

# EFFECT OF HIGH FEED TEMPERATURE ON NANOFILTRATION AND RO MEMBRANE PERFORMANCE<sup>1</sup>

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## SUMMARY

*An 8.0 m<sup>3</sup>/hr NF and 3.0 m<sup>3</sup>/hr SWRO membrane set up was used to determine the effect of feed water temperature on Nanofiltration (NF) and Seawater Reverse Osmosis (SWRO) membrane performance. Seawater from the open intake (15°C – 30°C) was mixed with seawater from the Multi Stage Flash Distillation (MSF) rejection stream (30°C – 40°C). This mixture of intake water with MSF rejects increased feed seawater temperature to NF and SWRO membranes by approximately 10°C. Increased seawater temperature, at a constant feed pressure (about 20 bar) and feed flow rate (about 8.0 m<sup>3</sup>/hr) to NF membranes, increased the NF total recovery rate by 10 %. When the NF permeate temperatures was increased by 5°C at a constant feed pressure (about 69 bar) and feed flow rate (about 3.0 m<sup>3</sup>/hr), SWRO membrane recovery rate increased by 8%. The energy consumption of water produced by NF-SWRO membranes receiving preheated feed water was about 4.34 kWh/m<sup>3</sup> compared to 5.26 kWh/m<sup>3</sup> for NF-SWRO membranes receiving normal temperature seawater from the open intake. An 18% reduction in SWRO energy consumption of potable water production was achieved using preheating feed water from the MSF stream.*

*An increase in bacterial density throughout the process was observed corresponding to elevated intake seawater temperatures. However, high temperatures did not increase bacterial growth performance. Consequently, temperatures between 35°C to 40°C did not enhance biofouling potential.*

## 1. INTRODUCTION

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Saudi Arabia is the world leader in desalinated water production primarily using MSF and SWRO. Its present capacity for desalinated water production from the sea and other raw water sources stands at over 6.05 millions m<sup>3</sup>/d [1]. The Kingdom has seawater desalination plants along the coasts of the Arabian Gulf and Red Sea. Saudi Arabia's 21% world desalted water production comes mainly from the MSF process. The Saline Water Conversion Corporation (SWCC) is the major producer of KSA's desalted water with a present production capacity of 3,353,068 million m<sup>3</sup>/d. Over 51% of this is produced by eastern coasts plants and 49% by western coast plants [2]. In addition to MSF, the Kingdom also produces drinking water from seawater reverse osmosis. Under the auspicious of SWCC, the Kingdom has an aggressive program to optimize the SWRO process for more efficient and economical production of potable water.

## 2. EXPERIMENTAL METHODS

Seawater from the open intake (15 °C -25°C) was mixed with MSF heat rejection unit cooling seawater (35 °C - 42°C) in a polyethylene storage tank to produce seawater feed, average temperature ≈ 30 °C. The mixed water was transferred by a transfer pump to the pretreatment unit. An 8.0 m<sup>3</sup>/hr load of pretreated seawater was transferred as feed to NF membranes and 3.0 m<sup>3</sup>/hr of NF permeate was fed to SWRO membranes. Four NF elements, 80" x 40" from GE Osmonics DK 8040 were arranged in series, two elements in series per pressure vessel in this experiment. The product of NF was fed to Six 6" x 40" SWRO elements arranged in series. The energy consumption was calculated using equation 1 [3]:

$$E_{SWRO} = \frac{Q_{f(SWRO)} \times H_{f(SWRO)} \times \rho}{366 \times Q_{p(SWRO)} \times e} \quad (1)$$

for calculation simplicity Equation 1 can be derived to be as follows:

$$E_{KWh} / m^3 = \frac{1 \times H_{f(SWRO)} \times 1.03}{\text{Recovery}_{(SWRO)} \times 366 \times 0.85} = \frac{0.003311 H_{f(SWRO)}}{\text{Recovery}_{(SWRO)}} \quad (2)$$

Biological samples were collected in sterilized containers. Samples were taken from intake, before dual media filter (BDMF), after dual media filter (ADMf), after cartridge

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filter (ACF), and product waters. Using aseptic technique and standard pore plate method, samples were transferred to Petri dishes and grown in 5.51% Diffco marine agar at 0 hr and 24 hr incubation times. Bacterial densities were determined and performance was measured as a function of generation time.

