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# OPERATION OF AL-BIRK SWRO PLANT WITH TOYOBO MEMBRANE INSTEAD OF DUPONT B-10 MEMBRANE

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## ABSTRACT

*Since its start-up in 1983, lower than expected plant performance had been observed at Al-Birk SWRO plant, capacity 2270 $m^3$/d. Initially, the plant was operated on two stages DuPont B-10 followed by B-9 polyamide hollow fine fiber membranes. Though the initial performance of the B-10 membrane was acceptable, but within three months of operation, due to membrane biofouling, the membrane performance dropped. A considerable drop in both salt rejection as well as plant productivity was observed. The intensity of fouling became so alarming that it necessitated frequent membrane cleaning, cartridge filter (CF) replacement, at nearly 10 days interval. To overcome the biofouling problem and in order to find a replacement to the discontinued B-10 chlorine intolerant membrane, one train in the plant was operated in one stage utilizing the chlorine tolerant Toyobo HB 9155 HFF cellulose triacetate membrane (CTA), which is also characterized by its ability to repulse the organic foulants. For comparison, the second train was kept in normal operation in two B-10 and B-9 stages. Furthermore, the Toyobo membrane is the only membrane now available as replacement of B-10 membrane without system modification. Both trains were operated under the same prevailing operating conditions. Intermittent chlorine injection (ICI)by passing 0.2 ppm $Cl_2$ in the feed for one hour only in 24 hours of operation was applied in the operation of HB9155 membrane and chlorination/dechlorination was applied in treatment of feed to B-10 membrane.*

*After a few months of operation, the membrane performance, as measured by permeate flow , water recovery, conductivity and $\Delta p$, were as follows: 46 m3/hr, 28%, about 120 µs/cm and 0.2-0.35 bar for Toyobo membrane, compared to 33 m3/hr, 25% - 20%, 120 µs/cm and 0.5-1.5 bar for B-10 membrane, respectably. There was a gradual decline in Toyobo HB9155 membrane performance, which was as discovered later, due to malmanufacturing of some membrane elements due to glue failure. Toyobo membranes, however, maintained a satisfactory performance, requiring no cleaning, contrary to DuPont B-10 membrane, which showed a drastic reduction in performance in spite of biweekly cleaning. The preliminary results indicate that, in addition to the suitability of Toyobo HB 9155 membrane as replacement of B-10,without changing the pressure vessels and with only minor modification in operating conditions, it can provide the solution to this outstanding of B-10 fouling problem. This, however, is being verified by the continuing long-term SWRO plant operation.*

