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Operational experience from hybrid RO system at SAFI wastewater re-use RO plant

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ABSTRACT

Operation of wastewater treatment plants can be very challenging due to the high fouling tendency of wastewater. Much knowledge has been gained over the past few years to guide design engineers on the optimum design for wastewater reverse osmosis (RO) plant. The implementation of this knowledge helps to improve the operation and performance of many wastewater plants. One such example is the SAFI (BESIX Group Company) plant in Ajman, UAE. Here, an microfiltration (MF) and RO plant was installed in 2010 to treat sewage effluent in order to supply high quality water for industrial and domestic reuse. The 6,800 m^3/d plant treats secondary effluent with MF and RO. There are two RO trains designed to operate at 18.6 $l/m^2 h$ and 75% recovery, for treating municipal treated effluent with 2,000–4,000 mg/l of total dissolved solids (TDS). When operation started in 2010, the rate of fouling on RO membranes was extremely high, with up to 66% flow decline in 3 months of operation. This was eventually attributed to higher than design operation temperatures, lack of regular biocide disinfection, absence of flushing and cleaning system, and no flux balance between the RO stages. A detailed analysis was made of the fouled elements, and it was found that the primary issue was biofouling. This paper will review the actions that were taken to correct the fouling issue and stabilize the RO performance. One of the key factors, which ultimately resolved the problem was the membrane change, from single element type to two different types of membranes, on each RO stage to better balance the flux between RO stages. This and other changes have resulted in the plant now to achieve the production goals with stable operation.

Keywords: Wastewater re-use; Reverse osmosis; Hybrid membranes design; Flux balance

1. Introduction

SAFI (Besix Group Company) waste water reclamation plant, located in the Emirate of Ajman (UAE), is the first plant in the region that brings the concept of commercialized "water reuse" fully into practice. It is a sustainable alternative to the use of well or desalinated sea water. Its customers comprise READYMIX, district cooling and cleaning companies. The plant reclaims tertiary treated wastewater from the Ajman Sewage Treatment Plant, by further polishing it with microfiltration (MF) and reverse osmosis (RO)

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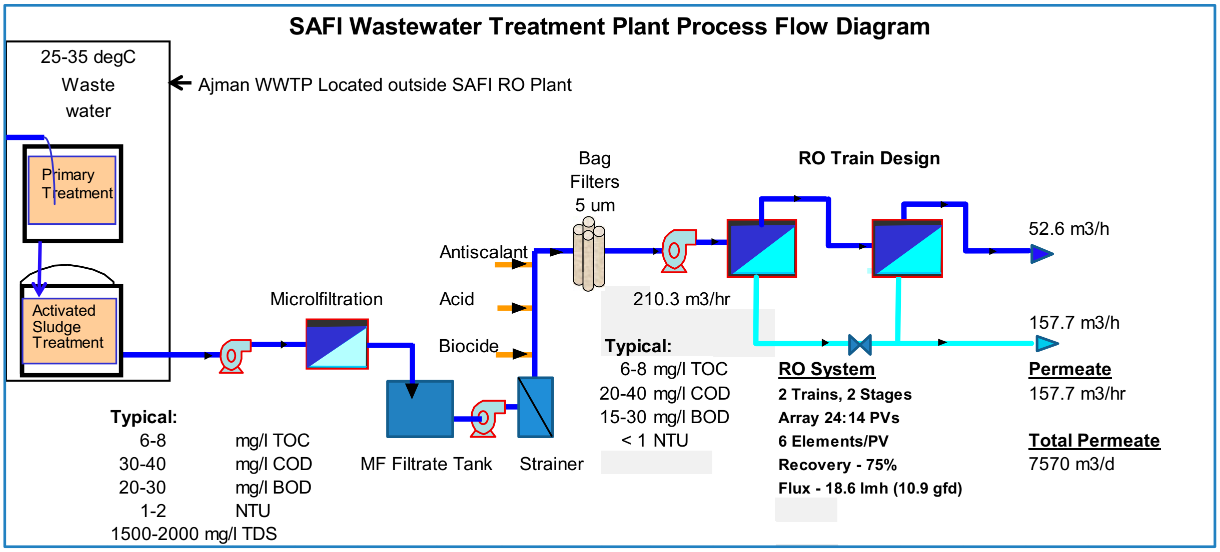

Fig. 1. SAFI plant process flow diagram.

processes (Fig. 1). The plant currently has a design production capacity of 6,800 m^3/d.

The RO plant was designed and initially equipped with Hydranautics LFC3-LD brackish water RO membranes, which were designed for use on difficult feed water with high organic content that is typical for surface or municipal wastewater sources. This type of membrane is also used on other wastewater re-use plants, in other parts of the world like Singapore or Spain. The plant was commissioned in 2010, but the initial operation of RO plant resulted in heavy fouling on RO membranes. A large combined effort by the plant operator, as well as the membrane and cleaning chemicals suppliers had to be used to bring plant operation into today's status. The plant was initially suffering from heavy fouling of the RO membranes, and very soon after star-up the RO trains lost a large portion of their production flow, which resulted in early replacement of Stage 1 RO membranes.