$$GT = [(IT) * LN2 / (LN [ ]_{final} - LN [ ]_{initial})] \quad (3)$$

GT= Generation Time

IT= Incubation Time

### **3. RESULTS & DISCUSSION**

#### ***3.1 NF Performance Evaluation***

Feed flow and feed pressure rates to NF membranes were maintained at 8.0 m<sup>3</sup>/hr and 22 kg/cm<sup>2</sup>, respectively. The feed temperature varied from 15°C (in winter) to 35 °C (in summer). In winter, the feed temperature was raised from 15 to 25 °C by mixing of MSF reject with sea water from the open intake. This mixing increased the recovery rate of NF membranes from 45 % at feed temperature of 15 °C compared to 60 % at feed temperature of 25 °C and the same feed flow and pressure rates. During summer, the feed temperature was raised from 25°C to 35°C using the same mixing procedure. As a result, the recovery rate of NF membranes increased from 60 % to 75 % again at the same steady feed flow and pressure of 8.0 m<sup>3</sup>/hr and 22 Kg/cm<sup>2</sup>, respectively.

Increasing feed flow temperature had an obvious effect on the NF permeate. At 25°C, feed permeate conductivity to SWRO membrane was about 49,000 μS/cm. However, conductivity of NF permeate was 52,000 μS/cm when feed temperature was raised to 35°C (Figure 1). An increase in feed temperature resulted in an increase in salt passage across membranes.

#### ***3.2 SWRO Performance Evaluation***

Both feed flow and pressure to SWRO membranes was maintained at 3.0 m<sup>3</sup>/hr and 69 Kg/cm<sup>2</sup>, respectively. SWRO spiral wound membranes received feed from the NF filtrate. The feed temperature to SWRO membrane (in winter) was about 22°C and the recovery rate was 42 %. After mixing the MSF rejection stream with seawater coming

from the open intake, the feed temperature to SWRO membranes was measured at about 30°C. This resulted in an 8% increase in SWRO membranes recovery bringing the total recovery rate to 50%. The permeate conductivity of SWRO membranes was 700  $\mu\text{S}/\text{cm}$  at a feed temperature of about 21°C. However, as expected, permeate conductivity rose to 900  $\mu\text{S}/\text{cm}$  when feed temperature was increased to 30°C. When feed temperature was increased to 35°C, RO permeate conductivity was rose up to 1300  $\text{mS}/\text{cm}$  (Figure 2).

At 22°C, for a duration of 600 hr, the total daily water production of the SWRO unit was 25  $\text{m}^3/\text{d}$ . On the other hand, the total daily water production increased to 35  $\text{m}^3/\text{d}$  at feed water temperature of 30 and 40°C (Figure 3). The quality of potable water produced by SWRO membranes was observed to be 250 ppm at feed water temperature of about 24 °C and 30°C. However, the quality of product water rose to 500 ppm at feed water temperature of about 40°C (Figure 5). The calculated energy consumption of NF-SWRO membranes receiving feed from the open intake at temperature of 20 °C was observed to be 5.26  $\text{kWm}^3/\text{hr}$  whereas the energy consumption of NF-SWRO membranes receiving mixed feed from the MSF reject and intake water at a feed temperature of about 30 °C was calculated to be 4.34  $\text{kWm}^3/\text{hr}$ , for a total reduction in energy consumption of 18 % due to rising feed temperature by applying this mixing technique. The energy consumption was calculated using equation (2).

### **3.3 Biological Study**

At low temperatures (16.5°C -22.0 °C), ambient bacterial ( 25°C-30 °C and >30°C-40 °C, respectively) densities ranged from 0 to 2 orders of magnitude. At medium and high temperatures (25°C-30°C) and (>30°C – 40°C, respectively), bacteria densities ranged from 1 to 3 orders of magnitude.

After 24 hr incubation and at low temperatures, bacteria density ranged from 1 to 4 orders of magnitude. At medium and high temperatures bacterial concentrations ranged from 3 to 5 orders of magnitude. Data indicates that elevated temperature did have an effect on bacterial growth, however, higher bacterial performance or proliferation was observed in the medium temperature range.

Bacterial proliferation was measured as a function of generation time. In this experiment, the rate at which bacterial density doubled (GT) was generally inversely proportional to changing feed water temperatures. Performance of bacteria peaked at temperatures hovering around 30°C followed by the high then low temperature ranges.