**Keywords**: *DuPont B-10, Toyobo HB 9155 HFF, Fouling, Membrane replacement.*

## الملخص

تم إنشاء محطة البرك للتحلية بالتناضح العكسي في عام ١٩٨٣م بطاقة إنتاجية ٢٢٧٠م$^{٣}$/يوم من خطي إنتاج متساويين بالإنتاج والمواصفات . في البداية تم تشغيل المحطة بأغشية ديبونت ب-١٠ في مرحله أولى وأغشية ب-٩ في مرحلة ثانية ، كلاهما من مادة البولي أميد (النايلون) . بالرغم من أن أداء أغشية ب-١٠ كان مرضياً في البداية إلا أن مستوى الأداء تدنى خلال الثلاثة أشهر الأولى من التشغيل بسبب تلوث الأغشية ، وفاق فرق الضغط عبر الأغشية (ΔP) الحد الأقصى أي ٤ بار ، وصاحب ذلك تدنى في مقدرة الأغشية لطرد الأملاح وبالتالي تدنت إنتاجية المحطة . وتفاقمت مشكلـة تلـوث الأغشيـة بالمحطة ، ولمواجهة هذه المشكل ارتفع معدل غسل الأغشية و تبديل المرشحات (Cartridge filter) مرة كل عشرة أيام. وأنعكس ذلك على إنتاجية المحطة مع زيادة في كلفة إنتاج المياه . وللتغلب على المشكلة الناتجة عن التلوث الحيوي للأغشية تم تغيير أغشية دوبنت ب-١٠ بالخط الأول ، والمعروف عنها أنها تتأثر بالكلور ، بأغشية تيوبو HB 9155 HFF ذات الشعيرات الدقيقة الجوفاء المصنوعة من مادة السيليولوز ثلاثي الأسيتيت (Cellulose Triacetate) والتي إلى حد لا تتأثر بمادة الكلور المعقم ، وبذا لها المقدرة على طرد الملوثات العضوية . وللمقارنة ظل خط الإنتاج الثاني يعمل بأغشية ديبونت كما كان يعمل سابقاً. وتم تشغيل هذين الخطين، الخط الأول على مرحلة واحدة والخط الثاني على مرحلتين، تحت نفس الظروف التشغيلية . كما تم معالجة أغشية تيوبو بحقن (٠,٢) جزء بالمليون من الكلور لمدة ساعة فقط لكل ٢٤ ساعة تشغيل ، مع إزالة الكلور كلياً من مياه التغذية إلى أغشية ب-١٠. علاوة على ذلك فإن شركة ديبونت أوقفت تصنيع الأغشية من نوع ب-١٠، لتصبح أغشية تيوبو هي الوحيدة من الأغشية الشعرية الدقيقة الجوفاء المتوفرة في السوق والتي يمكن استخدامها كبديل لـ ب-١٠ بدون تغيير اسطوانات الضغط مع تعديل طفيف في نظام التشغيل .

بعد مدة من التشغيل كانت :- كمية التدفق عبر الأغشية ، وكفاءة الإنتاج ومعدل الموصلية الكهربائية وفرق الضغط بين الأغشية كما يلي : ٤٦م$^{٣}$/ساعة ، ٢٨%، µs/cm١٢٠ ، ٠,٣٥ – ٠,٢بار على التوالي بالنسبة لأغشية تيوبو، بالمقارنة مع ٣٣م$^{٣}$/ساعة ، ٢٠%-٢٥%،µs/cm١٢٠ ، ٠,٥ – ١,٥ بار لأغشية ب-١٠ . وحافظت أغشية تيوبو على هذا الأداء مع بعض التدني في أدائها، وتبين لاحقاً أن السبب في ذلك كان خلل في تصنيع بعض الأغشية . وبالرغم من ذلك كان أداء أغشية تيوبو مرضياً ولم تحتاج للغسيل لمدة حوالي ستة أشهر ، في حين تدني أداء أغشية ب-١٠ بالرغم من أنها كانت تغسل مرة كل أسبوعين . وتشير النتائج الأولية للدراسة أن أغشية تيوبو ستكون بديلاً مناسباً لأغشية ب-١٠ خصوصاً بعد أن تم تصحيح الخلل الصناعي . وقد يكون تبديل الأغشية هو الحل المناسب لمشكلة تشغيل محطة البرك . وللتأكد من ذلك تقرر استمرار التجربة لمدة (١٨) شهراً بدلاً من (١٢)شهراً .


## 1. INTRODUCTION

In the seawater reverse osmosis (SWRO) process, membrane is the heart of the SWRO desalination plant and is considered to be one of its main cost components. If this major costly part in any SWRO plant is not selected properly, the economic success of the plant may not be achieved. The selection of a new membrane for a SWRO plant or replacement of an old or fouled membrane with a new one must be carefully considered in order to maximize the overall economic effectiveness of the process by lowering water production cost and by increasing the plant availability. The performance of a membrane depends on a number of factors, which are related to the membrane itself, plant site, feed water quality and pretreatment system as well as the operation and maintenance conditions of the plant. In order to avoid future problems in plant operation, which could lead to the degradation in membrane performance, precautionary measures are normally taken in selecting the proper membrane for the job at the selected site. Manufacturers' claim based on their factory test data are not sufficient and may not reflect their membrane behavior in actual operation. In this case user's data tends to be more reliable in predicting the actual plant performance as its relates to feed water quality and plant site. In spite of this, a thorough investigation of the site and feed water quality is very essential for the selection of the membrane, the plant design and its mode of operation.