One of the steps proposed by membrane supplier was to use hybrid membrane configuration, and installation of two different types of RO membranes to balance fluxes between stages on RO trains. This paper will present a review of different steps taken to

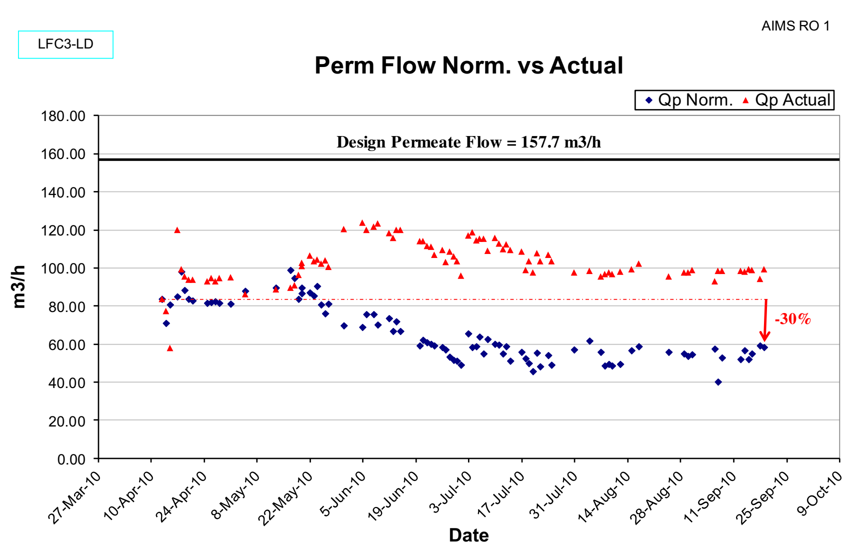

Fig. 2. RO1 normalized permeate flow until first replacement.

Table 1
SAFI RO plant design parameters

Feed water source	Tertiary treated municipal effluent from Ajman WWTP
Pre-treatment before RO	Microfiltration
Design feed water TDS	3,987 mg/l
Design RO capacity	3,785 m^3/d (157.7 m^3/h) per RO train
Number of RO trains	2
Design RO array configuration	Stage 1–24 pressure vessels × 6 elements Stage 2–12 pressure vessels × 6 elements
Design RO average flux	18.6 l/m^2 h
Design water temperature	25°C
Design RO recovery	75%
RO element type on both stages	Hydranautics LFC3-LD

stabilize the plant performance as well as the review of performance with hybrid configuration of RO membranes.

2. RO plant design parameters

Design parameters of SAFI RO plant are summarized in Table 1 above:

3. RO plant initial operation

The SAFI RO plant was commissioned in March 2010 and operation of RO train 1 started on 26 March 2010. Operating recovery at startup was kept low at 50%, and it was slowly increased to 65% until June 2010. Permeate flow was not at design values, but only at 91–114 m^3/h, which corresponds to flux of 10.2–13.6 l/m^2 h. Despite this conservative operation, the performance of RO was rapidly deteriorating and the unit lost 30% of normalized permeate flow (Fig. 2) until middle of September.

At the same time, the normalized differential pressure increased by 128% (Fig. 3) indicating very high rate of fouling on feed/brine flow path.

The RO train 2 started operations on 26 July 2010 at design permeate flow and recovery. Performance of this RO trains deteriorated even more rapidly and normalized permeate flow reduction reached 66% by the middle of October (Fig. 4). The normalized differential pressure on RO2 increased even more significantly (376%), within this short period of operation (Fig. 5).

The following issues were identified to be the main reasons for poor RO performance:

- Initial performance of MF pre-treatment was not as good as expected.

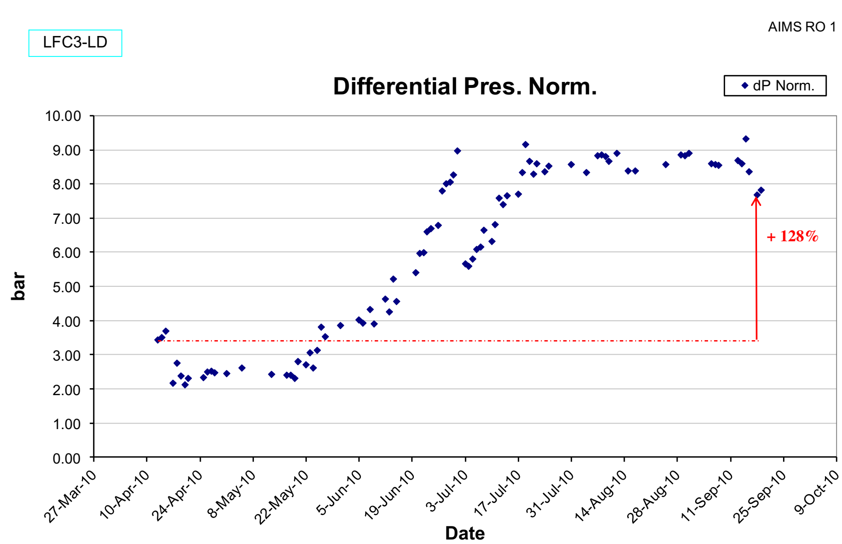

Fig. 3. RO1 normalized differential pressure until first replacement.