#### **4. CONCLUSIONS**

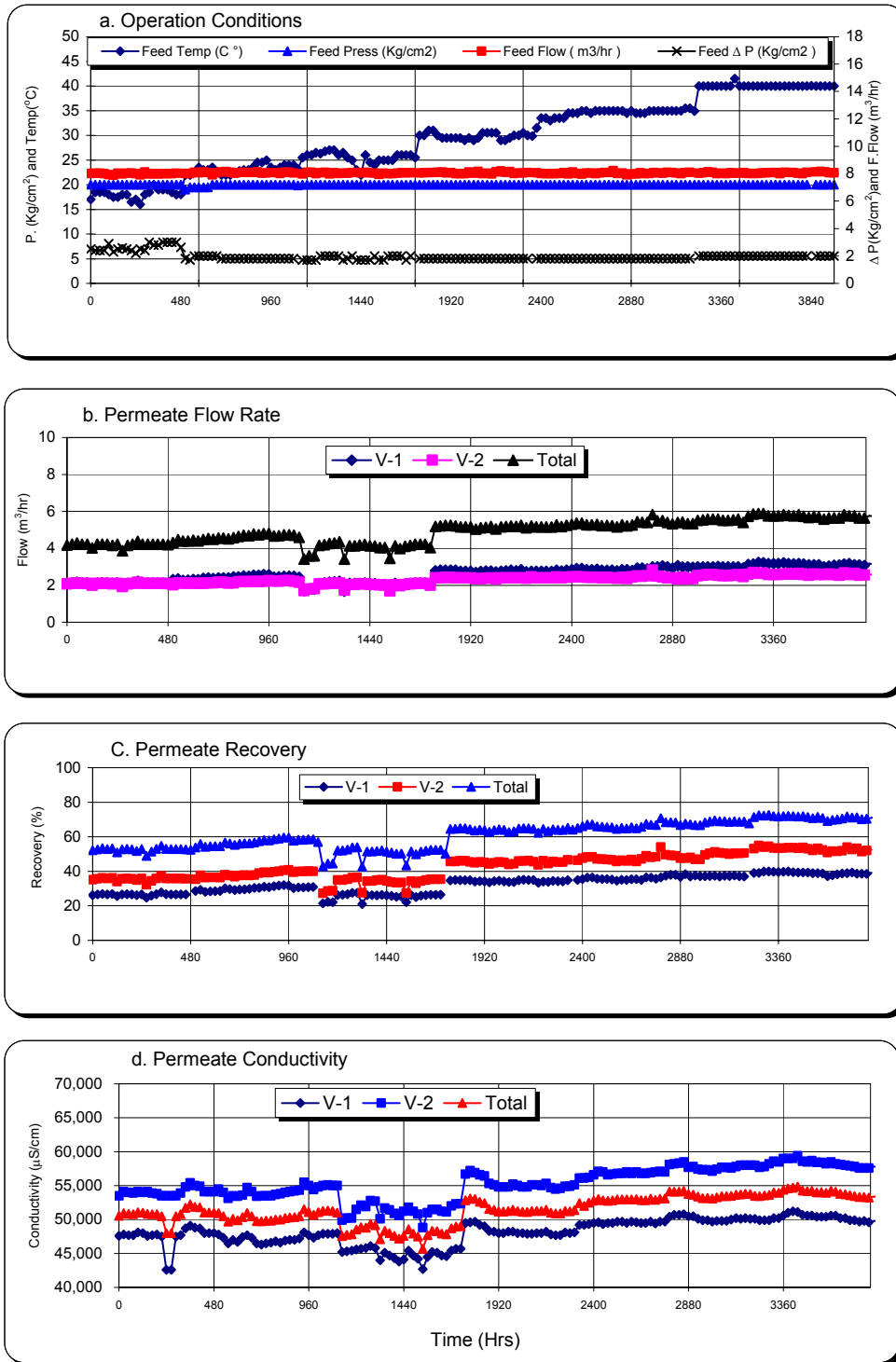
- (1) The optimum feed temperature of Fluid system SWRO membranes of 6" X 40" size was about 35°C with no observable increase in yield at higher feed temperature.
- (2) The energy consumption of NF-SWRO was reduced 18% by preheating the feed to NF-SWRO membranes utilizing seawater from MSF rejection stream
- (3) Potable water production cost are reduced as a result of reducing energy consumption
- (4) There is a 2% increase in water production rate per one degree rise in temperature. However, the increase in feed water temperature may accelerate the rate of membrane degradation.
- (5) Results did not indicate that biological activity was detrimental to the process. Optimal performance was observed around 30 °C. At higher temperatures biofouling potential was not as great.

