Desalination and Water Treatment
www.deswater.com

10 (2009) 245–254

1944-3994 / 1944-3986

IMS SWRO Kindasa — Two years of operational experience

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Received 30 September 2008; Accepted 10 August 2009

ABSTRACT

Kindasa Water Services (KWS) derived its name "Kindasa" from the first seawater desalination plant built in Jeddah in the early 19th century. KWS is a limited liability company January 2000. KWS owns and operates desalination plants for supply of water to various industries, compounds etc. Recently KWS has built and is operating sea water reverse osmosis (SWRO) desalination plant in Jeddah Islamic Port with Hydranautics's integrated membranes system (IMS®). KWS has selected hybrid pretreatment system consisting of conventional dual media filtration in conjunction with the latest state-of-the-art ultrafiltration (UF) process to produce stable RO feed water quality that remains unaffected by the seasonal changes of the seawater quality. KWS's SWRO plant is the largest IMS operating already for two years in very difficult water. A pretreatment system was successfully commissioned in June 2006, and reverse osmosis section was commissioned in August–September 2006. There are different views in desalination industry on the use of membrane pretreatment utilizing or upstream of seawater reverse osmosis systems. Up to date unbiased information about real long term operational experience is not available. On the contrary, there are quite a few papers presenting membrane pretreatment as a "magic solution" to reverse osmosis performance problems. Two years of successful operational experience of this large SWRO IMS® working in very difficult raw water conditions has shown that this technology is viable, but it has also shown that this technology still needs proper attention and tuning and can create disappointment on end-user's side if certain design aspects and operational aspects are not properly addressed at the early stage of operation. Information will be provided which shows that close cooperation between technology supplier and user can solve these operational issues. Kindasa SWRO IMS® is designed for product capacity of 25,500 m^3/d at 95% availability. The present plant production is 26,840 m^3/d. The seawater is treated by 8 ultrafiltration racks equipped with Hydranautics HydraCap 60 and downstream by seawater reverse osmosis trains equipped with Hydranautics SWC3 seawater reverse osmosis membranes operating at 50% recovery. Product water is further treated in partial second pass trains utilizing Hydranautics low energy ESPA 2 membranes. The paper presents long term experience, operational data as well as normalized data and discusses all aspects of the plant operation and performance in detail. The plant is a key reference for future development of SWRO plants for difficult waters in the Middle East area as well as for global view of SWRO desalination and serves as "model plant" to demonstrate viability of MF/UF as pretreatment upstream of SWRO.

Keywords: IMS; Ultrafiltration; Pretreatment; Seawater reverse osmosis; Performance

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Presented at EuroMed 2008, Desalination for Clean Water and Energy Cooperation among Mediterranean Countries of Europe and the MENA Region, 9–13 November 2008, King Hussein Bin Talal Convention Center, Dead Sea, Jordan.

1. Introduction

Kindasa Water Services Co. (KWS) built its first private, Phase A (14,000 m^3/d) seawater reverse osmosis (SWRO) desalination plant in 2000 to supply potable water to the Jeddah Islamic Port (JIP) and the industries located in Jeddah Industrial City (JIC).

Based on successful operation of Phase A plant and encouraged by the increasing water demand from existing and new customers, KWS decided to increase its water production capacity. KWS built and is presently operating Phase B1 SWRO desalination plant with design permeate production capacity of 25,500 m^3/d. The plant is equipped with Hydranautics integrated membranes system (IMS®) which includes ultrafiltration (UF) pretreatment followed by double pass reverse osmosis (RO).

Both Phase A and B1 plants are located on the Red Sea coast known for algae bloom. As a result of the algae bloom the operation of Phase A plant, which uses a conventional pretreatment system, becomes unstable and very difficult.

As a result of Phase A plant operational experience, KWS selected a hybrid pretreatment system utilizing both media filtration and the latest state-of-the-art UF process for Phase B1 plant to provide RO with feed water quality that remains unaffected by the seasonal changes of the seawater quality.

KWS's Phase B1 SWRO plant is the largest seawater IMS® operating for two years under very difficult water conditions.

Pretreatment was successfully commissioned in June 2006 and the RO part of the plant commissioning was completed in August–September 2006. The plant has been running at its full capacity since November 2006.

2. Description of the plant

Kindasa Phase B1 SWRO IMS® is designed to produce 25,500 m^3/d of potable water at 95% availability (see Table 1 for the main plant design parameters).

The seawater is treated by the process stages as shown in Fig. 1.

2.1. Intake

Plant intake is located in berth wall of the Berth 39, which is isolated from the open sea. With berth depth of about 15 m, seasonal algae blooms and frequent movement of ships in berth, the water quality in the intake changes quite frequently. Seawater passes through berth wall via 49 holes of 200 mm diameter into a 250 m long intake pipe with a diameter of 1,000 mm.

2.2. Coarse screening

Two screen bars and 2 travelling band screens are installed in the intake chamber prior the intake pumps.

2.3. Intake pumps

Four (3 duty + 1 standby) intake pumps, each with capacity of 954.3 m^3/h, deliver pre-screened water to further treatment steps.

2.4. Chemical conditioning

- Dosing of sulphuric acid — seawater pH is adjusted to 6.7 by dosing of sulphuric acid to produce enough CO_2 required for permeate re-hardening in post-treatment.
- Dosing of calcium hypochlorite for intermittent shock disinfection of pretreatment.
- Dosing of inorganic coagulant ($FeCl_3$) — dosing set exists, but has never been used since the plant start up.
- Dosing of coagulant aid — dosing set exists, but has never been used since the plant start up.

2.5. Media filtration

Five roughing dual media horizontal filters (Fig. 2) filled with filtration sand and pumice operate at filtration velocities of 16–21 m/h.

Fig. 2. Dual media filters.

2.6. Mechanical filtration

Four (3 duty + 1 standby) automatic self cleaning strainers with mesh size of 100 microns to protect downstream UF modules.