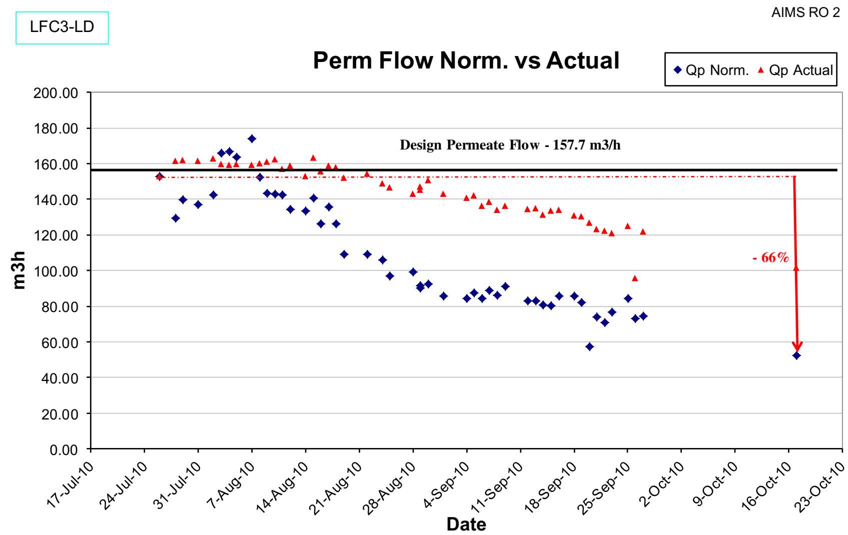

Fig. 4. RO2 normalized permeate flow until first replacement.

- The RO design was based on water temperature of 25˚C only and did not take into consideration the full temperature range of 25–37˚C, and therefore no flux balance between RO stages was considered, resulting in very high flux on first stage elements at high water temperature (Fig. 6).
- No biocide was used on RO feed during first two weeks of operation, and only shock biocide dosing was used October 10 afterwards.
- Absence of flushing and CIP system until August 2010.
- Increased biological activity in MF filtrate tank—worsening the RO feed water quality.

4. Element autopsy results

A lead element from RO train 1 was sent to Hydranautics for re-test and autopsy (Figs. 7 and 8) to evaluate it's condition. The weight of element after removal from pressure vessel was 23 kg (clean element weight is about 14–16 kg), which indicated heavy fouling. Re-test of this element confirmed flow

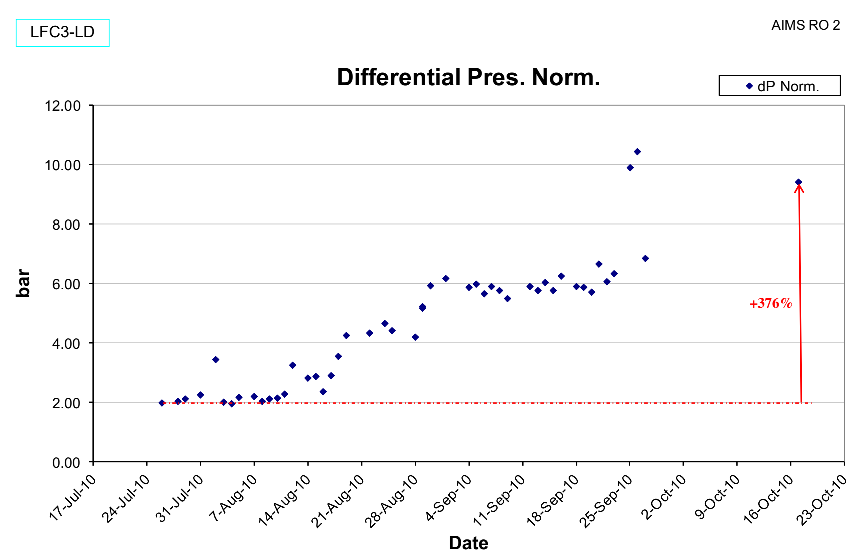

Fig. 5. RO2 normalized differential pressure until first replacement.

Stage	Perm. Flow m3/hr	Flow/Vessel Feed m3/hr	Flow/Vessel Conc m3/hr	Flux l/m2-hr	Beta	Conc.&Throt. Pressures bar	Conc.&Throt. Pressures bar	Element Type	Elem. No.	Array
1-1	140.0	8.8	2.9	26.2	1.17	10.5	0.0	LFC3-LD	144	24x6
1-2	17.7	5.0	3.8	5.7	1.02	10.0	0.0	LFC3-LD	84	14x6