#### **5. RECOMMENDATIONS**

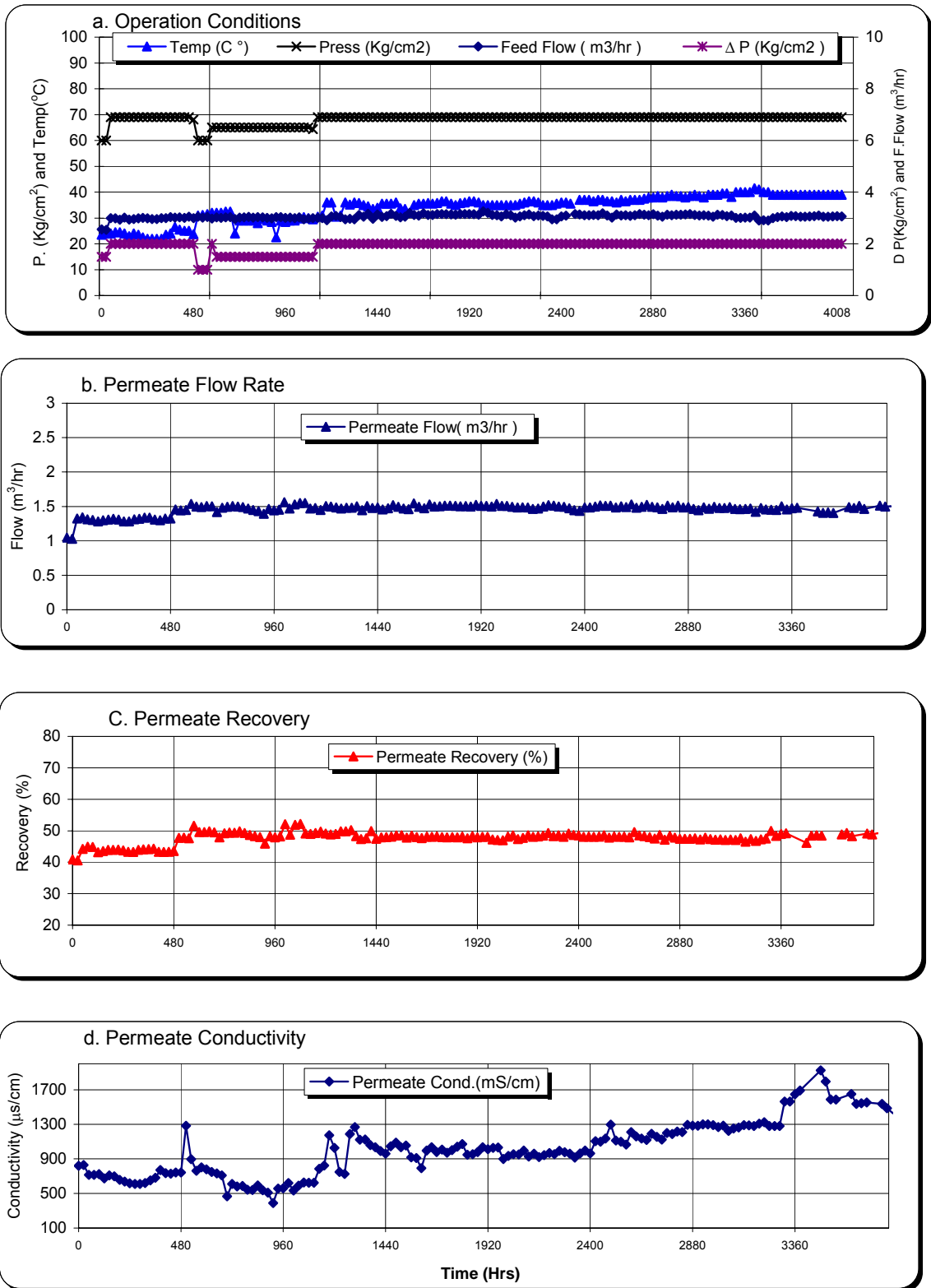
- (1) The feed temperature tolerance of SWRO membranes is about 35°C and should not exceed this value.
- (2) As this mixing process, which leads to rise in feed temperature, reduces the energy consumption of SWRO by 18%, it is strongly recommended to implement it in the current hybrid MSF-SWRO plants, e.g., Jeddah, Yanbu and Al-Jubail. In addition, it is recommended to be included in the design for new hybrid MSF-SWRO plants.