2.7. Ultrafiltration (Fig. 3)

- Eight UF racks, each containing 88 Hydranautics HydraCap 60 hollow fibre UF modules with hollow fibre diameter of 0.8 mm and nominal MWCO of 100–150 KDa.
- Dosing of calcium hypochlorite for disinfection backflush (CEB1) at rate of 20 mg/l of free Cl_2.
- Dosing of sulphuric acid for acidified backflush (CEB3).

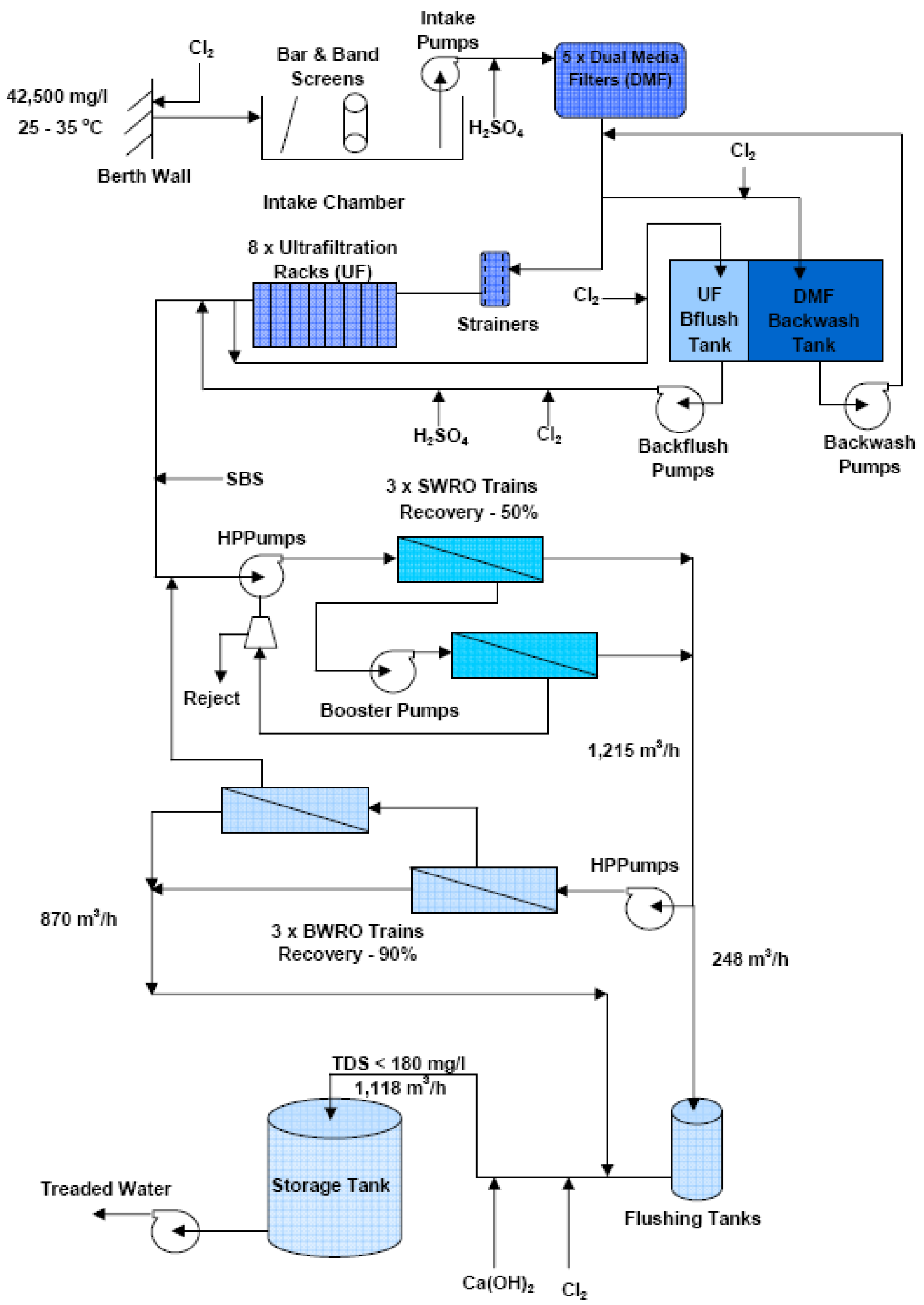

Fig. 1. Kindasa Phase B1 flow diagram.

2.8. Seawater reverse osmosis (Fig. 4)

Three seawater RO trains in two stage configuration, with 87 pressure vessels in the 1st stage and 60 pressure vessels in the 2nd stage. Each pressure vessel houses 6 Hydranautics SWC3 seawater RO membranes. Each SWRO train produces 405 m^3/h of permeate at 50% recovery. Each train is equipped with variable frequency drive on high pressure pump motor and energy recovery turbine for best energy efficiency. A booster pump is used to increase the feed pressure for the 2nd stage membranes.

2.9. Brackish water reverse osmosis

Three brackish water RO trains in a two-stage configuration with 28 pressure vessels in the 1st stage and 10 pressure vessels in the 2nd stage. Each pressure vessel houses 6 Hydranautics ESPA2 low energy membranes.

Fig. 3. Ultrafiltration.

Fig. 4. SWRO trains.

BWRO treats 80% of permeate produced by the SWRO trains. Each BWRO train produces 290 m^3/h of permeate at 90% recovery.

2.10. Post-treatment

Permeate from SWRO and BWRO is blended and post-treated by saturated lime water to increase pH up to 8.5 and adjust LSI to slightly positive value. Calcium hypochlorite is injected for disinfection at the rate of 0.2–0.3 mg/l of free Cl_2.