When evaluating RO membrane it is important to take into account certain criteria such as chemical resistance, biological resistance, mechanical strength, cleanability, storability, and membrane area and flux rate. These factors have profound effect on membrane salt rejection and product flow, which consequently reflect on the water production cost. A variety of new SWRO membranes and fabrication methods as well as membrane configuration are now available commercially. With unique polymer system their salt rejection and water flux have been improved. To ensure reliable performance and long term economical operation of the plant should, therefore, focus on above membrane properties.

Al-Birk SWRO was built in 1983 utilizing DuPont B-10 polyamide hollow fine fiber (HFF) membrane. Repeated degradation in plant performance was observed [Osta and Bakheet, 1987; Hassan et al, 1989; Hassan et al, 1991; Winters, 1994]. One cause of this severe operational problems at Al-Birk SWRO plant was attributed to biofouling. Recently, SWCC-RDC has concluded a research project dealing with the investigation of biofouling at this plant [Jamaluddin et al, 1999]. In the said project, experiments were carried out to study the biofouling problems and how to overcome them by varying the pretreatment modes, including operation without chlorination. The problems, however, could not be alleviated and although chlorination was found to enhance biofouling, the source water quality was incriminated as a major cause of the operational problems in this plant. The problem with chlorination stems from the huge bacterial regrowth following dechlorination [Applegate et al, 1989]. Another alternative, a chlorine resistant membrane, Toyobo HFF, where chlorine disinfected feed is allowed to pass over the membrane, thus suppressing bacterial growth and preventing formation of serious biofouling, has been investigating since 4th April, 2001 with the objectives:

(i) To compare Toyobo HB9155 and DuPont B-10 membrane performance at Al-Birk SWRO plant under same operating conditions with the exception of intermittent chlorine injection (ICI) in case of HB9155 membrane and continuous chlorination/dechlorination for B-10 membrane.

(ii) To investigate the effect of pretreated water quality on performance of the two membranes (B-10 and HB9155).

(iii) To compare the susceptibility of the two brands of membranes to biofouling.

(iv) To evaluate the biofouling potential of source water, pretreated RO feed water, and brine reject in terms of bacterial density and biofilm formation.

## 2. BRIEF DESCRIPTION OF AL-BIRK SWRO PLANT

A schematic flow diagram of the plant is given in Fig.1. The plant consists of two identical trains (Train 100 and Train 200), which are fed seawater delivered through a concrete open intake chamber at a depth of 6 to 7 meters below seawater level and about 300 meters from sea shore. The incoming seawater feed is screened ahead of seawater pump by a traveling band screen of mesh size 1 mm. Downstream seawater pump, the flow is split into two streams, one to train 100 and the other to train 200. Each train has individual feed pretreatment and desalination section. For train 100, the desalination is now conducted in two stages. The first stage utilizes DuPont B-10 HFF SWRO membranes, while the second stage utilizes DuPont B-9 brackish water membranes. Train 200, the experimental train, utilizes only one SWRO stage of Toyobo HB9155 SWRO membranes, the second stage was isolated. The SWRO stage of each train has six identical banks/racks. Each rack normally contains 18-19 permeators/modules. The second stage contains one bank per train with three rejects staging. Normally, 25 permeators/modules are installed in the second stage unit. The number of permeators may vary in all stages, lower in number when membranes are new and is higher in number after long service (approx. one year) to maintain steady product flow. Part of the second stage reject from train 100 is recycled and mixed with feed to first stage. Final product is transferred to product tank via suck-back tank. Permeate flushing of membranes actuates automatically at any loss of pressure during emergency or normal shutdown, at a flushing rate of 40 $m^3$/h, for DuPont membrane in train 100.