#### **6. REFERENCES**

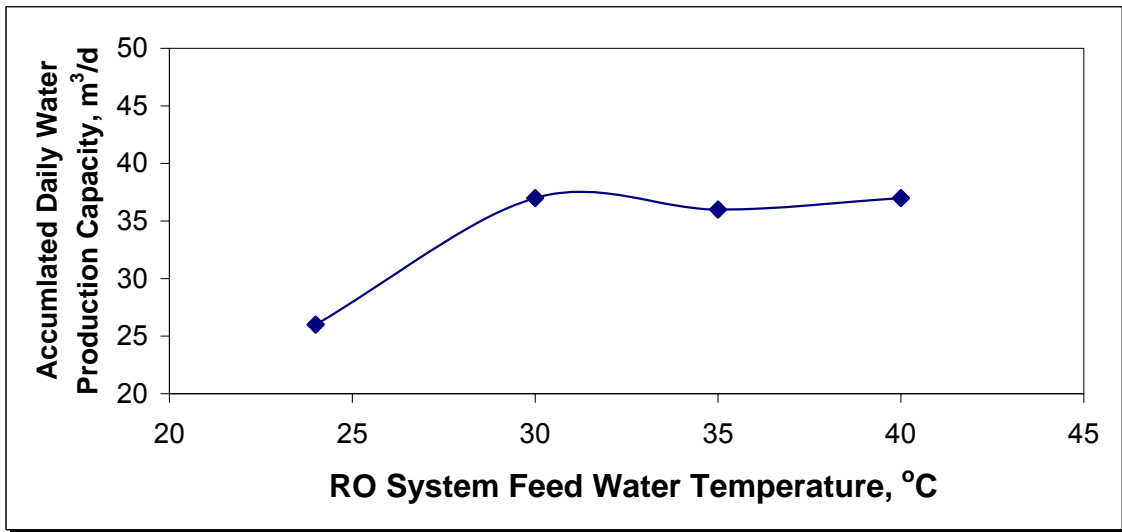
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2. Information department of SWCC, Kingdom of Saudi Arabia, Riyadh.
3. Water Treatment Handbook, A Halsted Press Book, John Wiley & Sons. See also "Pump Handbook (Second Edition), Igor J. Karassik William C. Krutzsch, Warren H. Franser and Joseph P. Messina, (Fifth Edition) McGraw Hill International Edition, Industrial Engineering Series.



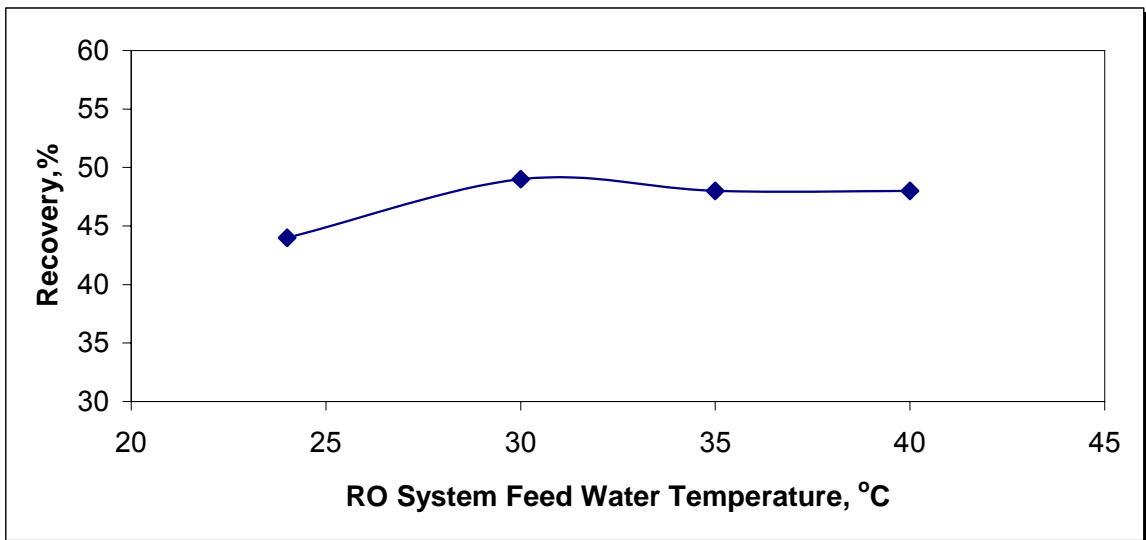
**Figure 1. Performance of NF8" Osomotic DK 8040 Membranes: a. Operating Conditions, b. Flow Rates, c. Recovery and d. Conductivity vs. Time**