3. Operational results

3.1. Pretreatment

Hybrid pretreatment combining media filtration and ultrafiltration was selected for Phase B Kindasa plant by KWS to avoid operational problems experienced on their Phase A plant which is equipped with media filtration pretreatment only. The selected combination of filtration technologies was also tested and tuned for 12 months on pilot plant installed on the site during detailed design phase of the project. Although the cost comparison between UF and other conventional types of pretreatment is always in favour of conventional technology in terms of CAPEX (Fig. 5), Kindasa Phase B experience shows that UF together with high velocity filtration is able to continuously produce high and stable feed water quality for downstream RO membranes.

The plant construction began in the 1st quarter of 2004 and pretreatment started to produce first water in June 2006. Since its initial start up, the pretreatment performance confirmed the right choice of technology (roughing media filtration followed by UF) for the difficult seawater conditions present on the site. Even without any chemical conditioning (like coagulant injection), except the pH adjustment required for permeate re-hardening and inhibition of scaling on SWRO, membrane pretreatment supplies excellent and stable feed water for the SWRO plant.

Roughing dual media filters, operating at filtration velocities of 16–21 $m^3/m^2/h$, continuously produce filtered seawater with turbidity average levels of 0.1–0.25 NTU and SDI of 4.5–5.5 for the downstream UF plant. A usual filtration cycle of media filtration is between 48 to 72 h depending on the raw seawater quality.

The ultrafiltration plant was designed to operate at a dead-end filtration mode with the average flux of 90–104 $l/m^2/h$, feed turbidity of 1–10 NTU and transmembrane pressure (TMP) of 1.2 bar. The design filtration cycle was 30 min and CEB1 (chlorinated backflush) frequency was 8–10 h each. Operation of the plant had however confirmed that these values were selected quite conser-

Table 1
Main plant design parameters

Plant capacity at 95% availability, m^3/d	25,500
Seawater TDS, mg/l	42,500
Seawater temperature, °C	25–35
Media filtration velocity, m/h	16–21
Ultrafiltration capacity, m^3/d	56,500
Ultrafiltration flux, $l/m^2/h$	97
Ultrafiltration recovery, %	94
Combined RO recovery, %	47.9
SWRO recovery, %	50
SWRO flux, $l/m^2/h$	13.4
BWRO recovery, %	90
BWRO flux, $l/m^2/h$	34.2
Permeate TDS, mg/l	<250
Permeate chlorides, mg/l	<150
Specific power consumption, kWh/m^3	4.6 of RO permeate

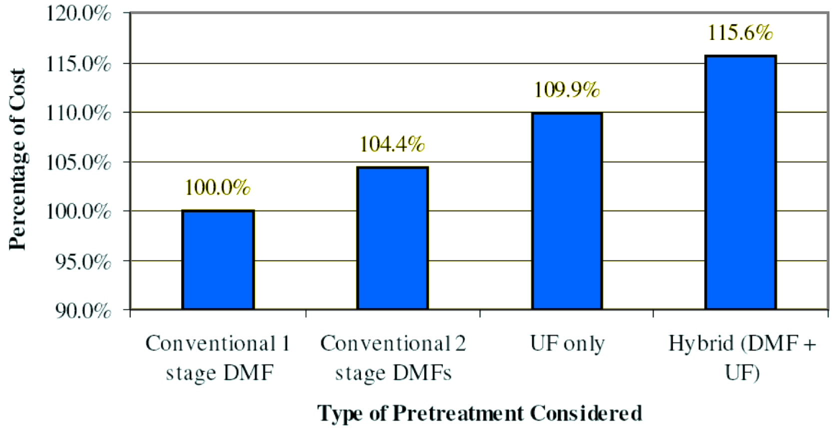

Fig. 5. Kindasa SWRO CAPEX cost comparison for different pretreatment options [3].

vatively. Currently, the UF plant is running with filtration cycles of 70 min with 45 min being the shortest cycle during the worst seawater conditions. The frequency of CEB1 is also much longer than the design, with 20 h at present time. There were periods of difficult seawater quality when filtration and CEB1 cycles had to be shortened due to the increased rate of the TMP rise (Fig. 7). However, they had never been shorter than the design values. From the beginning of the plant operation until March 2008 the average TMP was 0.1–0.2 bar without the necessity of chemical cleaning of the UF modules. As the plant operation was optimized and backflush and CEB1 frequencies extended during the operation, current TMP values reach 0.3–0.5 bar (Fig. 8) without any detrimental effect on the UF performance in terms of flux or filtrate quality. On the other side, extended filtration and CEB1 cycles reduced backflush water and chemicals (calcium hypochlorite) consumption. It is also necessary to underline that during the 2 years of the UF plant operation it was not necessary to use any coagulant injection into UF feed even during the worst seawater conditions.

Quality of the UF filtrate is continuously monitored by online turbidity and SDI meters. Not all turbidity data are available continuously as there were problems with online instrument. Since the beginning of operation the UF plant produces filtrate with the turbidity values of 0.04–0.05 NTU with inlet turbidity values of up to 0.25 NTU (Fig. 6). SDI_{15} of the UF inlet and outlet is also