### 2.1 Normal Operating Conditions

Seawater from an open sea sub-surface zone is chlorinated at the intake chamber (Fig. 1) by dosing about 3.3±0.2 ppm calcium hypochlorite Ca(OCl) followed by about 2.5 ppm of the coagulant, a polyelectrolyte (PE), magnifloc C-573, a solution of poly quaternary amine in water, at up-stream of dual media filters (DMF). The filtration is done initially by coarse filters (average sand grain size 1.35 mm, depth 105 cm and diameter 2.8 m) followed by DMF which consists of 0.55 mm grain size sand for a depth of 40 cm above which is 0.8-1.6 mm particle size anthracite for a depth of 40 cm, bottom layer is 1.35 mm particle size coarse sand for a depth of 30 cm, vessel diameter is 3 meters. Automatic back-washing follows the program: 5 minutes drain, 5 minutes air scouring, 7 minutes backwash, 3 minutes filling and 5 minutes settling time. Programmed back-washing frequency for coarse filters is 1 to 2 days and for DMF every 3 to 5 days. The backwash pump (BWP) has a capacity of 210 $m^3$/h at 17.5 bar head. The filtrate was dechlorinated by dosing SBS up-stream of CF as shown in Fig.1. The water is then streamed through 5 micron CF unit for fine filtration prior to desalination. The 1st stage desalination is operated at a feed pressure of 60 bar, feed flow 150-160 $m^3$/hr at ambient temperature (29-33°C). Second stage is operated at feed pressure of 28 bars.

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## 3. RESULTS AND DISCUSSIONS

Figure 2 shows the performance of HB 9155 membrane versus operation time for over 4200 hrs, under the operation conditions, (feed: flow, temperature, SDI and pressure) shown in same figure. No membrane cleaning for the HB 9155 was carried out during this period as compared to nearly twice monthly cleaning of the B-10 membrane in Train 100. For the first 1400 hrs of operation the HB 9155 Train product flow ranged between 1050 to 1000 $m^3$/d at about 28% recovery, after which it started to decline, reaching about 870 $m^3$/d at the 2400 hrs of operation, rising back to 50 $m^3$/d at the 2500 hr operation, for a loss of over 100 $m^3$/d within the last 1000 hrs of operation, i.e., at the rate of 0.1 $m^3$/d. True, with the natural expected membrane compaction decline with time, the membrane product flow should, more or less, follow the dotted line in Figure 2b. One obvious reason for this decline is the insufficient feed pretreatment, to clean the feed from its content of suspended solids and bacteria, as evidenced by the rise shown in Figures 2a and 3b of the silt density index (SDI) values in the operation region 1500 to 2500 hours as well as the frequent cartridge filter replacement (CFR), 3 times within less than a month, during the period. Another possible reason contributing to the product decline could be in the decline of quantity of feed received by the membrane, as shown in Figure 2a. Raising the feed from 3500 $m^3$/d at the operation hour 2400 to 3750 $m^3$/d at the operation hour 2450 pushed up the product flow from about 880 $m^3$/h to 960 $m^3$/h, Figure 2b. There was also slight (≈ 2$^o$C) decrease in feed temperature during the period as shown in Figure 2a, which would be another factor in performance decline. Still, a third possibility could it be that there was a gradual build-up of fouling or biofouling components on the membrane surface? The latter (biofouling) possibly is due to insufficient chlorine dosing in the feed. However, the permeate flow after 2500 hrs of operation period to now remained almost steady, about 900 m3/d, at nearly 24% recovery. The seawater quality as measured by SDI values remained <4 (Fig.3b) and steady during this period (2500-4200 hrs.). It indicates that the earlier production decline could be prevented if pretreated seawater feed SDI values could be maintained <4 for all the operation period. Still another possible reason for permeate decline is the deformation of some membrane elements under high pressure. This was observed upon inspection of membrane elements.

