Ultrafiltration Pre-treatment to RO: Trials at Kindasa Water Services, Jeddah, Saudi Arabia

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Abstract

Kindasa Water Services (KWS) currently operates an RO facility at Jeddah Port on the Red Sea in Saudi Arabia, using conventional pre-treatment, to provide a 14 mld output. Due to an increasing requirement for treated water services, a contract has recently been placed with Weir Westgarth for a new desalination facility to expand the capacity of RO treated water from 14 to 40.5 mld (3.7 to 10.7 MGD).

The original system has operated well for most of the time since it was brought into supply in 2000. However, occasional poor quality conditions have occurred during storms, or periods of algal bloom, which have resulted in SDI's to the RO exceeding target levels. Accordingly, an interest was expressed in utilizing Ultrafiltration (UF) as an alternative to conventional pre-treatment, to improve RO feed quality, and guarantee on-stream time.

The UF trial was highly successful in achieving stable membrane permeability and a consistent filtrate SDI when operated under optimized process conditions. Utilizing ferric chloride dosing, with acidification, the trial has operated at a flux of 95 lmh, and at a transmembrane pressure of 0.15-0.20 bar. The recovery was 94%.

An average SDI of 2.2 has been obtained in the UF filtrate, approximately 2 units better than the existing conventional treatment. By utilizing an Air Enhanced Backwash on a daily basis, the trial has shown that filtrate SDI's of less than 3.0 can be obtained at all times, even under the poor feed quality conditions that occur during algal blooms.

Hydranautics has gained experience with UF pre-treatment to RO in 3 other case studies in the Gulf of Mexico, the Red Sea, and the Mediterranean. In each case, UF was demonstrated to provide excellent pre-treatment to RO, with no RO cleaning required in 6 month trial periods. In addition, the Integrated Membrane System guarantee offered by Hydranautics for the UF-RO system minimizes process risk for all parties.

This paper will review the data from the UF trial at Kindasa, and from the three other case studies mentioned above. The benefits for the RO facility at Kindasa will be quantified with regard to both technical and commercial parameters.

1. INTRODUCTION

Kindasa Water Services (KWS) operates an RO system with conventional pre-treatment and Hydranautics seawater membranes at their facility at Jeddah Port, Saudi Arabia. KWS now plan to expand their RO facility using capillary Ultrafiltration (UF) as an alternative to conventional pre-treatment.

This report describes a one year trial, starting in March 2002, to demonstrate the feasibility of treating the seawater with Hydranautics' HYDRAcap UF technology. The pilot trial rig has been supplied and operated by Kalsep, a Hydranautics subsidiary with extensive UF systems experience, based in the UK.

The trial has been operated by and Kindasa Water Services (KWS), with the scientific assistance of Bushnak, an engineering consultant based in Jeddah.

The trial has been carried out in three phases:

Phase1: 26th March – 17th July 2002

In the first phase of the pilot program, the feed for the UF trial rig was taken from the current feed to the Dual Media Filters (DMF), post acidification and ferric dosing. The feed was therefore optimized for conventional pre-treatment.

Phase 2: 29th July – 31st Oct 2002

At the end of June, the decision was taken by KWS to dose polyelectrolyte into the DMF feed. Since this would not be suitable for the standard 0.8 mm UF fiber, and was not necessary for performance enhancement of the UF, it was decided to relocate the trial rig to the feed intake of the Water Treatment Works. This had the additional advantage that the dosing conditions could be independently optimized for UF operation.

Phase 3: 1st Nov – 12th March 2003 (ongoing)

In the third phase of the trial, the seawater was fed to the UF unit without $FeCl_3$ dosing.

2. EXPERIMENTAL

A trial rig consisting of feed tank, feed pump, 80 micron manual strainer, 40" HYDRAcap module, backwash tank and backwash pump has been used for the trial. The module has a membrane area of $30m^2$ and the fiber diameter is 0.8mm. During filtration the water flows from the inside to the outside of the fibers and contaminants build up on the inner surface. Figure 1 shows a PFD for the pilot.

