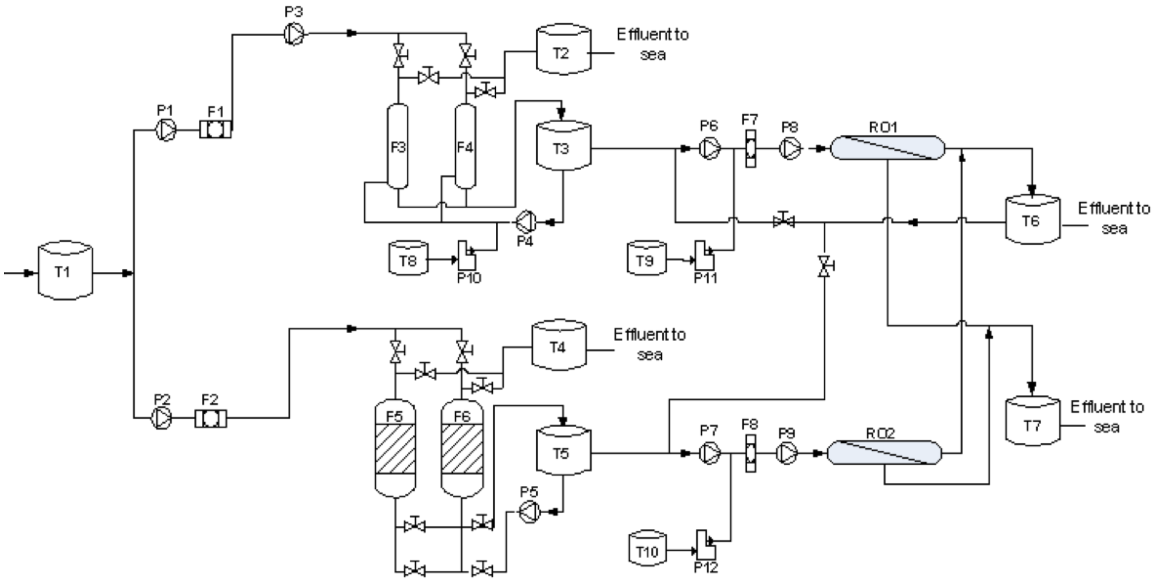
2.2.2. Ultrafiltration (UF) Pilot

The ultrafiltration (UF) system is housed in a single 40-feet shipping container and is designed to pretreat RO feed water for the removal of suspended solids. The UF system includes two HYDRAcap 60-LD UF modules. Each module includes 323 ft^2 (46.5 m^2) of membrane surface area in the form of capillary fibers with internal bore diameter of 0.047 inches, the UF membrane specifications are given in Table 2.2. During service, feed water is pressurized by the system feed pump. The pressurized feed water is fed through the back washable disc filter for the removal of particles > 130 microns. Effluent from the disc filter is fed to the ultra-filter vessels for further removal of suspended particles of MWCO 150,000 Daltons.

Table 2.2: Characteristics of the UF membrane

Membrane Characteristics	Value
Material	Hydrophilic Polyethersulfone
Nominal membrane area	500 ft^2 (46 m^2)
Fiber dimension	ID: 0.03″ (0.8 mm) OD: 0.051″ (1.3 mm)
Molecular Weight Cut-Off (MWCO)	150,000 Daltons
No. of fibers	13,200
Maximum operating temperature	40 °C (104 °F)
pH operating range	4.0 - 10.0

The feed water exiting the UF module is combined with additional feed, re-pressurized by the UF recirculation pump, and recirculate through the UF modules where more pretreated water is collected. Overall recovery of the UF system is controlled by a diaphragm valve on the recirculation line which



P1/P2/P6/P7: Booster pump	F3/F4: UF vessel	T6: Permeate flush tank
P3: Recycle pump	F5/F6: Media filter	T7 : Concentrate tank
P4/P5: Backwash pump	F7/F8: Cartridge filter	T8: NaOCl storage tank
P8/P9: High pressure pump	T1: Feed tank	T9/T10: Scale inhibitor tank
P11/P12: Injection pump	T2/T4: Backwash effluent tank	RO1/RO2: SWRO Unit vessel
F1/F2: Disc Filter	T3/T5: Filtrate tank	

Figure 2.1: UF, MMF and SWRO pilot plants

allows a portion of the recirculating flow to be discharged as reject, Periodically, the module is backwashed, using permeate collected in the backwash tank, to remove contaminants from the system and maintain a constant trans membrane pressure (TMP). Chemical dosing of the backwash water can be performed as required to maintain a stable TMP. A chemically enhanced backwash (CEB) is performed on a regular basis to control organic fouling. Effluent from the UF system is fed to the filtrate storage tank and then fed to SWRO2. The UF process flow diagram is shown in Figure 2.1.