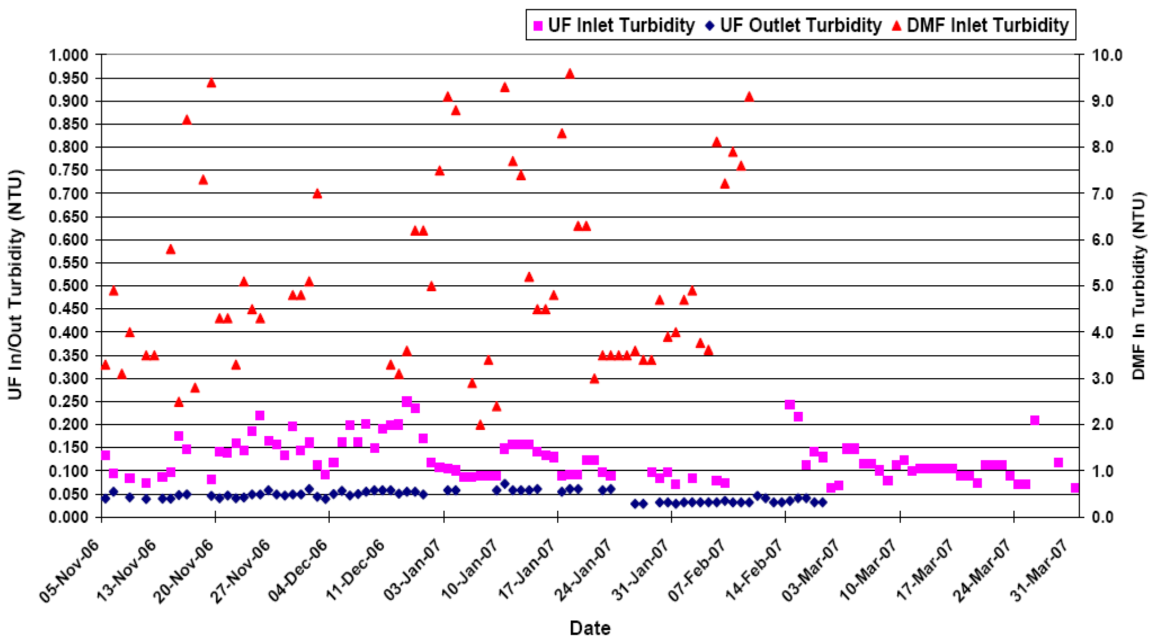

Fig. 6. DMF inlet and UF inlet and outlet turbidity trends.

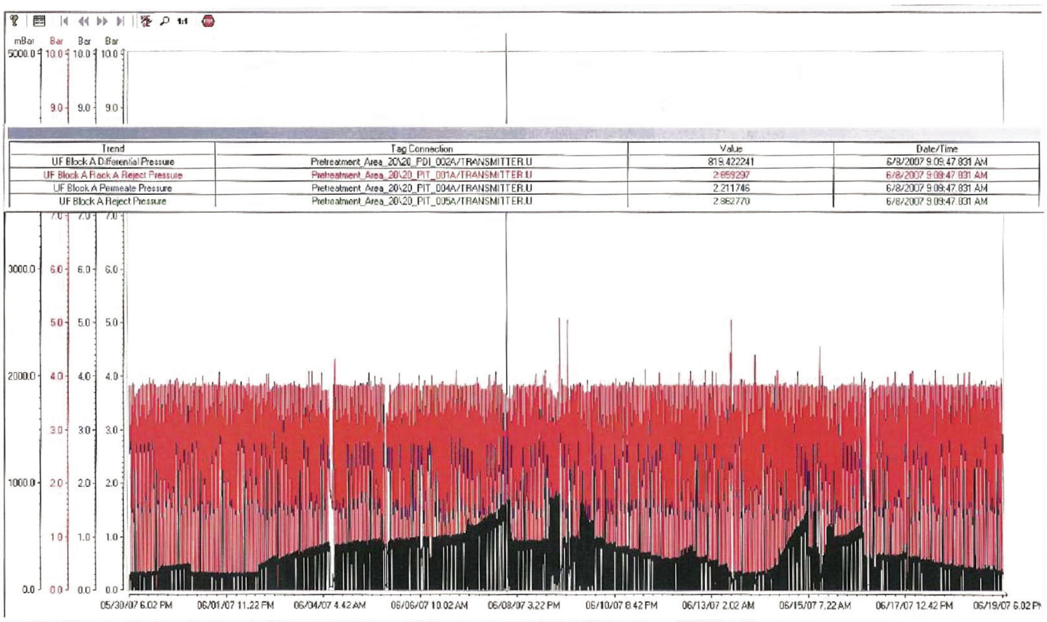

Fig. 7. TMP trend (black colour) on the UF rack A during high seawater turbidity periods in July 2007.

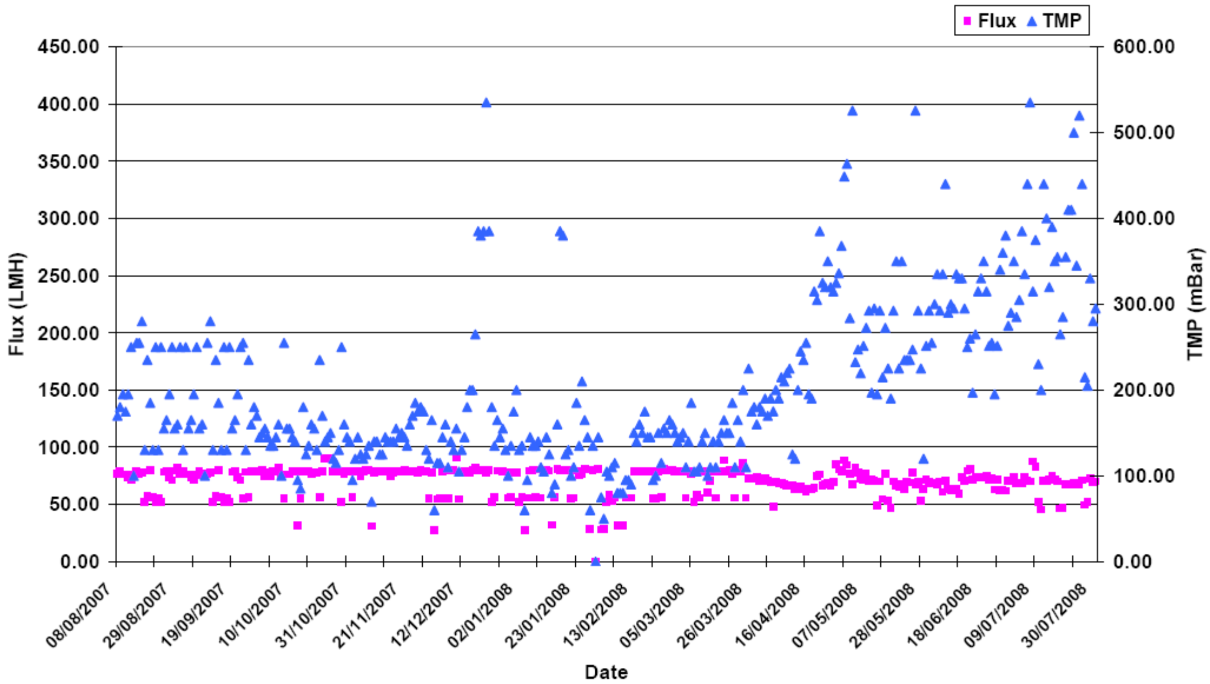

Fig. 8. UF rack A — flux and TMP trends.

monitored with outlet values being most of the time less than 1 and few maximum values not exceeding 3.