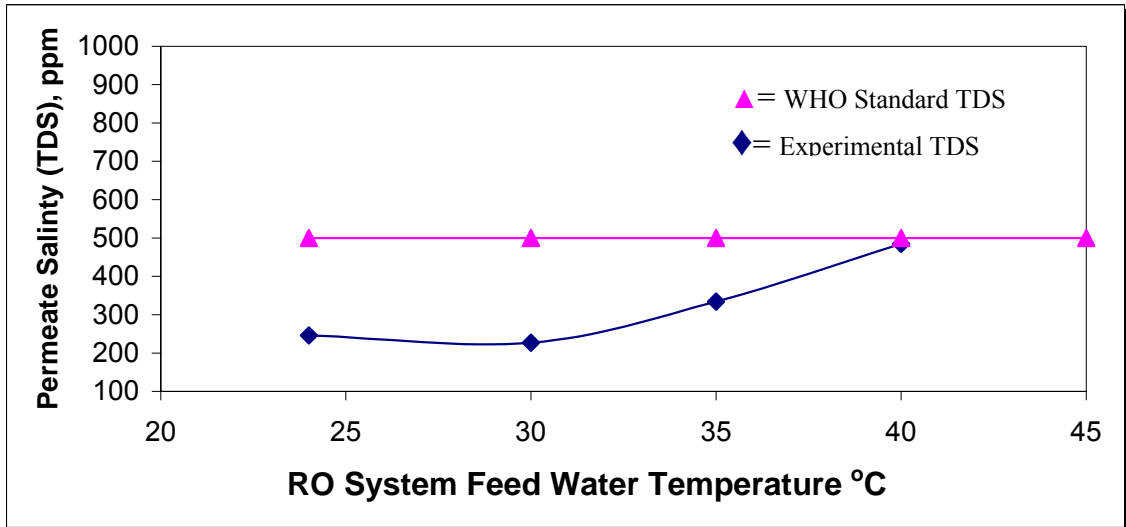
**Figure 2. Performance of Fluid system 6" spiral wound SWRO membrane: (a) Operating Conditions, (b) Flow Rates, (c) Recovery and (d) Conductivity vs. Time**



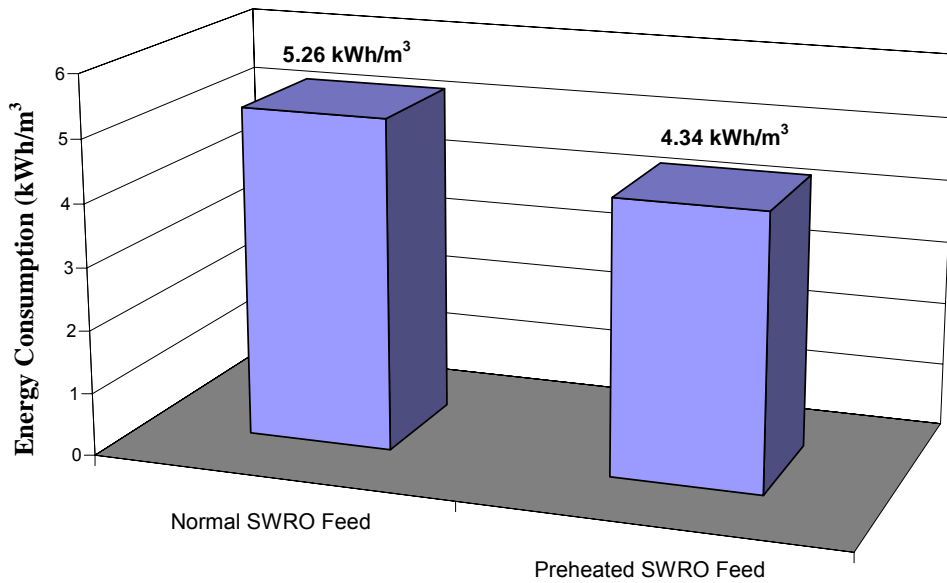
**Figure 3. Accumulated Daily Water Production Capacity vs. RO feed water temperature**