Stg	Elem no.	Feed pres bar	Pres drop bar	Perm flow m3/hr	Perm Flux lm2hr	Beta	Perm sal TDS	Conc osm pres	Cumulative Perm Ion levels Ca	Mg	Cl	B	SiO2
1-1	1	11.0	0.1	1.3	35.1	1.16	29.9	3.0	0.25	0.23	11	0.00	0.05
1-1	2	10.8	0.1	1.2	32.4	1.17	36.3	3.6	0.29	0.27	14	0.00	0.06
1-1	3	10.7	0.1	1.1	29.0	1.19	44.9	4.3	0.36	0.34	17	0.00	0.07
1-1	4	10.7	0.1	0.9	24.9	1.20	57.1	5.3	0.46	0.43	22	0.00	0.09
1-1	5	10.6	0.0	0.7	20.2	1.10	74.7	6.3	0.61	0.56	28	0.00	0.12
1-1	6	10.6	0.0	0.6	14.9	1.17	100.2	7.5	0.82	0.76	38	0.00	0.16
1-2	1	10.3	0.1	0.4	10.3	1.07	120.6	8.2	0.98	0.91	45	0.00	0.19
1-2	2	10.3	0.1	0.3	7.4	1.06	144.8	8.7	1.13	1.06	53	0.00	0.22
1-2	3	10.2	0.1	0.2	5.5	1.04	171.6	9.1	1.31	1.22	61	0.00	0.26
1-2	4	10.2	0.0	0.2	4.1	1.03	200.5	9.3	1.52	1.42	70	0.00	0.30
1-2	5	10.1	0.0	0.1	3.1	1.03	231.2	9.6	1.79	1.67	83	0.00	0.35
1-2	6	10.1	0.0	0.1	2.3	1.02	263.1	9.7	2.14	1.99	99	0.00	0.42

Fig. 6. RO design projection with LFC3-LD without permeate backpressure at 35˚C.

reduction by 66% and salt passage increase by 108%. Analysis of foulant sample determined that it was 86.4% organic by nature.

5. Proposed measures to improve RO plant performance

The following actions were proposed to improve and stabilize performance of RO trains and bring production back to design values:

- Immediate actions
  - Re-use less fouled elements (with weight below 20 kg), and replace heavily fouled elements with new.
  - Change flow direction of re-used elements.
  - Perform aggressive high pH cleaning, including flushing, with non-oxidizing biocide (DBNPA).
  - Start immediately with continuous injection of biocide into RO feed to keep biological fouling under control.
  - Reduce operating recovery to 62% in order to keep higher brine flow per pressure vessel.
  - Reduce operating flux to conservative value of 11.2 l/m^2 h.
  - Apply permeate backpressure on first stage elements in order to provide better flux distribution between stages and lower flux on lead elements on first stage (Fig. 9).

Fig. 7. Foulant on membrane sheet.

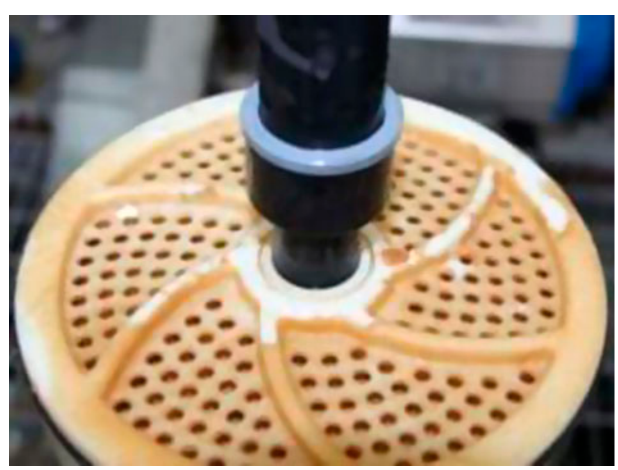

Fig. 8. Organic slime on feed ATD.

Stage	Perm. Flow m3/hr	Flow/Vessel Feed m3/hr	Flow/Vessel Conc m3/hr	Flux l/m2-hr	Beta	Conc.&Throt. Pressures bar	Conc.&Throt. Pressures bar	Element Type	Elem. No.	Array
1-1	122.3	8.8	3.7	22.9	1.13	10.6	1.5	LFC3-LD	144	24x6
1-2	35.4	6.3	3.8	11.3	1.03	10.1	0.0	ESPA2-LD	84	14x6

Stg	Elem no.	Feed pres bar	Pres drop bar	Perm flow m3/hr	Perm Flux lm2hr	Beta	Perm sal TDS	Conc osm pres	Cumulative Perm Ion levels Ca	Mg	Cl	B	SiO2
1-1	1	11.1	0.1	1.1	29.5	1.13	35.2	2.9	0.29	0.27	13	0.00	0.06
1-1	2	11.0	0.1	1.0	27.3	1.10	41.5	3.4	0.34	0.31	16	0.00	0.07
1-1	3	10.9	0.1	0.9	24.7	1.14	49.4	3.9	0.40	0.37	19	0.00	0.08
1-1	4	10.8	0.1	0.8	21.7	1.15	59.7	4.5	0.48	0.45	23	0.00	0.10
1-1	5	10.7	0.1	0.7	18.5	1.10	73.5	5.3	0.59	0.55	28	0.00	0.12
1-1	6	10.7	0.0	0.6	15.0	1.14	91.7	6.0	0.74	0.69	34	0.00	0.15
1-2	1	10.4	0.1	0.9	23.4	1.14	98.0	7.1	0.60	0.56	28	0.00	0.12
1-2	2	10.4	0.1	0.6	16.7	1.11	108.2	8.0	0.72	0.67	33	0.00	0.14
1-2	3	10.3	0.1	0.4	11.6	1.09	121.7	8.7	0.85	0.79	40	0.00	0.17
1-2	4	10.2	0.1	0.3	7.6	1.06	137.9	9.3	1.01	0.94	47	0.00	0.20
1-2	5	10.2	0.0	0.2	4.7	1.04	156.2	9.6	1.20	1.11	56	0.00	0.24
1-2	6	10.1	0.0	0.1	2.9	1.02	175.9	9.9	1.42	1.32	66	0.00	0.28

Fig. 9. Hybrid RO design projection with permeate backpressure.