Operational recovery of the UF plant is as high as 94.8%, which is above the design value of 94%. The design of the UF plant includes also particle count monitoring of inlet and outlet water, as SDI is not the most appropriate parameter for UF filtrate quality quantification. Unfortunately, the online particle counter has been out of operation since the plant commissioning and no continuous data are therefore available. Particle counts were monitored by a portable device during the pilot testing and full scale plant commissioning and performance test. All measurement results show UF filtrate particle counts of less than 5 particle/ml on 2–5 micron size range confirming that UF is almost a 100% barrier against suspended solids.

Two years of operational results from Kindasa UF plant as pretreatment to SWRO confirmed that this technology is capable of delivering RO feed water with very low turbidity, SDI (Fig. 9) and particle count values, thus completely eliminating particulate fouling of the RO membranes. However, as it will be discussed later on, there are issues necessary to be addressed with UF as RO pretreatment, particularly associated with biofouling of the RO membranes. Although some short-term studies [2] claimed complete elimination of biofouling of the RO membranes when UF pretreatment is used, longer term Kindasa experience is different and more in line with other expectations and theories [3].

3.2. Reverse osmosis

The first SWRO train was commissioned in August 2006 and a complete RO plant has been in operation since October 2007.

Each SWRO train produces the design output of 405 m^3/h. The production is divided between two stages, with the first stage producing 280 m^3/h and the 2nd stage producing 125 m^3/h. Combined permeate quality from both stages is 300–400 mg/l of TDS. Even at operating recovery of 50% there is no need for additional antiscalant injection, as feed water is acidified to pH of 6.5–6.7 in pretreatment. Performance of the SWRO trains is stable since the start-up in terms of production and permeate quality as it can be seen from Figs. 10–13.

At the beginning of the SWRO plant operation, there was almost no fouling of membranes present for the first three months of operation and SWRO was running at very stable differential pressure conditions.

In December 2006, when seawater intake chlorination was introduced with weekly frequency, the differential pressure started to rise rapidly which resulted in the first cleaning in March 2006 after 6 months of operation and a number of chemical cleanings during the following operating period.

Hydranautics together with KWS have been working very closely to bring fouling under control, which resulted in a number of operational changes on pretreatment:

- change in the frequency of pretreatment disinfection
- change in the type of pretreatment disinfectant
- change in the frequency of UF CEB1
- other operational changes on UF

As it can be seen from differential pressure behaviour (Fig. 13), the situation was improved and partially stabilized and further steps are being implemented to keep it under control. Kindasa experience has confirmed so far that although the UF is a perfect barrier against inorganic particles and large molecular organic matter, however it does not provide the same barrier to small organic matter responsible for biofouling of the RO membranes.

Partial 2nd pass BWRO trains treat 80% of SWRO product to meet the required final product quality. Each BWRO train delivers 290 m^3/h of high purity permeate

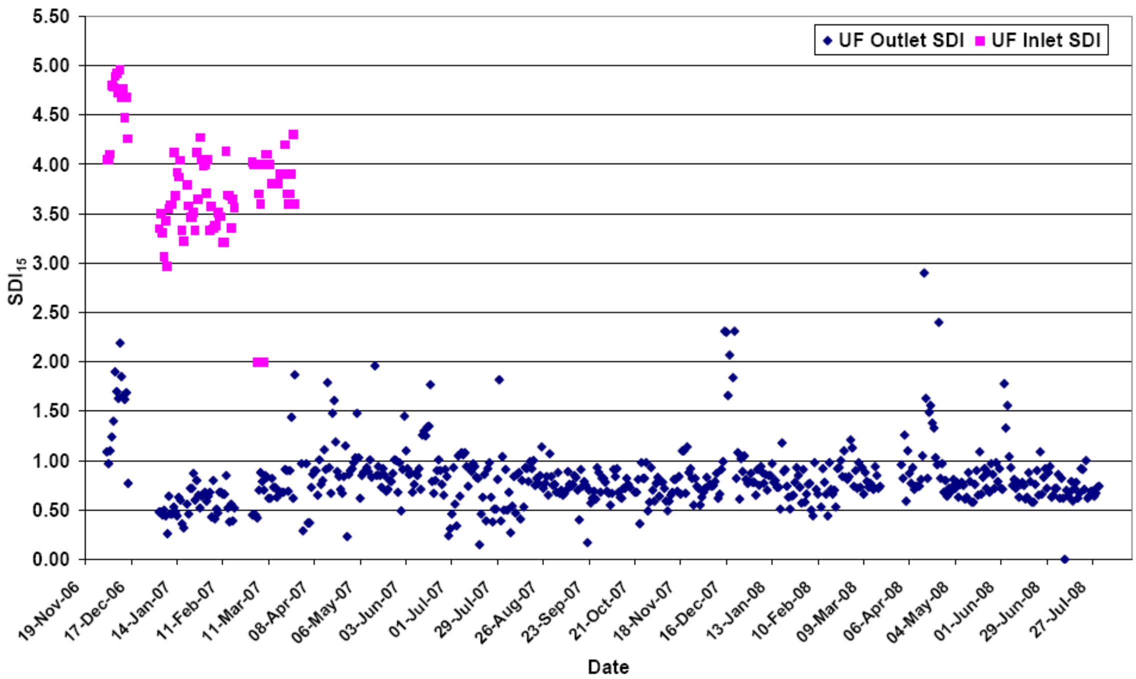

Fig. 9. UF inlet and outlet SDI trends.

