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Potable Water Production from Third River in Nasiriyah City

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Introduction

Water is vital for all living creatures on Earth. About 97% of water on Earth is ocean seawater, leaving only 2.5% of water on Earth as fresh water, and about 99% of that water is ice and underground. Due to population growth, industrialization, and climate change, water scarcity has become one of the most pervasive problems afflicting people throughout the world.

All water for drinking purposes must be treated to achieve standard quality. Therefore, there is a significant challenge to produce suitable drinking water. General treatment of drinking water consists of several stages to remove or reduce suspended and dissolved solid and microbial pollutants (Doosti et al., 2012). The choice of which treatment to use from the great variety of available processes depends on the characteristics of the water, the types of water quality problems likely to be present, and the costs of different treatments (Mohammad and Entesar, 2010).

Test	Range Value	Test	Range Value	Test	Range Value
pH	7.8 – 8.6	Ca ²⁺	230 – 450 mg/l	COD	12 mg/l
Temp.	15 – 33.6 °C	Mg ²⁺	296 – 435 mg/l	BOD	2.5 mg/l
TSS	6542 mg/l	O & G	31.5 mg/l	DO	7 mg/l
TDS	5410 – 9600 mg/l	NO ₃	1.55 – 0.87 mg/l	PO ₄	0.02 – 0.29 mg/l
Cl ⁻	1350 – 2350 mg/l	Alk	184 – 295 mg/l	Na ⁺	1389 mg/l
SO ₄ ²⁻	634 – 1780 mg/l	Acid	Nil	K ⁺	8.8 mg/l
COND.	7920 – 12050 µs/cm	Turbidity	0.4 – 100 NTU	Ba	0.138 mg/l
TH	1930 – 3440 mg/l	NaCl %	16.652 %	Sr	0.0916 mg/l

Table 1: Specification of Third River Water

Coagulation is a process used to neutralize charges and form a gelatinous mass to trap (or bridge) particles, thus forming a mass large enough to settle or be trapped in the filter. Flocculation is the step where destabilized colloidal particles (or the particles formed during the coagulation step) are assembled into aggregates. Flocculation is gentle stirring or agitation to encourage the particles thus formed to agglomerate into masses large enough to settle or be filtered from the solution (Rahul et al., 2014). Coagulation is the step where colloidal particles (similar to spheres of a diameter of less than 1 micrometer) are destabilized (SNF, 2003).

Microfiltration (MF) is the process of removing particles or biological entities in the 0.025 µm to 10 µm range from fluids by passage through a micro porous medium such as a membrane filter (Hjerpe and Olsson, 2012). Reverse Osmosis is a water filtration method. It is referred to as hyper-filtration as it is the highest known form of filtration to date, removing all solids including metal ions and aqueous solids in brackish water application

(Robertus, 2006 and Sourirajan, 1970). This operation is a membrane separation process in which brackish water permeates through a membrane by applying a pressure larger than the osmotic pressure of the brackish water.

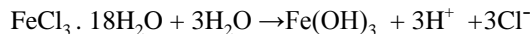
The membrane is permeable for water, but not for the dissolved salts and molecular organic contaminants from water. In this way, a separation between a pure water fraction (the permeate) and a concentrate fraction (the retentate) is obtained. Most RO membranes are thin-film composite membranes and the membranes are usually configured in spiral wound modules (Hanane, 2008 and Merten, 1966).

Chemical Reactions

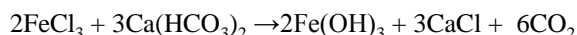
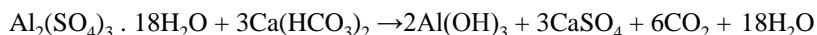
The addition of alum (hydrated aluminum sulfate) to water produces insoluble aluminum hydroxide according to the reaction (MRWA, 2003):



While the addition of ferric chloride to water produces insoluble ferric hydroxide, according to the reaction (MRWA, 2003):



Aluminum and iron coagulants react with bicarbonate alkalinity (HCO_3^-) in acid drainage creating aluminum; ferric hydroxide flocs can be represented by the following equations (MRWA, 2003):



Theoretical Aspects

1. Water and Solute Fluxes

The Water and salt Fluxes through RO membrane can be described by two models: solution-diffusion model and irreversible thermodynamics models. The two models are selected based on the credibility they have among researchers as well their domination in practical applications. The two models are conceptually different. The expressions for water and salt (solute) fluxes through the membrane are given by the following equations (Thor and Harald, 2006):

$$J_w = A_p (\Delta P - \Delta \pi)$$

$$J_s = \left(\frac{D}{K\delta} \right) \Delta C$$

Where J_w is the product water flux, A_p is the pure water permeation, ΔP is the operating pressure, $\Delta \pi$ is the difference in the osmotic pressure across the membrane, J_s is the flux of salt permeating the membrane, $(D/K\delta)$ is the salt permeability coefficient, and ΔC is the difference in salt concentration across the membrane. The salt permeability coefficient takes

into account the diffusivity coefficient of the salt through the membrane, D , the partitioning of salt concentration between the bulk solution and the membrane, K , and the membrane thickness, δ . The model considers $(D/K\delta)$ as an intrinsic parameter, which is not calculated by dividing the diffusivity coefficient to the product of the partitioning coefficient times the membrane thickness (Ahmed, 2007 and Rana, 2011).