2.2.3. RO Pilots

The two seawater reverse osmosis (RO) systems are both housed in a single 40-feet shipping container and are designed to produce potable water from Mediterranean seawater. Each of the two RO systems are capable of producing up to 3.5 gal/min (0.8 m^3/hr) of permeate at a recovery of 35%. Each RO system includes six (6) TFC 4040SW Koch high rejection SWRO membranes. Tables 2.3 and 2.4 summarize the SWRO design parameters and predicted results obtained using Koch's KMS ROPRO 8.04 design software.

Pretreated feed water is pressurized by the individual RO booster pumps and fed through two cartridge filters in series (20 and 5 micron). The feed is then further pressurized by the individual RO high pressure pumps to 1000 psi. The high pressure feed enters the RO pressure vessel, each holding six four inch diameter seawater RO membrane elements in series. Approximately 35% of the feed is recovered as permeate and passes through to the individual permeate flush tanks. Recovery rate of the RO unit is controlled by the individual reject control valves. Upon startup, the motorized reject by-pass valves open allowing feed water to flush through the system to remove any air and ensure that the system is full of freshly pretreated feed water. After a delay set, the reject by-pass valve slowly closes and the recovery rate is manually adjusted to the proper level with the reject control valve. Permeate is diverted by the permeate diversion valves until proper permeate quality is achieved.

Table 2.3: RO membrane specification [6]

Parameters	TFC®- SW membrane
Model	4040 - SW
Permeate flow	4.9 m^3/d
Chloride rejection	99.75%
Active membrane area	6.9 m^2
Feed spacer	0.8 mm

3. Results and Discussion

The most important purpose of the pilot study was to determine whether the quality of the SWRO feed could meet the demands [2]. The turbidity and SDI_{15} for filtrated water produced using Conventional and UF pretreatment systems are an important parameters to control the feed water quality of RO.

3.1. Filtrate Quality of UF

The UF system performance was very well in terms of stable operation as well as filtrate quality. This was demonstrated by the stable flux around 45 (L/m^2 hr) and stable trans membrane pressure (TMP) 0.4 bar of the UF system and also low SDI15, and low turbidity, the SDI15 vary from 0.4 to 2.8 and the turbidity vary from 0.09 to 0.22. The results for the turbidity and SDI_{15} measurements of the UF filtrate are presented in Figures 2.2 and 2.3, respectively. 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 0.22 NTU.

3.2. Conventional Pretreatment Filtrate Quality

The reduction of particulate and suspended solids by conventional pretreatment was achieved by using media filtration. The filtration velocity of the media filters was 0.67 L/hr. Backwash with filtrate water was applied at least once a day, usually after a preset differential pressure across the media filter is reached. The performance evaluation of the conventional pretreatment system showed that the filtrate water quality was generally good with average turbidity 0.33 NTU Figure 2.2, while it is not always capable of achieving SDI_{15} values that meet the requirements set by the RO membrane manufacturer; typically, less than three. The results SDI15 measurements of the media filtrate are presented in Figure 3. It was shown that over 70 % of the conventional media unit SDI_{15} values were over 3.0.