- Future actions:
  - Full replacement of RO membranes on both stages with hybrid configuration—lower flow, LFC3-LD elements on stage 1 and higher flow, ESPA2-LD elements on stage 2.

Weight check of elements from RO trains showed that elements on first stage are heavily fouled and many elements were having the weight exceeding 20 kg. As there were not enough new LFC3-LD elements available for replacement, some of the heavier elements had to be re-used. It was decided to transfer all second stage elements into first stage and combine them with lowest weight elements removed from first stage. As it was not possible to find quick solution for backpressure application on first stage, it was recommended to install different, higher permeability ESPA2-LD elements on second stage (Table 2). Such configuration created natural flux balance between stages by allowing more production from second stage and thus reducing flux on first stage elements (Fig. 9).

Table 2
LFC3-LD vs. ESPA2-LD Specification

Element	LFC3-LD	ESPA2-LD
Flow (m^3/d)	41.6	37.9*
Rejection (%)—stabilized	99.7	99.6
Rejection (%)—minimum	99.5	99.5
Membrane area (m^2)	37.1	37.1
Element	LFC3-LD	ESPA2-LD
Surface charge	Neutral	Negative
F/B spacer thickness (mm)	0.864	0.864
F/B biostatic spacer	Yes	Yes
Test TDS (mg/l NaCl)	1,500	1,500
Test pressure (Bar)	15.5	10.5

*This flow corresponds to 59 m^3/d when tested at 15.5 bar feed pressure.

6. RO operation with new configuration

The RO train 1 was the first one to use this new, hybrid configuration of elements. It re-started operation in November 2011, and it has been in continuous operation until September 2013 when all first and second stage elements were replaced with new ones. In total, eight chemical cleans were performed between November 2011 and September 2013 with typical cleaning frequency of every 2–3 months (Fig. 11). All chemical cleans were performed on first stage elements only, as this stage was experiencing increase in differential pressure between cleanings. Unfortunately, the cleaning system on site is not equipped with heater, which has negative effect on cleaning efficiency particularly in winter months. This is visible on normalized trends when cleanings were not fully restoring the performance on stage 1. The second stage differential pressure was stable since beginning of operation with new elements, hence no cleans were performed on this stage. Furthermore, additional steps on plant were taken to improve RO performance. The MF filtrate tank is cleaned every 14 d to minimize biological after-growth as well as all feed pipes are cleaned periodically with sodium hypochlorite solution followed by flushing.

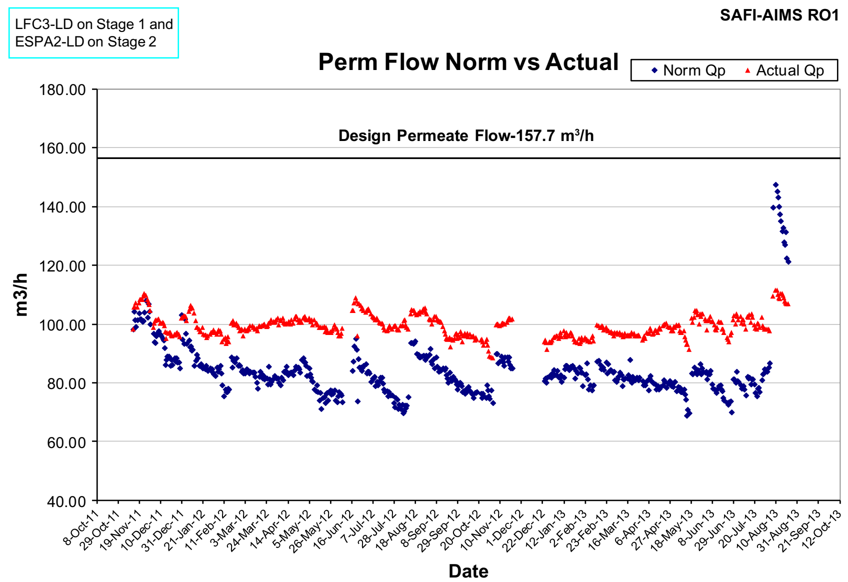

Fig. 10. RO 1 normalized and actual permeate flow after partial replacement.

Permeate production was kept continuously at 98–105 m^3/h, which corresponds to 62-66% of initial design values (Fig. 10). Operating flux was kept at 11.9 $l/m^2 h$ in average. During this operating period, biocide was used daily for 40-60 min on first stage and 30-40 min on second stage at concentration of 200–250 mg/l (as trade product) (Figs. 11 and 12).