To restore the original product flow to 1075±25 m3/d, Toyobo membrane cleaning is required in order to remove the foulants, which are likely to be accumulated during rough seawater condition on membrane surface. It is expected that, if water quality (SDI < 4) is maintained after the cleaning, decline in permeate flow will be within the acceptable limit caused by usual membrane compaction. To conclude that Toyobo membrane is a potential replacement for the DuPont B-10 membrane requires to complete the continuous operation of the plant for remaining experimental period (5 months). Meanwhile, Toyobo Membrane Company has to work on strengthening the physical structure of the membrane to prevent the membrane element deformation at high pressure (60 bar) operation, though this elements (HB9155) was claimed to tolerate pressure up to 84 bar.

The measured differential pressure across the membrane (ΔP) indicates that ΔP remained less than 0.5 bar for racks # 1, 4 and 5 and exhibited a sharp rise above 0.5 for the Rack #2. Rack # 3 has a low ΔP value less than 0.5 for the first 600 hours of operation, rising to ΔP = 0.55 in the operation regain 700 to 1600 hours followed by a steep rise to ΔP ≈ 0.9 bar in the operation regain of 1600 to 1800 hours and gradually dropping back to a value of ΔP ≈ 0.4 bar. Since all the five racks are arranged in parallel, and are operated under same conditions, all receive the same feed, it is anticipated that they will have the same performance behavior, suggesting the possibility of an instrumental error in measuring this value. With this observed variation in ΔP no conclusive results can be accurately drawn from ΔP measurement, except that the ΔP limit of 2 bar is much higher than the observed values.

The behavior of permeate recovery ratio with operation time is shown in Figure 2c, while Figure 2d shows the permeate quality versus operation time. The permeate recovery ratio tends to follow the same behavioral performance trend as the permeate flow, (compare Figure 2b and 2c). Again, as was postulated for the membrane product flow, the same is postulated for the permeate recovery ratio, where its performance should have followed the dotted line shown in Figure 2c instead of the observed solid line in same figure. Unlike the above performance of membrane HB9155 product flow and recovery ratio, the permeate water quality continued to be excellent, product conductivity remain less than 200 us/cm, i.e. TDS less than 110 ppm, with only a small rise toward the tail end in Figure 2d.

## 4. CONCLUSIONS

(1) During the seven months of continuous operation, Toyobo membrane showed better performance, in both permeate flow as well as in permeate quality (TDS), than DuPont B-10 membrane.

(2) As no cleaning was done for the last seven months operation, Toyobo membrane cleaning could restore the membrane permeate flow to a value of about 1050 $m^3/h$.

(3) Differential pressure across membrane (ΔP) remained very low, suggesting no membrane fouling. However, as was discovered later, the drop in permeate flow with operation time was due to malmanufacturing in some membrane elements, glue failure, which was corrected by the Toyobo company.

(4) Continuous operation of Al-Birk plant with the new Toyobo membrane in Train 200 for remaining experimental period (5 months) is to be continued under same operation conditions, after membrane cleaning.

(5) It is necessary to maintain pretreated seawater feed SDI<4 to Toyobo HB9155, in order to obtain steady performance compared to SDI<3 for DuPont membrane.

(6) As Toyobo membrane does not require frequent cleaning like DuPont B-10 and it gives steady flow of comparatively higher recovery and better quality, cost of water production will consequently be reduced by utilizing Toyobo membrane.

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## 5. RECOMMENDATIONS

1. To improve Al-Birk SWRO plant energy economy and performance by increasing line yield, a hydraulic turbo charger can be placed to recover energy from SWRO reject as well as to boost feed pressure to a second stage Toyobo membrane to be operated at high pressure up to 84 bar. This improvement in enhancing plant performance deemed necessary because of the low SWRO recovery of about 24%.

2. To ensure better quality seawater feed at Al-Birk SWRO plant, the probability of a beach-well as an alternate intake needs to be investigated, or alternatively.

3. *Upgrading of present pretreatment by*: (a) Introduction of extra media bed and proper media size, (b) Introduction of intermediate pretreated seawater storage facility (i.e., clear well), (c) installation of standby CF housing can increase plant availability and performance.