RO program licensed to:	Dr. Stefan Rybar					
Calculation created by:	SR					
Project name:	Jeddah KWS			Permeate flow:	404.00	m3/hr
HP Pump flow:		809.7	m3/hr	Raw water flow:	777.5	m3/hr
Recommended pump press.:		62.7	bar	Booster pump pressure:	14.7	bar
Feed pressure:	58.6 bar	60.0	bar	Permeate recovery ratio:	49.9	%
Feedwater Temperature:		27.3	C(81F)			
Feed water pH:		6.7		Element age:	1.9	years
Chem dose,ppm (100%)		29.3	H2SO4	Flux decline % per year:	8.0	%
Acidified feed CO2:		24.9		Salt passage increase, %/yr:	8.0	
Average flux rate:		13.3	lm2hr	Feed type:	Seawater - open intake	

Stage	Perm. Flow m3/hr		Flow/Vessel Feed m3/hr	Flow/Vessel Conc m3/hr	Flux l/m2-hr	Beta	Conc.&Throt. Pressures bar	bar	Element Type	Elem. No.	Array
1-1	273.3	273.4	9.3	6.2	15.2	1.04	58.5	1.0	SWC3	522	87x6
1-2	131.3	130.7	8.9	6.8	10.6	1.03	71.4	1.0	SWC3	360	60x6

Projected dP is 1.5 bar in 1st and 1.5 bar in 2nd stage. Real dP is 2.95 bar in 1st and 1.71 bar in 2nd stage

Ion	Raw water 1 mg/l	Raw water 1 meq/l	Feed water 1 mg/l	Feed water 1 meq/l	Permeate 1 mg/l	Permeate 1 meq/l	Concentrate 1 mg/l	Concentrate 1 meq/l
Ca	440.9	22.0	423.9	21.1	1.08	0.0	844.9	42.1
Mg	1506.9	124.0	1448.7	119.2	3.70	0.1	2887.9	237.7
Na	12800.0	556.5	12353.5	537.1	151.20	1.6	24507.0	1065.5
K	427.0	10.9	412.6	10.6	6.31	0.0	817.3	21.0
NH4	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0
Ba	0.000	0.0	0.000	0.0	0.000	0.000	0.000	0.0
Sr	0.000	0.0	0.000	0.0	0.000	0.000	0.000	0.0
CO3	0.6	0.0	0.2	0.0	0.00	0.0	0.3	0.0
HCO3	145.2	2.4	113.2	1.9	2.28	0.0	223.7	3.7
SO4	3800.0	79.2	3681.1	76.7	10.34	0.0	7337.2	152.9
Cl	22397.3	631.8	21606.9	609.5	242.17	1.6	42886.4	1209.8
F	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0
NO3	8.0	0.1	7.9	0.1	0.65	0.0	15.1	0.2
B	5.00		5.03		2.36		7.69	
SiO2	1.3		1.3		0.01		2.5	
TDS	41532.2		40054.2		420.1	328.0 mg/l	79530.0	
pH	8.0		6.7		5.2		7.0	

Fig. 10. SWRO Train A — startup vs. projected values.

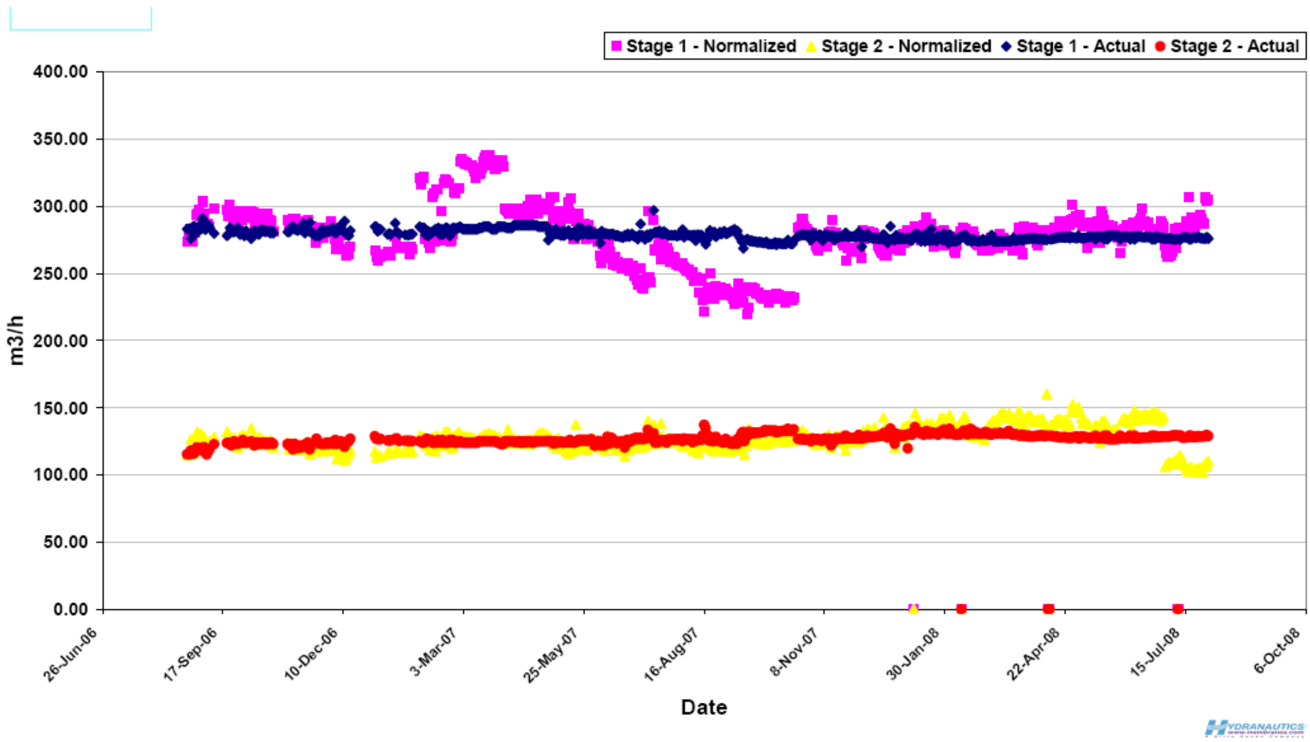

Fig. 11. SWRO Train A — comparison of normalized and actual permeate flow.