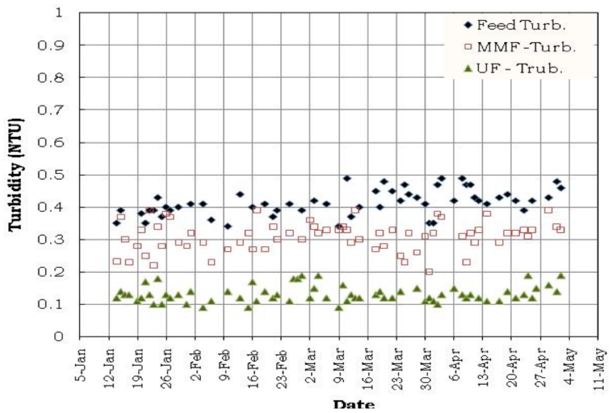


Figure 3.1: Turbidity (NTU) results from the membrane filtration and conventional media pretreatment

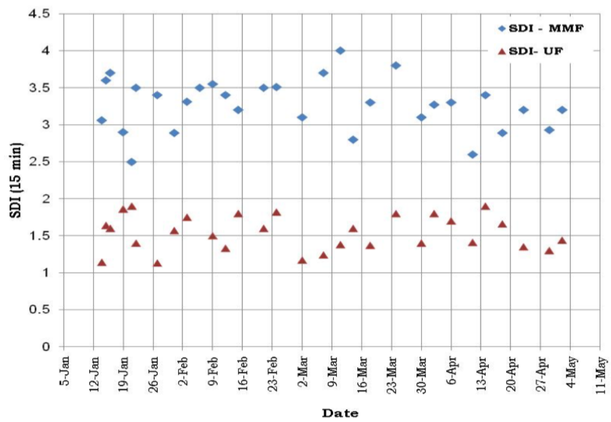


Figure 3.2: SDI_{15} results from the membrane filtration and conventional media pretreatment

3.3. RO Performances

RO membrane pilot was run at a TMP of 50 bar, with a cross flow of 30 L/hr from 1st of January to the end of May Figure 2.4. Two kinds of pre-treated seawater have been fed to the two RO pilots: pretreated seawater by MMF system and pretreated by UF system. In comparison with the result observed from both pretreatment system that the RO loss a little of its permeability within the test period.

4. Conclusion

The main conclusions of these trials are the following:

- Both tested UF membrane and MMF were capable to deliver low turbidity filtrate, regardless of changes in seawater turbidity during the period tested.

Table 2.4: Koch's KMS ROPRO Predicted SWRO system results [7]

Element	Inlet Pressure (bar)	ΔP (bar)	NDP (bar)	Element Flux (LMH)	Permeate TDS (mg/L)
1	59.1	0.2	29.4	27.1	89.6
2	58.9	0.2	26.8	23.7	111.2
3	58.7	0.2	24.1	20.4	138.7
4	58.5	0.1	21.6	17.4	173.9
5	58.4	0.1	19.1	14.7	218.5
6	58.2	0.1	16.8	12.3	274.8
Average			23.7	19.3	167.8

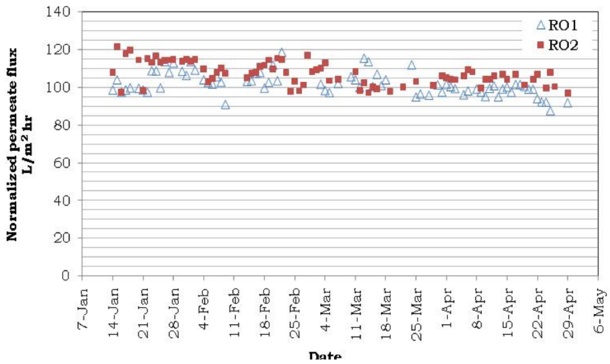


Figure 3.3: Normalized permeate flux results from the operation of RO1 and RO2 pilot plants

- The UF system can perform well in terms of stable operation as well as filtrate quality. This was demonstrated by the stable flux around 45 L/ (m^2hr) and stable TMP 0.4 bar of the system and also low SDI_{15}, low turbidity.
- The UF filtrate quality was better, especially regarding the SDI_{15}, than the filtrate quality monitored at MMF, the UF filtrate was always between 0.09 and 0.22 NTU while the MMF filtrate was 70% more than 3 which reached the maximum allowable value (SDI_{15} less than 3) that recommended by the RO membrane manufacturers
- Ultrafiltration module proved to be perfectly applicable to seawater pretreatment prior to RO processes.
- The RO systems connected to the two pretreatment units showed a stable performance, in terms of normalized flow and normalized salt passage, at a recovery ratio of 35% and at a flux of 110 L/ (m^2hr).

Acknowledgment

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