Figure 1: Process Flow Diagram

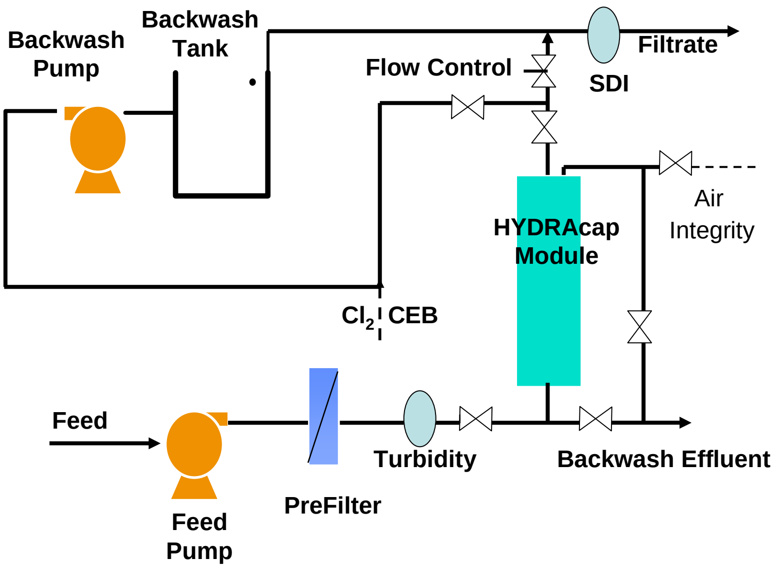


Figure 2 shows details of the module, with one quarter of the right hand end cap cut away.

Figure 2: HYDRAcap Module

Periodically, the module is backwashed, using permeate collected in the backwash tank, to remove contaminants from the system and maintain a constant TMP (transmembrane pressure). 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 with 20 ppm Cl_2 to control organic fouling, particularly by algae.

At the start of phase 2 and during phase 3, an additional CEB was employed based on the following protocol: Caustic/Cl2 CEB (pH12.5 / 50 ppm Cl2) followed by acid CEB (pH 1.5 – 2.0).

From time to time, and air enhanced backwash is utilized to improve the removal of solids from the fiber. This procedure is carried out automatically on production units, but has to be carried out manually on the pilot rig. A summary of the Directflow Process Sequence is shown in Figure 3.

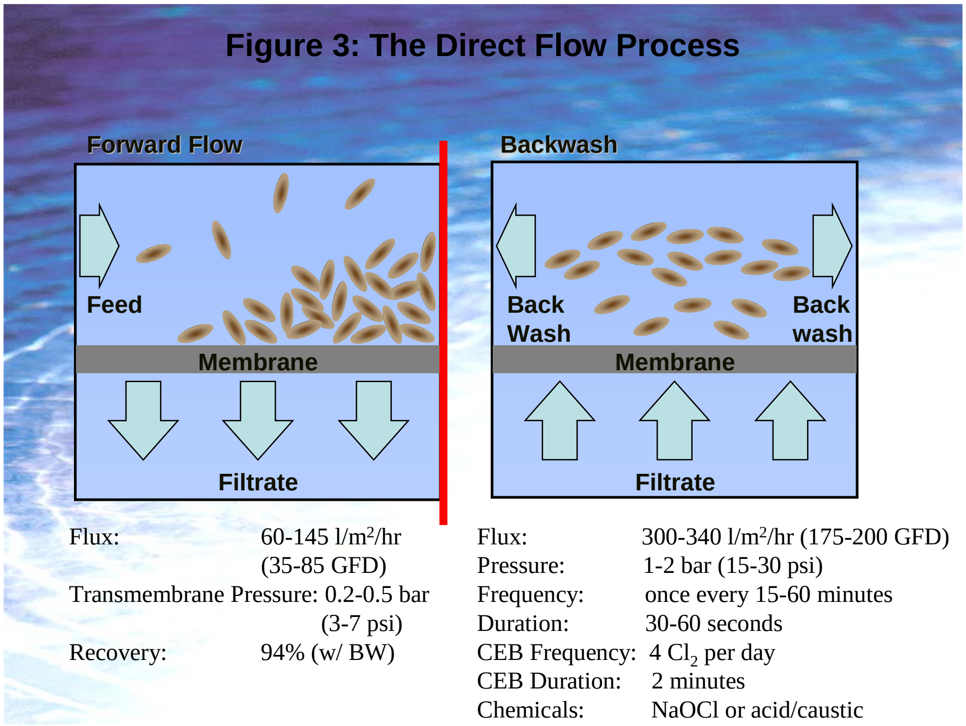


Figure 3: The Direct Flow Process

Flux: 60-145 l/m^2/hr (35-85 GFD)
Transmembrane Pressure: 0.2-0.5 bar (3-7 psi)
Recovery: 94% (w/ BW)

Flux: 300-340 l/m^2/hr (175-200 GFD)
Pressure: 1-2 bar (15-30 psi)
Frequency: once every 15-60 minutes
Duration: 30-60 seconds
CEB Frequency: 4 Cl_2 per day
CEB Duration: 2 minutes
Chemicals: NaOCl or acid/caustic

2. RESULTS AND DISCUSSION

During the trial, inlet feed turbidity has averaged 4.5 NTU, and normally varied in the range 3-6 NTU, though storms can increase the turbidity to 10 NTU.