In order to increase the RO1 production and satisfy increasing demand for water by SAFI customers, it was decided in summer 2013 fully replace all RO membranes on train RO1 with new. Together with replacement, the RO train was also equipped with valves on permeate headers from stage 1 to have possibility to apply permeate backpressure. Replacement of membranes was conducted in August 2013 and train was re-started on 1 September 2013 at design flow and recovery (Fig. 13). Continuous permeate backpressure of 1–1.5 bar on stage 1 permeate is

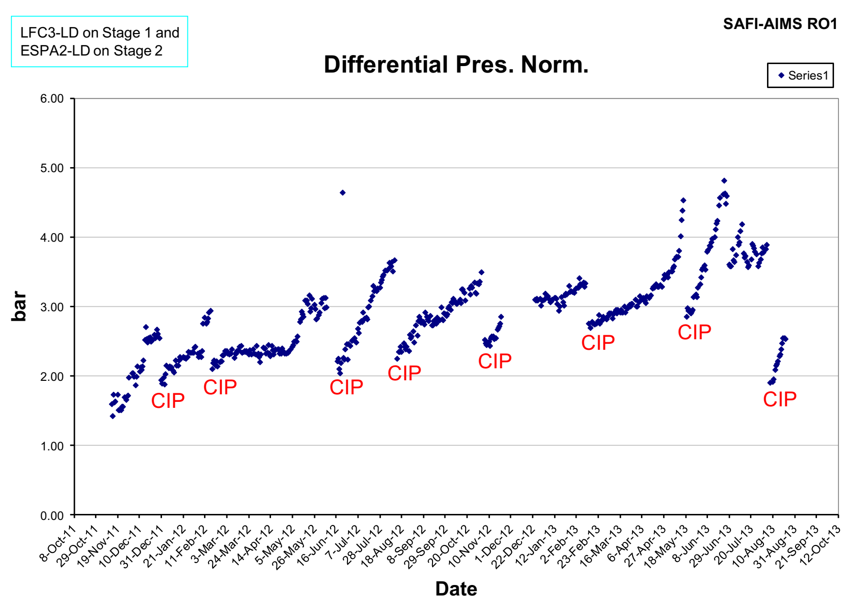

Fig. 11. RO1 normalized differential pressure after partial replacement.

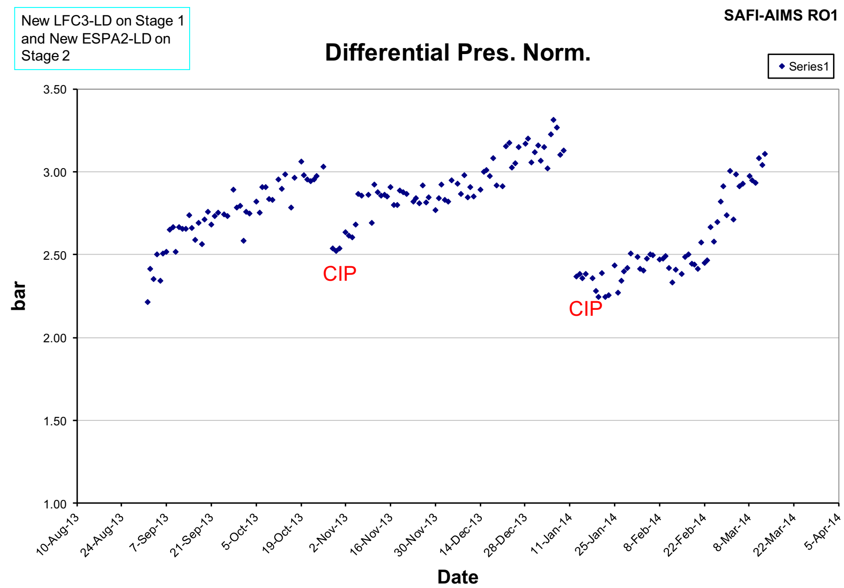

Fig. 12. RO1 normalized differential pressure after full replacement.

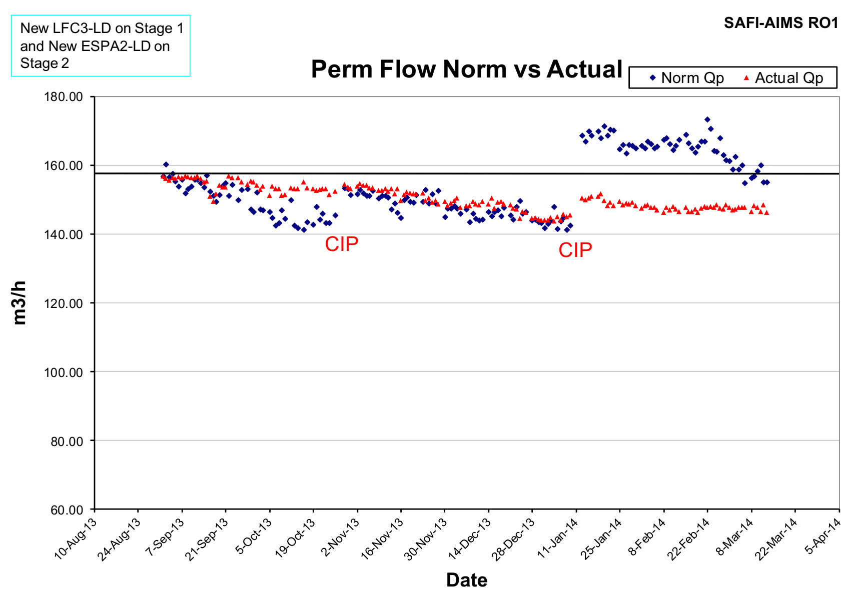

Fig. 13. RO1 normalized vs. actual permeate flow after full replacement.