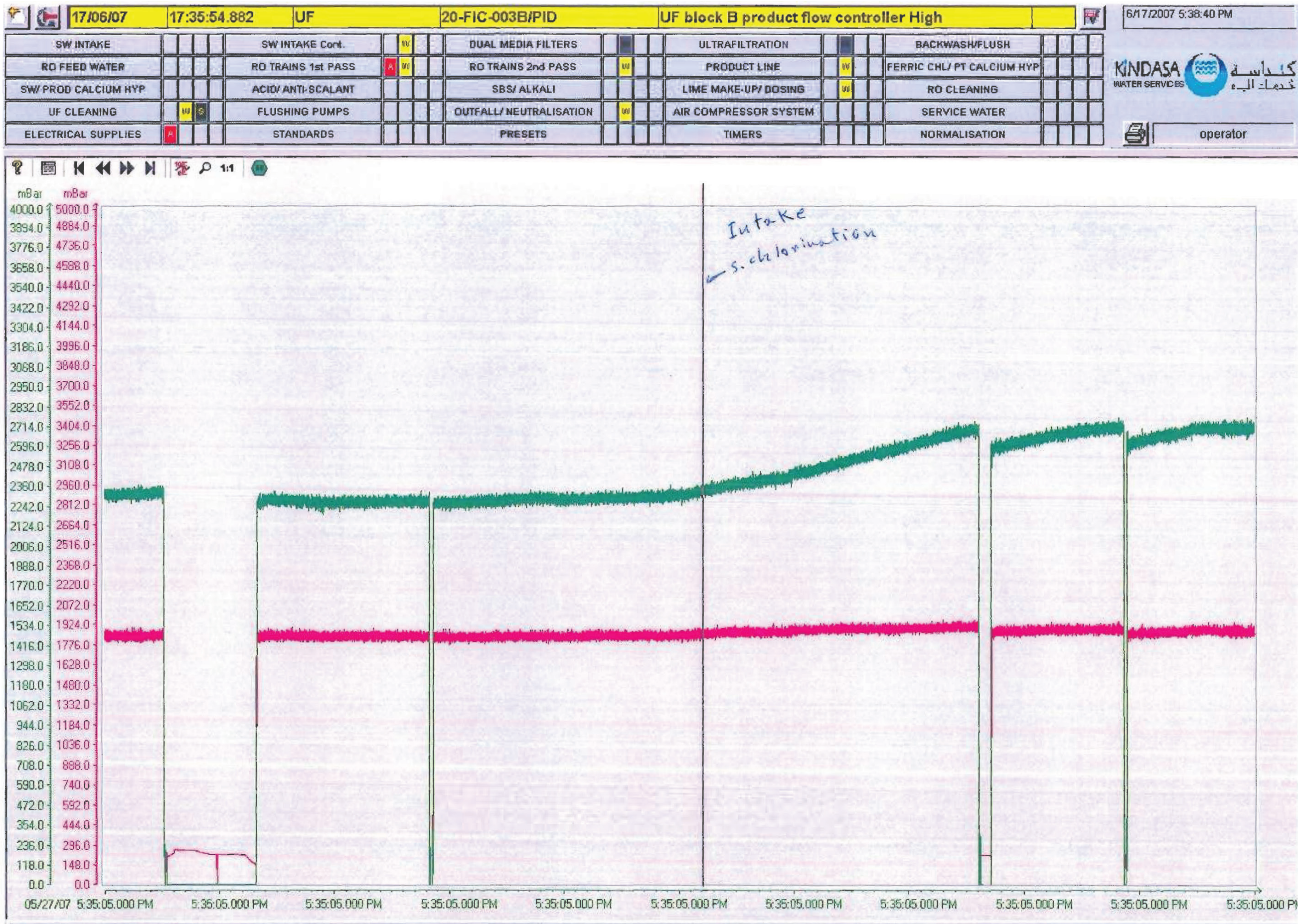

Fig. 12. SWRO A — differential pressure trend on the 1st (green) and the 2nd (red) stage before and after pretreatment shock chlorination in June 2007.