When algae blooms occurred in May, June and September, the turbidity increased to 5-6 NTU. With no algae bloom, turbidity ranged from 3-4 NTU. After ferric chloride dosing, the turbidity fell to approximately 1-2 NTU.

The pre-treatment conditions for Phase 1 are shown in Table 1:

Table 1: Phase 1 Dosing Conditions

Ferric Chloride dosage, as Fe Cl_3	2 ppm
as Fe	0.7 ppm
Acidification	pH 6.7

During phase 2 pre-treatment a chemical trial was initiated aiming at reducing the Fe dosing level.

The following steps were evaluated;

- No Ferric dosing, no acidification
- Ferric dosing at 0.1ppm, no acidification
- Ferric dosing at 0.1ppm, with acidification

These experiments all resulted in rather rapid fouling of the membrane.

In further evaluations, after 1st Sept, it was found that a minimum dosing concentration of 0.3 ppm, together with acidification to pH 6.7, represented the optimum for stable permeability , such as had been shown in Phase 1 with significantly higher dosing rates (Fe at 0.7ppm).

The contact time prior to UF has been a nominal 20 minutes for Ferric dosing. However, the feed tank was not baffled, so some short circuiting could have occurred.

During Phase 3, ferric dosing was discontinued, and backwash and cleaning frequencies were optimized to control TMP increase.

3.1 Membrane Operating Conditions

The following operating parameters were employed throughout all three phases of the trial:

Table 2: Membrane Operating Parameters

Average Flow Rate (Flux)	2.85 m^3/hr (95 lmh)
Filtration Time	30 minutes
Backflush Flow Rate (Flux)	9 m^3/hr (300 lmh)
Backflush Duration	20 seconds
Backflush down-time	< 1 minute
Disinfection Backflush	Every 6 hours
Hypochlorite dosage concentration	20 ppm
Disinfection Soak Time	2 minutes

A chlorinated backflush was used for every backwash during the first few days of operation in phase 1, i.e. once every 30 min, but this frequency was found to be unnecessary. The CEB frequency was then reduced to once every 12 backwashes, i.e. 4 times a day. This resulted in an improvement in recovery due to the saving in soak time, and a substantial reduction in rinse volumes (since the UF filtrate needs to meet RO feed specs in terms of Cl_2 residual).

Provision had been made in the pilot operation for acid CEB’s to control ferric fouling, and caustic CEB’s to combat algal fouling. However, no acid or caustic CEB’s were required, during optimized feed dosing. An air enhanced backwash (BF2) has been used intermittently (initially once per week during phase 1, but increased to once per day during phase 2) to remove any build up of particulates in the fiber lumen.

During phase 3, air enhanced backwash frequency was increased to once per day, combined with a weekly caustic/citric CEB.

3.2 Performance

The UF performance for Phase 1 and for Phase 2 after 1st Sept is summarized below:

Table 3: Flux and TMP for Optimized Dosing Conditions

Average Flux	95 l/m^2.hour
Average TMP	0.15 – 0.20 bar

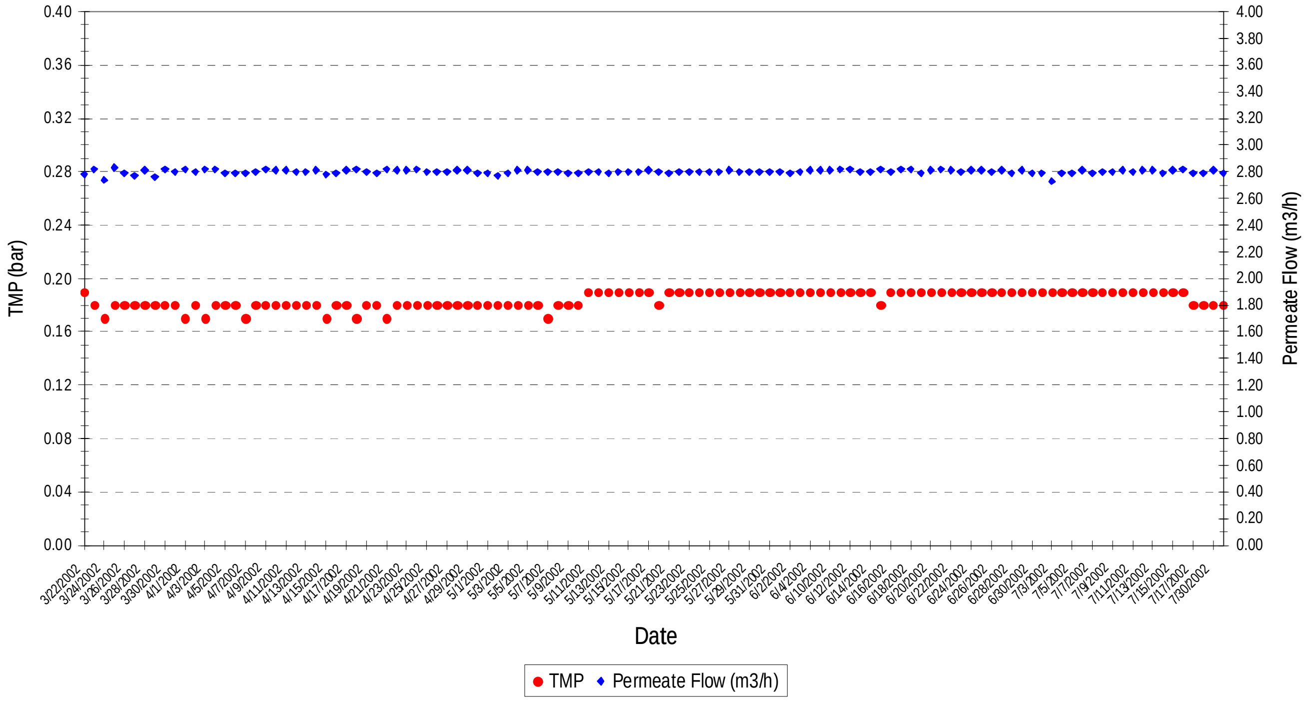
During phase 3, the flux was maintained at 95 lmh, whilst TMP increased from 0.2 to 0.4 bar between weekly caustic/citric CEB's.