4. *Modification of processing techniques*: (a) Low capacity operation during rough sea condition. (b) Intermittent permeates flushing operation. (c.) Occasional shock dosing of disinfectant. (d) Improved back-washing strategies could be the temporary remedy during high SDI problem at Al-Birk plant.

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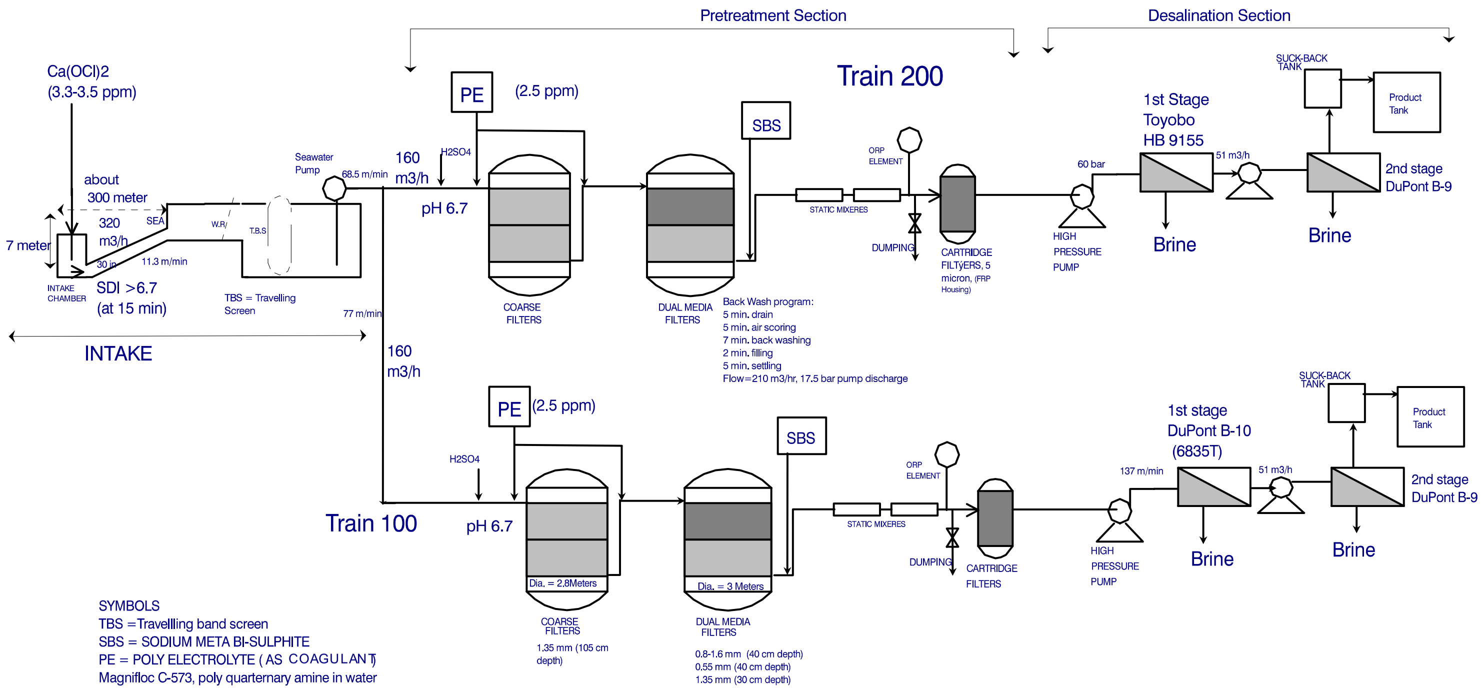


**Figure 1 : Schematic Flow Diagram of Al-Birk SWRO Plant Showing the Arrangement of Toyobo and DuPont Membranes : Toyobo HB9155 Membranes in 1st Stage of Train 200, DuPont B-10 and B-9 in 1st Stage of Train 100 and 2nd Stages of Both the Trains, Respectively.**