**Figure 4. RO system Recovery vs. Feed water temperature**



**Figure 5. RO permeate TDS vs. feed water temperature**



**Figure 6. Energy Consumption Comparison of water Produced by SWRO membranes receiving preheated and normal feed**

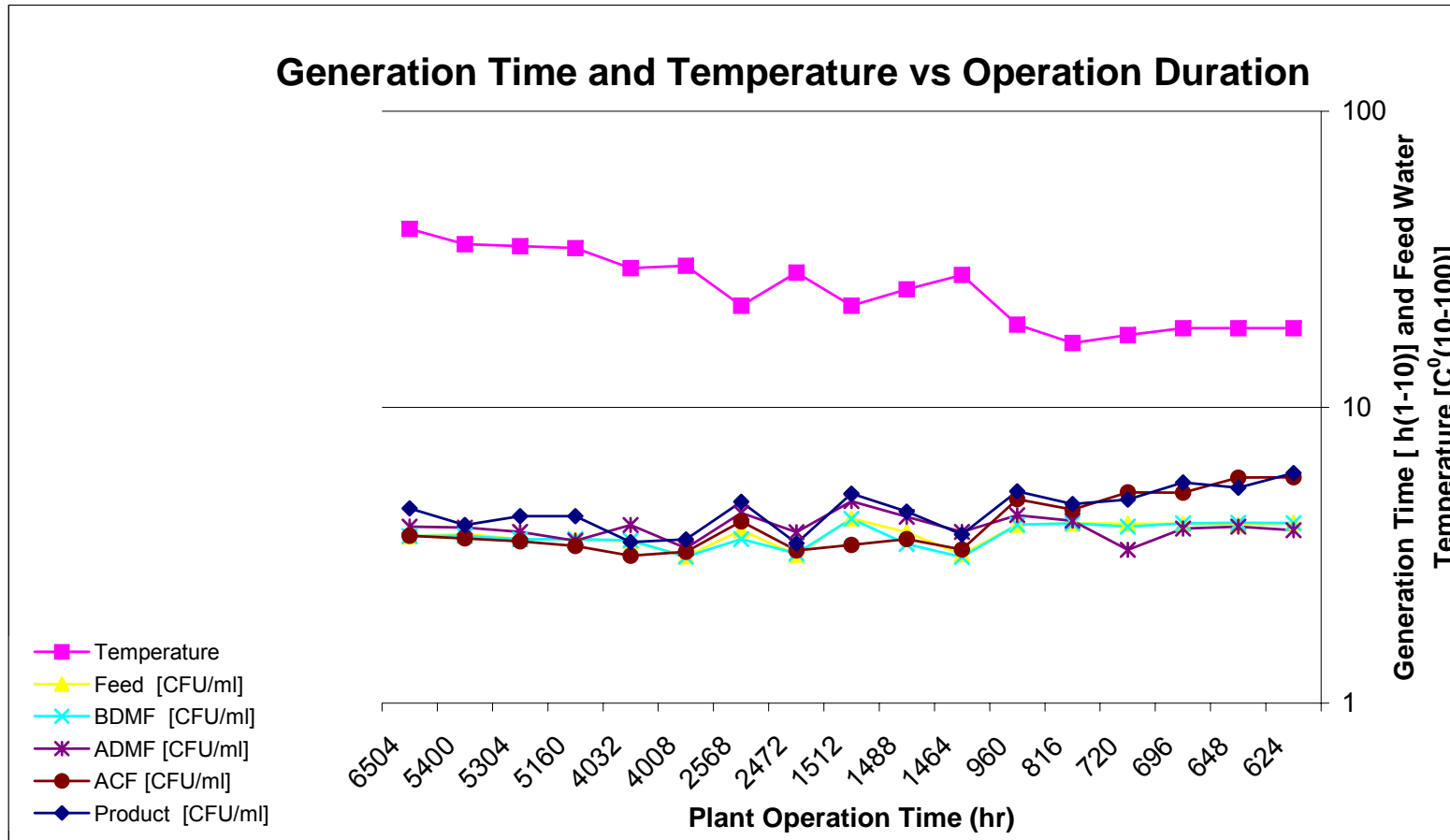


Figure 7. Generation time and temperature vs. operation duration