The recovery associated with the operating parameters listed above is 94%.

3.3 Flux and Transmembrane Pressure(TMP)

Stable flux and TMP have been achieved throughout phase 1, and during phase 2 from 1st September onwards, as shown in Figures 4 and 5. In phase 1, the concentration as Fe was 0.7 ppm. In phase 2 this was reduced to 0.3 ppm. The total time of completely stable operation has been 6 months, with no chemical cleaning, other than chlorinated back flushes 4 times per day.

Figure 4: TMP vs Permeate Flow
Phase 1: March - July 2002



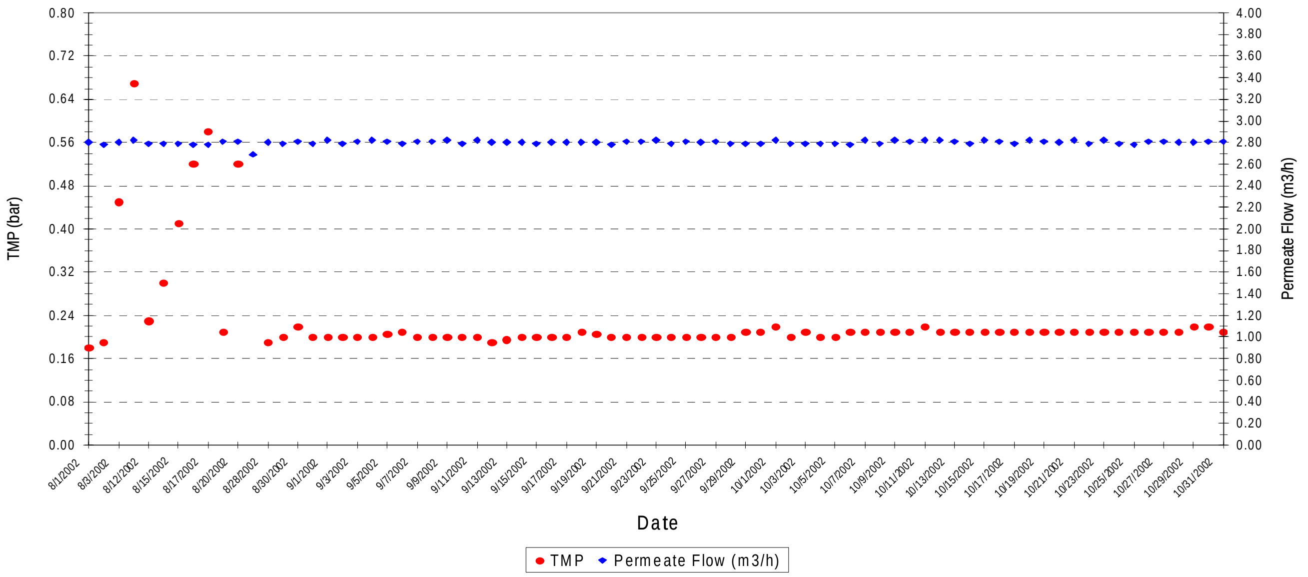
The FeCl3 nominal contact time employed during the trial has been 20 minutes. This value has not been optimized, since it can be easily accommodated in the proposed main plant design.