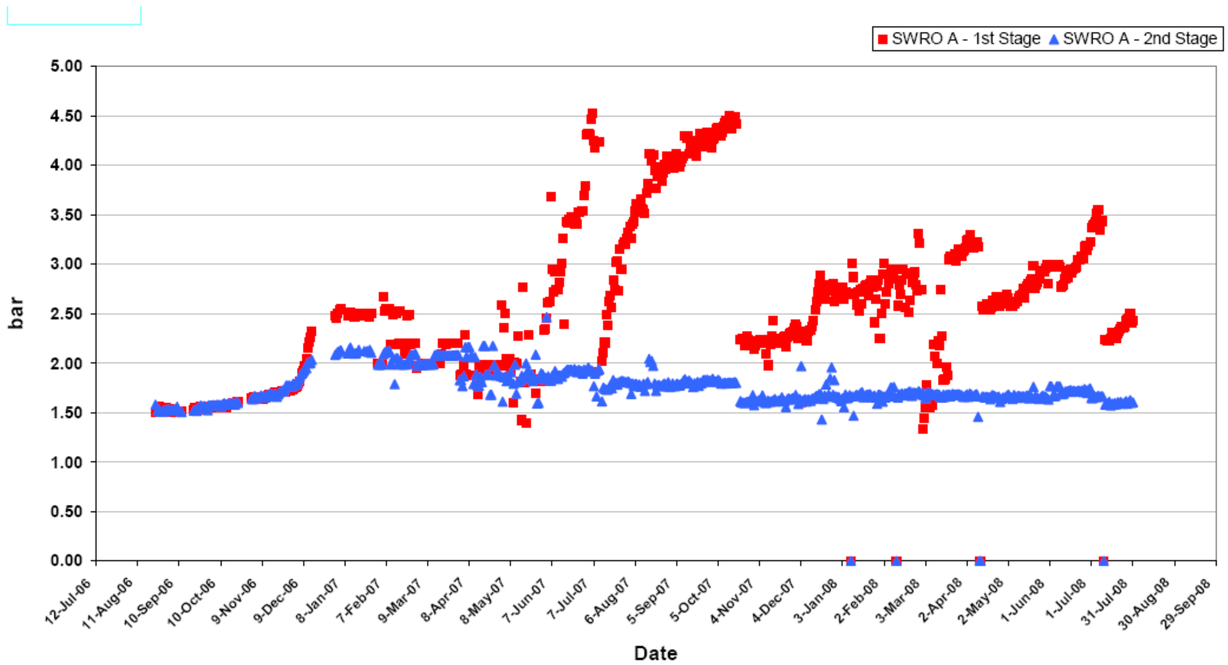

Fig. 13. SWRO Train A — normalized differential pressure trend.

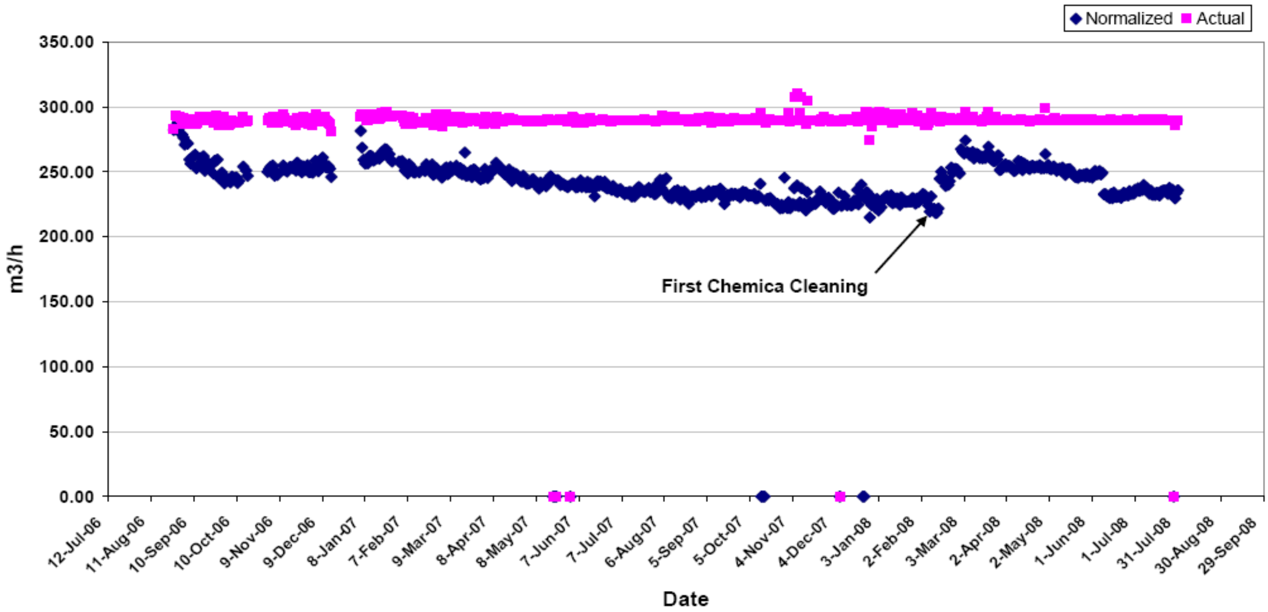

Fig. 14. BWRO Train C — comparison of normalized and actual permeate flow.

at a recovery of 90% and TDS concentration of 5–10 mg/l. BWRO trains were cleaned just once in February 2008 during 2 years of operation. The reason for cleaning was the increase in feed pressure and a declining trend on normalized permeate flow during the long term operation as a result of biofouling.

Concentrate from BWRO trains is recycled back to the feed of SWRO trains to boost thr overall RO plant recovery to 47.9%.

The permeate from both SWRO and BWRO plants is blended to obtain required final product quality of less than 250 mg/l TDS. The plant currently produces 26,800 m^3/d of high quality permeate at availability of 98%. The plant is capable of producing its design output at a specific power consumption of 4.6 kWh/m^3 of permeate water.

4. Conclusion

The performance results of Kindasa Phase B1 desalination plant during the first two years of operation confirm that IMS® design, in this case combined with dual media filtration, is an effective and feasible solution for SWRO desalination plants even at such a difficult location as the Jeddah Industrial Port.

The plant has been in operation for 2 years without the necessity of any chemical cleaning on the UF modules. Pretreatment is providing excellent feed water quality concerning parameters like SDI, turbidity or particle counts for RO plant without the use of any coagulants and coagulant aids despite many times difficult seawater quality with turbidity values reaching 10 NTU. However, biofouling on downstream RO membranes has shown that UF pretreatment is not a universal solution for any type of fouling.

The RO system continuously delivers the product water with quality and quantity better than the design. There are ongoing issues with biofouling on the RO membranes, but the reasons are understood and measures are discussed and implemented step by step to keep the fouling under control.

As the Kindasa SWRO plant is entering its 3rd year of operation, preparations are already under way to extend its capacity by addition of the 4th RO train and two UF racks as a result of successful IMS® operation.

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