applied since beginning of operation to reduce flux on first stage LFC3-LD elements and push more production into ESPA2-LD membranes on second stage. Biocide injection was also changed from shock to continuous. First chemical cleaning on stage 1 was performed after 2 months of operation and second chemical cleaning was performed after 4 months. The second cleaning included also stage 2 elements. Such cleaning frequency is comparable with previous operation after partial replacement, but we need to take into account that current operating flux and recovery is much higher than before.

The second RO train was re-configured in same way as RO1 in June 2012 and was in operation with such configuration until end of August 2013. During this period it was producing 91–96 m^3/h at recovery of 62% (Fig. 14). There were two chemical cleanings performed during this period, one in January and one in May 2013. Both cleanings were triggered by differential pressure increase on first stage membranes

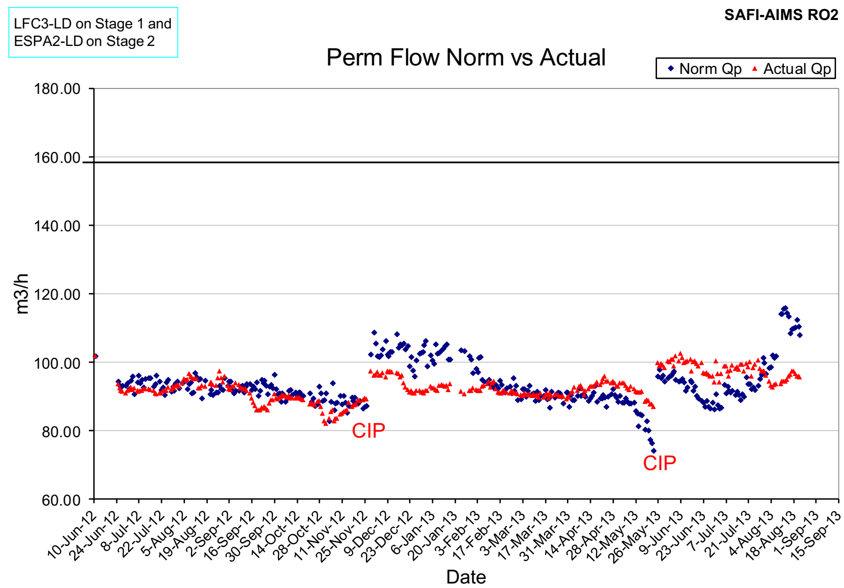

Fig. 14. RO2 normalized permeate flow after first partial replacement.

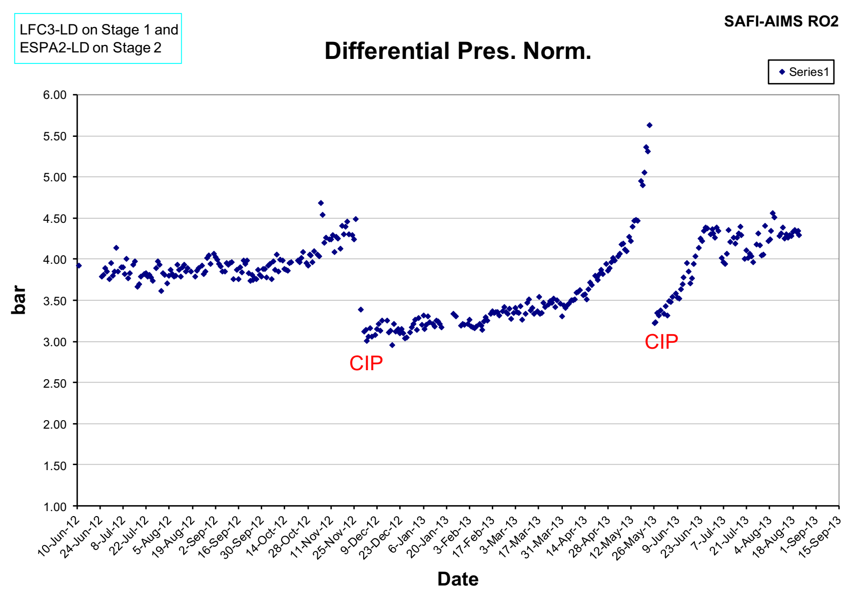

Fig. 15. RO2 normalized differential pressure after first partial replacement.

(Fig. 15). The reason for only two cleanings on this RO train is that it was in operation only for 2–3 h/d until September 2012 according to market demand for RO permeate water. In October, it was decided to increase operating hours on this train to reduce load on RO1 and run both trains equally.