Flux and TMP have not varied with changes in feed quality.

At the start of phase 2, no dosing was employed, which resulted in an immediate and dramatic rise in TMP. However, the baseline TMP was readily restored to the original value by a standard CEB cleaning sequence, which has been designed on the main plant to be carried out automatically if the TMP rises.

Figure 5: TMP vs Permeate Flow

Phase 2: August - October 2002

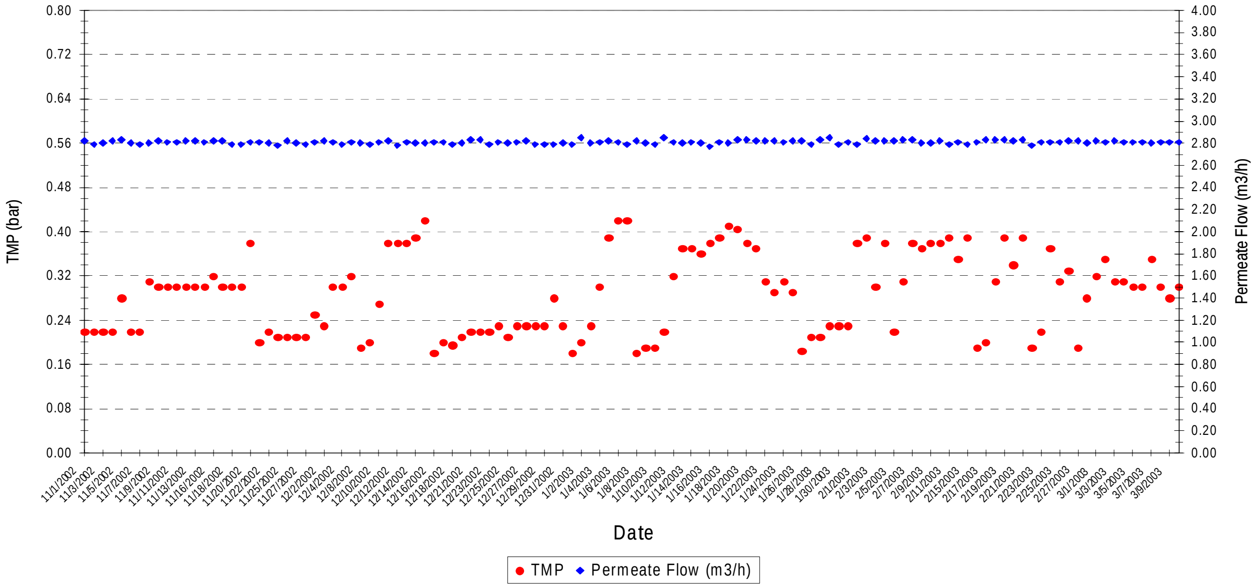


After the absence of dosing at the start of phase 2, low non-optimized dosing was tried. Again TMP rose, though not quite as quickly as in the no dosing case. Baseline TMP was again restored by CEB's. It was demonstrated that the optimum minimum dosing concentration is 0.3 ppm Fe, together with acidification to pH 6.7, for stable permeability.

Figure 6 illustrates flux and TMP during phase three, in which no $FeCl_3$ dosing was employed. By increasing air enhanced backwash frequency to once per day, and the standard caustic/citric CEB frequency to once per week, the rise in TMP was limited to an increase from 0.2 bar to 0.4 bar, with the 0.2 bar baseline TMP re-established after each clean.