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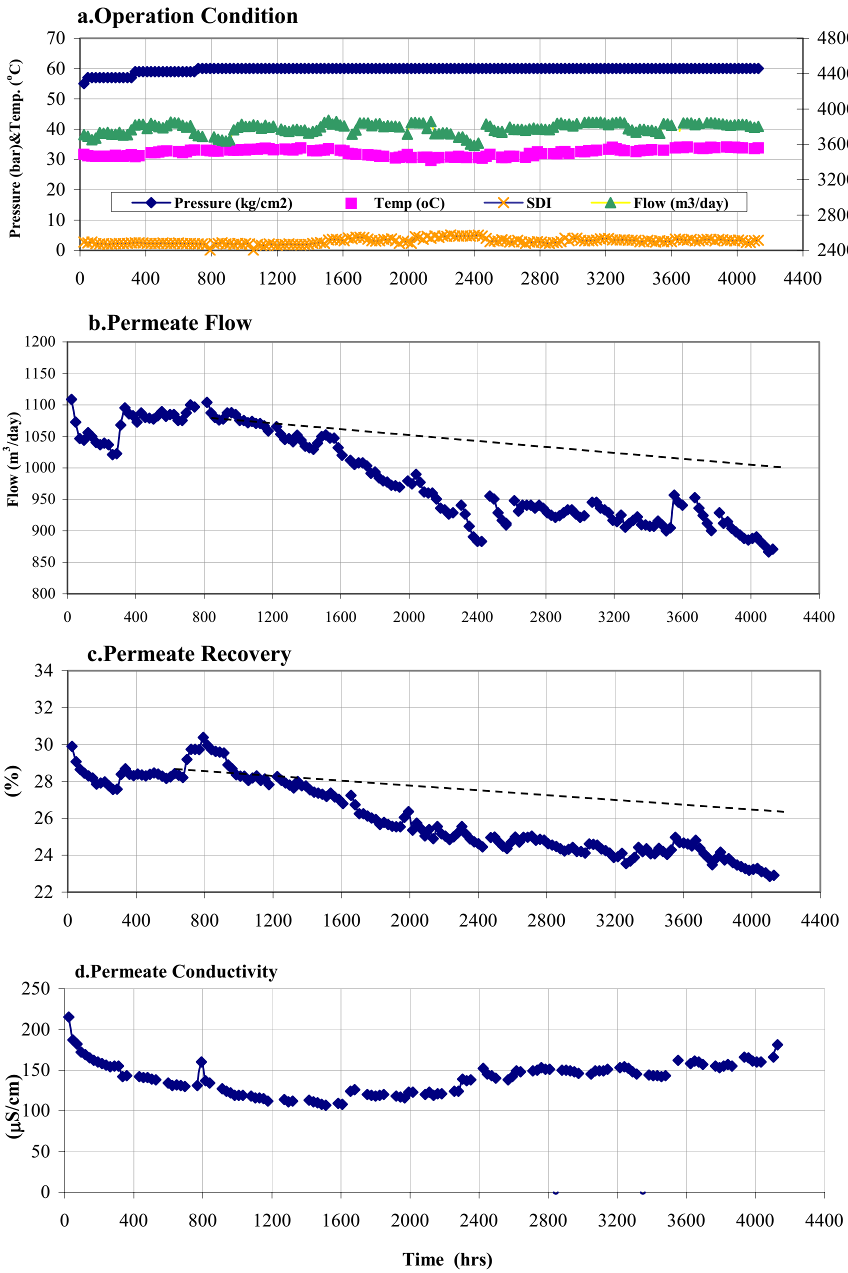


**Figure 2: Performance of Al-Birk Plant Train 200 with TOYOBO (HB9155) Membranes: a.Operation Conditions, b.Permeate Flow, c.Recovery Ratio and d.Permeate Conductivity vs. Operation Time.**