Same as on RO1 during this operating period, biocide was used daily for 40–60 min on first stage and 30–40 min on second stage at concentration of 200–250 mg/l (as trade product).

When all membranes were replaced on RO1, the RO2 was "rejuvenated" in such a way, that three most heavily LFC3-LD elements on first stage were replaced with ESPA2-LD elements removed from second stage of RO1. Hence, the RO2 stage 1 is currently equipped with 3 × LFC3-LD and 3 × ESPA2-LD and stage 2 with all ESPA2-LD. Train is in operation with this configuration since end of August 2013, and first chemical clean was performed in March 2014 (Fig. 17). However, it is necessary to say that this train is working at reduced

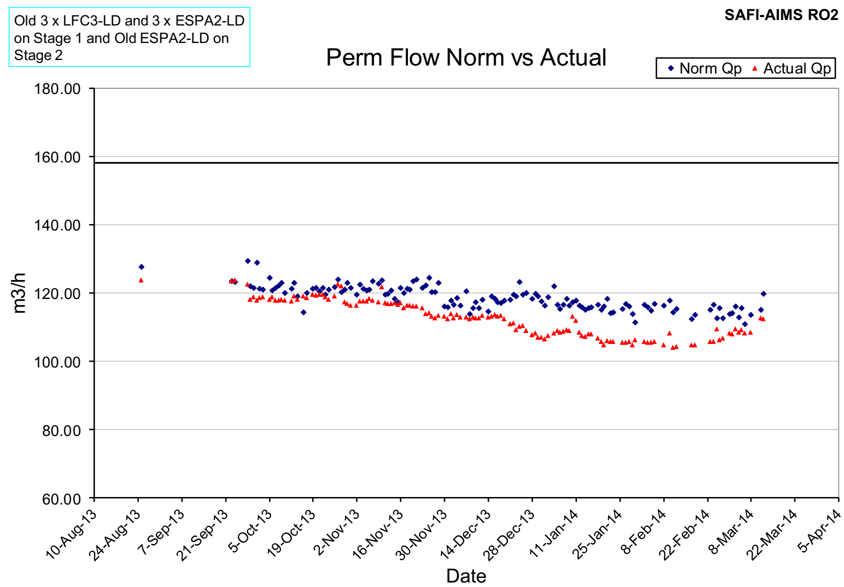

Fig. 16. RO2 normalized permeate flow after second partial replacement.

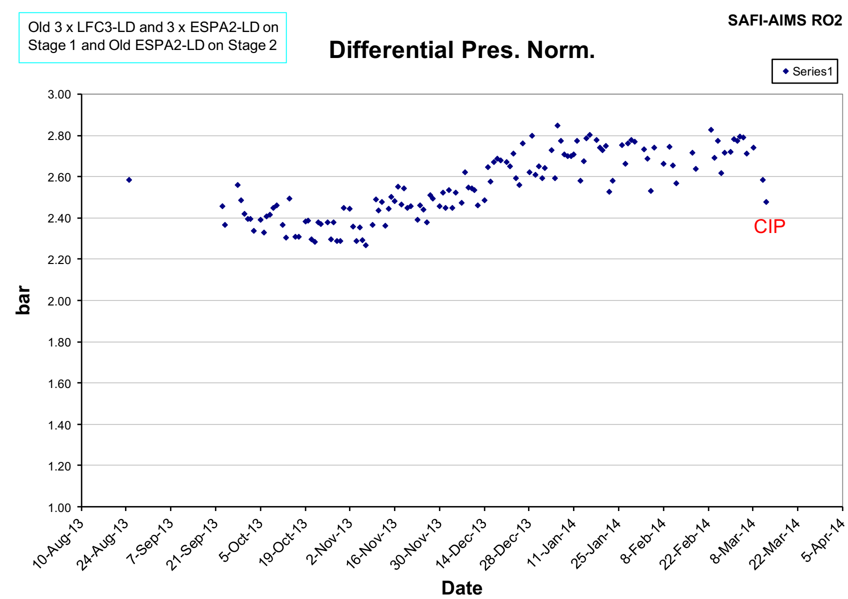

Fig. 17. RO2 normalized differential pressure after second partial replacement.

flow of 113 m^3/h and recovery of 63–65% (Fig. 16). This RO train is now also provided with the facility to apply permeate back pressure on first stage to balance the fluxes. It is expected that this train will also be replaced with new RO elements in 2014–2015 due to ever increasing water demand from SAFI customers.

7. Conclusions

Operation of hybrid membranes configuration at SAFI (Besix Group) waste water RO plant confirmed the following important points to be taken into account during design and operation of RO plants running on municipal tertiary treated effluent:

(1) Flux balance between RO stages is important factor for stable operation on feed water with high fouling potential and particularly at high feed water temperatures.
(2) Use of hybrid membrane configuration with different permeabilities on each RO stage can provide natural flux balance and can be used instead or in combination with permeate back-pressure.
(3) Continuous use of biocide on RO feed is essential for control of biological fouling and stable RO operation on this type of applications even when micro or ultrafiltration is used as RO pre-treatment.
(4) Heater on cleaning system is inevitable to obtain good cleaning efficiency particularly on feed water with high fouling potential.