Figure 6: TMP vs Permeate Flow

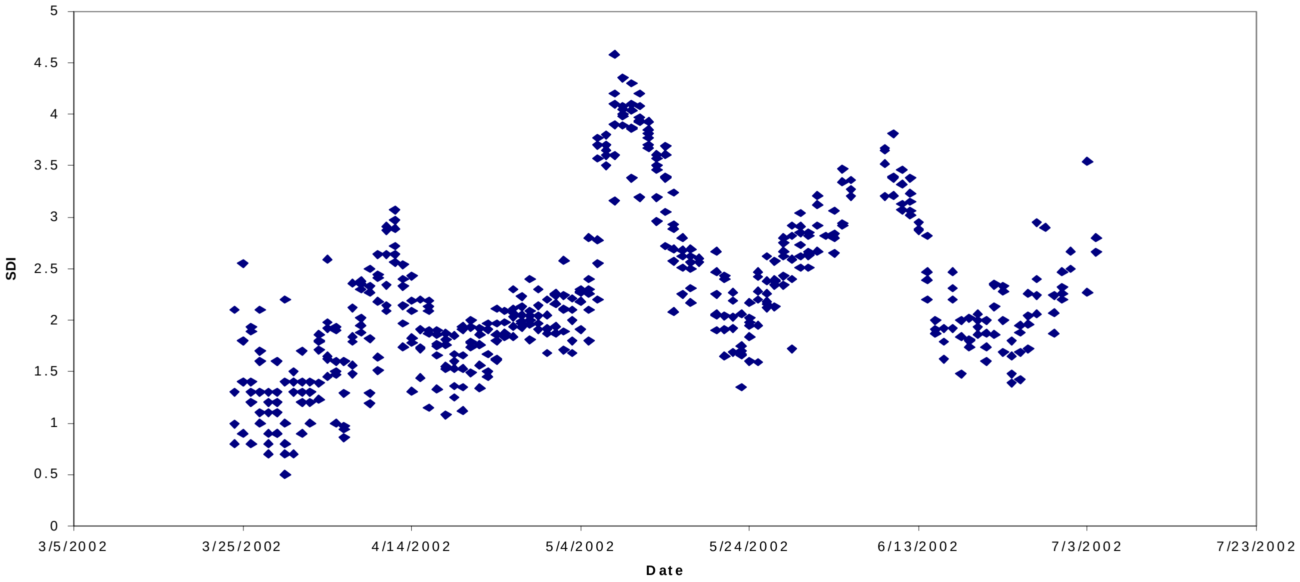
Phase 3: November - March2003



3.4 Filtrate SDI

The filtrate quality during the trial has been monitored by measuring the SDI. Figure 7 shows SDI values during phase 1. The arithmetical average of all SDI values has been 2.2, with 85% of values falling below 3.0.

Figure 7 SDI After UF
Phase 1: March - July 2002



SDI values in the filtrate show some variation during the trail for several reasons. At the start of the trial, values were low, typically <2.0. However, within 2 weeks, values rose towards 3.0. On 9th April, an air enhanced backwash (ARBT) was carried out, without air pressurization, which resulted in a significant reduction in SDI values.

For the next month, SDI remained at approx 2.0, but then the first algae bloom of the year occurred in early May, resulting in a sudden sharp rise in SDI. On approx the 11th May, a second ARBT was performed, again resulting in a sharp decline in filtrate SDI. Algae were again present in June, as evidenced by a sustained elevated turbidity; a third ARBT on 8th June reduced SDI from approx 4.0 to 2.0.

The sequence of events during the Phase 1 trial illustrated the importance of ARBT in maintaining the lowest possible filtrate SDI. Without it, solids build up in the fiber, and eventually, filtrate SDI increased. If ARBT's were carried with sufficient frequency, this SDI increase could have been avoided.

The sporadic frequency of ARBT during the trial was due to the fact that they had to be carried out manually, and the timing with which they were performed was variable. In the main plant design the ARBT has been designed to be carried out automatically; and it has been concluded that an appropriate frequency would be daily, particularly during algal blooms. At this frequency, there would be no measurable reduction in overall plant recovery.

During Phase 2, a further important observation has been made; the Phase 1 ARBT was carried out with a simple drain down of the fiber lumen. However, in Phase 2, the lumen has been pressurized with 1 bar air pressure at the end of the drain down (identical to the main plant ARBT process). It has been observed visually that the air pressurization displaces more solids than the simple drain down used in phase 1, thus enhancing efficiency.

In consequence of the discussion above, it is clear that an optimized main plant process, with a daily ARBT, would consistently achieve an average filtrate SDI of 2.0 or less, with all values below 3.0, since the only values above 3.0 in a year of operation were those where an ARBT operation was clearly required.

It is also interesting to note that during troubled operation in August in terms of flux and TMP stability, filtrate SDI remained low.

During phase 1, the DMF filtrate SDI was normally between 4.0 – 4.5, with excursions above 5. A comparison of DMF and UF filtrates for a 15 day period in phase 1 is shown in Figure 8. The UF filtrate was approximately 2 SDI units lower than the DMF.