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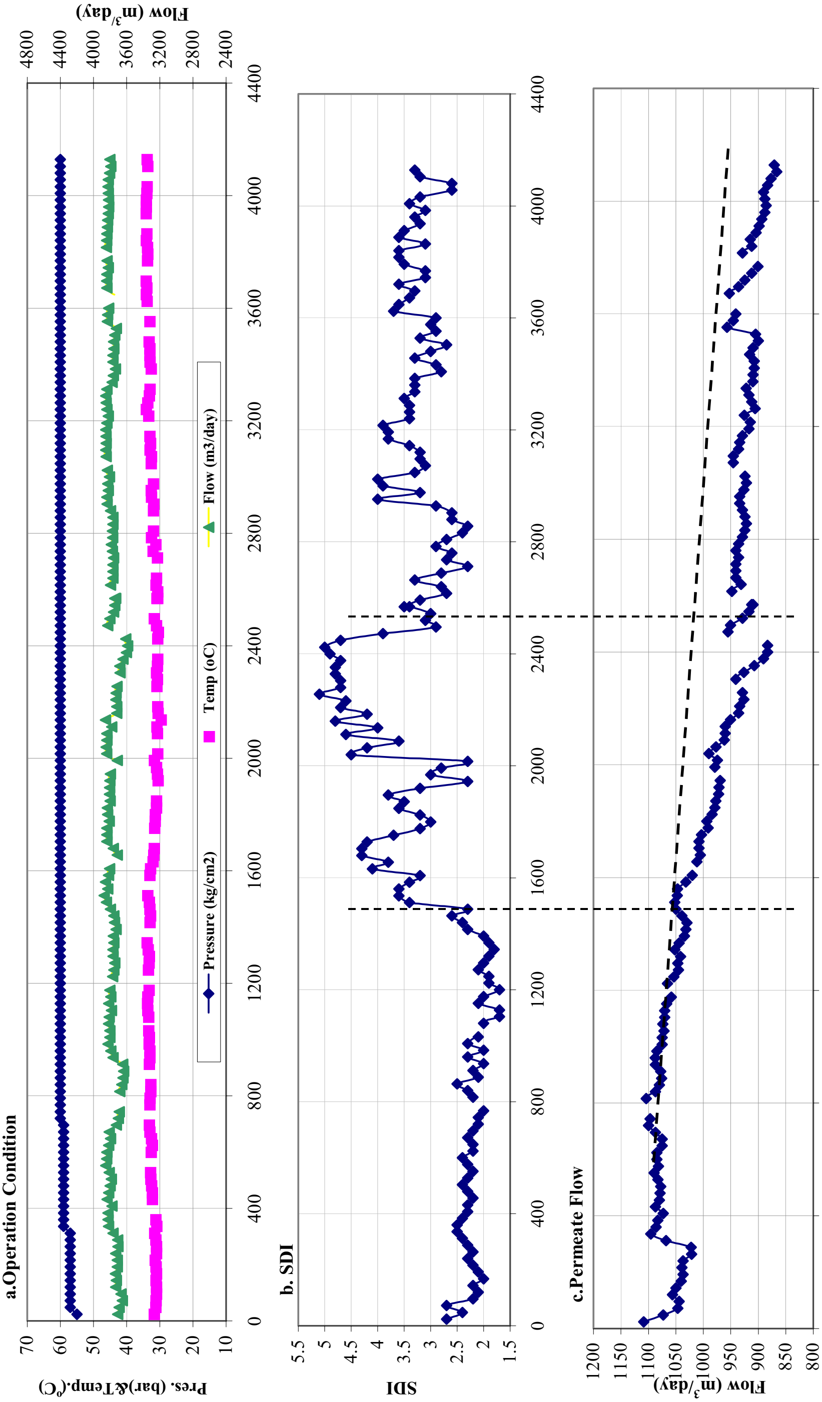


**Figure 3: Performance of Al-Birk Plant Train 200 with TOYOBO (HB9155) Membranes: a.Operation Conditions b.SDI and c.Permeate Flow vs. Operation Time.**