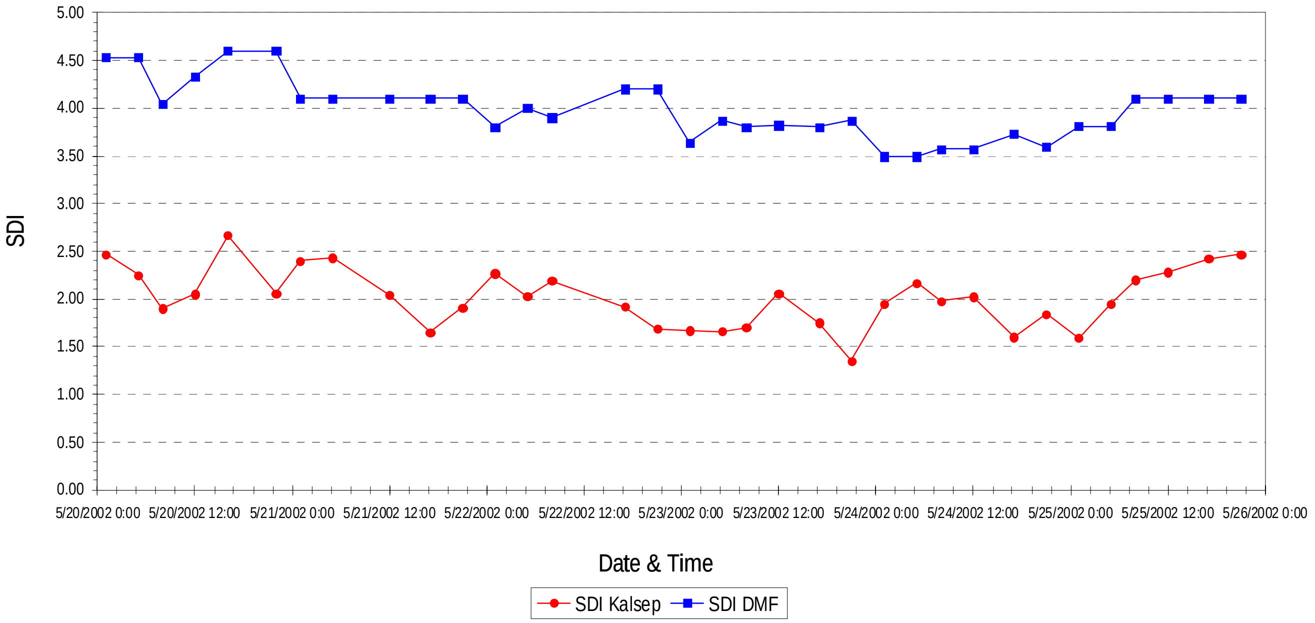


Figure 8 SDI: UF vs DMF
20 - 25 May 2002

Figure 9 shows the relationship between SDI and the amount of foulant present in the feed. The data is taken from an experimental study reported in a paper presented at the IWA Conference in 1998 (Ref 1). The data show that SDI is related to the amount of fouling material by an exponential function; thus a reduction of SDI from 5.0 to 3.0 represents a reduction in foulant of 75%. Therefore UF achieves an important advantage over DMF by keeping SDI’s below 3.0.

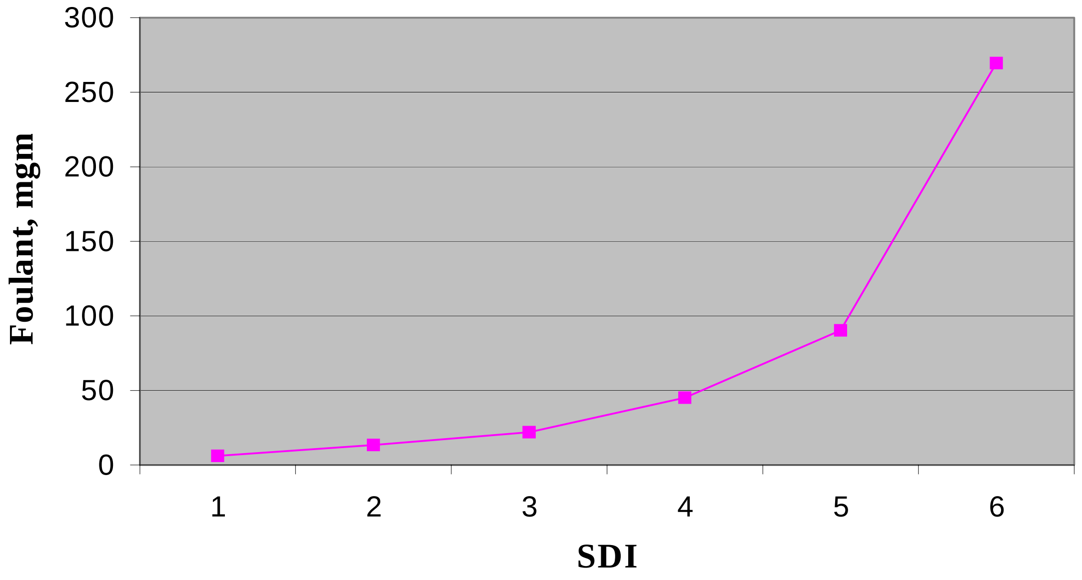


Figure 9 Foulant vs SDI

3. UF-RO EXPERIENCE

Figures 10 – 12 show the results of three RO case studies that have been carried out with Hydranautics UF and RO membranes, and summarizes the benefits of UF pre-treatment to RO operation.

The first of the three studies was carried out at Tampa Bay, on a low salinity, highly organic feed in the Gulf of Mexico. The UF enabled the RO to be run at much more aggressive flux and recovery than conventional pre-treatment. RO was run for 3 months on UF filtrate without cleaning.

Fig 10 Case Study 1: Tampa Bay, Gulf of Mexico

Feed Conditions

TDS	15,000 – 28,000 ppm
Turbidity	1 - 10 NTU (3 – 4 NTU av)
Temp, deg C	15 – 32 deg C

RO Design – Post UF

- Flux: 20.4 lmh (12 gfd)
- Recovery: 65%
- Membrane replacement: 10%

RO Design – Post Conventional (DMF)

- Flux: 13.6 lmh (8 gfd)
- Recovery: 35-50%
- Membrane replacement: 15%

RO Pilot Operation post UF

- 3 months without cleaning on an 8 element vessel
- 20.4 lmh (12 gfd) flux, and 65 % recovery confirmed

The second and third studies were carried out by MEDRC at the Red Sea and Mediterranean Sea, with feeds similar in temperature and salinity to Kindasa, but with water quality either side of the Kindasa quality (Ref 2). The Red Sea study was carried out at Eilat.

Fig 11 Case Study 2: Red Sea

Feed Conditions

- TDS 42,000 ppm
- Turbidity 0.2 – 1.1 NTU
- Temp, deg C 20 – 30

UF Pilot Operation

- Test operated Sept 1998
- 12 months, stable operation

RO Pilot Operation

- 6 months without cleaning on an 8 element vessel
- 19 lmh (11 gfd) flux, and 55 % recovery confirmed

UF-RO trails were carried out at each location for 6 months without cleaning. In comparison to conventional pre-treatment trials operated in parallel, RO performance benefited from more aggressive RO design parameters, and improved on-stream time for the RO during storms, when the conventional pre-treatment failed to meet the guaranteed RO feed SDI of 5.0 consistently. Figure 12 summarizes the third study carried out Ashdod on the Mediterranean.

Fig 12 Case Study 3: Mediterranean

Feed Conditions

- TDS 40,500 ppm
- Turbidity 1 - 10 NTU
- Temp, deg C 15 – 30 (39)

UF Pilot Operation

- Test operated Feb 2000
- 8 months, stable operation

RO Pilot Operation

- 6 months without cleaning on an 8 element vessel
- 15 – 19 lmh (9 - 11 gfd) flux, and 50 % recovery confirmed

The three case studies show that UF filtrate is a suitable feed for RO, and the dissolved species that pass through the UF do not result in fouling of the RO. The benefits of UF to RO design and performance are as follows:

- IMS guarantee – SDI to RO is not a guarantee parameter
- RO membrane replacement reduced significantly
- Low space – >33% saving with UF
- Surface water, with poor or variable quality; avoidance of S/D or operation with out of spec feed
- Reduced requirement for RO disinfection and cleaning; avoidance of downtime or production loss

Figure 13 shows a UF-RO IMS installation at Brazos River, Texas, with a HYDRAcap UF system supplied by Leopold.

4. CONCLUSIONS

- Performance of the HYDRAcap module is excellent with a stable TMP of <0.2 bar at an average flux of 95 l/m^2.hour, provided that a $FeCl3$ dosing concentration is employed at pH 6.7.
- Permeate SDI's have averaged 2.2; projected values for a main plant operation average 2.0, with all values falling below 3.0. This is at least 2 SDI units below the current DMF, and would reduce fouling material on the RO by approx 75%. If Hydranautics provide both UF and RO stages, UF quality ceases to be a guarantee parameter due to the IMS guarantee.
- Recovery is 94%, with backwash and rinse volumes at around 6 % of forward flow.
- Hypochlorite backflushing (20 ppm) maintains the TMP at normal low levels.
- Acid or caustic Chemically Enhanced Backflushing have only been necessary when no dosing was employed, or when there were dosing problems; when used, baseline flux and TMP have quickly been re-established.
- Case studies at 3 locations on similar seawater feeds utilizing Hydranautics' UF and RO have shown that the RO has operated for 6 months downstream of UF without the need for cleaning, and that no problems have been experienced with RO fouling by dissolved organics passing through the UF.

Figure 13: IMS Installation at Brazos River, Texas

References

Ref 1: Silt Density Indices (SDI), percent plugging factor (%PF): Their relation to actual foulant deposition. S.S. Kremen, M.Tanner, Desalination 119 (1998), pages 259-262.

Ref 2: Development of new technologies for the reduction of fouling and improvement of performance in SWRO systems. MEDRC, Oman, July 2001.

Acknowledgements

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