2. Recovery

The recovery is the percentage of the feed flow that passes through the membrane and becomes the permeate stream. It is an estimation of the performance of a membrane system. It measures the volumetric fraction of permeate to the feed showing how much of permeate is recovered from the feed. It is also called separation efficiency.

$$R_v = \frac{Q_p}{Q_f} \times 100\%$$

Where R_w is the recovery percentage, Q_p is the permeate (or product) flow rate and Q_f is the feed flow rate (Richard, 2012 and Uche, 2011).

3. Salt Rejection Percentage

Membrane salt rejection is a measure of overall membrane system performance, and membrane manufacturers typically state a specific salt rejection for each commercial membrane available. Salt rejection through RO membrane (crossflow operation) is nominally given by:

$$R_s = \left(1 - \frac{C_{permeate}}{C_{feed}} \right) \times 100\%$$

Where R_s is the rejection percentage, C_{feed} is the concentration of a specific component in the feed solution to the membrane process and $C_{permeate}$ is the concentration of the same specific component in the cleaned discharge stream leaving the membrane system (Nicholas, 2002).

4. Concentration Factor

The concentration factor (CF) is the ratio of the concentrate TDS concentration in the concentrate or reject stream to its concentration in the feed stream (Lauren et al., 2009):

$$CF = \frac{C_{concentrate}}{C_{feed}}$$

Materials and Methods

Materials:

- Water samples: from Third River.
- Coagulants: alum $[Al_2(SO_4)_3 \cdot 18H_2O]$, ferric chloride $[FeCl_3]$ and Polyelectrolyte.

Methods:

- Jar test apparatus: A conventional unit was used with three beakers, each 1000 ml in

- capacity.
- HACH (2100 N) Turbidimeter: to measure the turbidity of the samples throughout the experimental work in NTU unit.
 - pH meter (type inoLab 7110 basic pH/mV/T benchtop meter WTW): to measure the pH variation during the chemical reaction.
 - MF Membrane: Water filter cartridge 5 μm and water filter cartridge 1 μm are used.
 - RO Membrane: KFLOW element (0.1 – 2.1 MPa and 5 – 40°C) fits in standard residential membrane housings was used.
 - Vessels: Two vessels with capacity of 25 liters were used as feed and concentrate vessels. In addition, vessel with a capacity of 10 liters was used as permeate vessel.
 - Pump: One centrifugal pump (10 – 30 l/min, 20 – 12 m.H, 370 Watt, 220 – 240 V, 2.5 A, MARQUIS) was used.
 - High Pressure Pump: Positive displacement, diaphragm pump was used.
 - Pressure Gauge is used in the feed line to indicate the feed brine pressure (range of 0 – 20 psi).
 - Rotameter: Calibrated rotameter (range of 1 – 7 LPM) is used.
 - Heater: One submersible electrical coil (220 Volt, 1000 Watt) was used as a heating media.
 - Total Dissolved Solid (TDS) Meter: The concentration of the feed, the reject (outlet concentration) and the permeate (product solutions) were measured by means of a digital TDS hand – held meter.
 - Digital Balance: A digital balance with four decimal points (Sartorius BP 301 S max. 303 g, d = 0.1 mg) is used.
 - Furnace: A Barnstead/ Thermolyne Small Benchtop Muffle Furnace, Type 1400, Thermo Scientific was used in the sulphate test.

Procedure:

The practical part of this work consists of three stages: Coagulation/Flocculation process, Microfiltration, and RO process.

1. Coagulation and Flocculation Process:

- Set of experiments were done using three initial turbidity contents: 30, 50 and 100 NTU
- The first sets of tests were to find the efficiency of turbidity removal using alum, ferric chloride, and polyelectrolyte as individual coagulants. The second trail was to test speed and time of slow mixing and settling time with the above coagulants in turbidity removal.
- The experimental work (jar test) was performed as rapid mixing at 100 rpm for 2 min.
- Samples were withdrawn from the top inch of each beaker for turbidity measurement.
- Turbidity was measured by using the turbidimeter.

2. Microfiltration:

Known turbidity and TSS water is fed into 5 μm MF membrane and 1 μm MF membrane severally then the turbidity and TSS of outlet was measured.

3. RO Membrane Separation Process:

- An experimental rig was constructed in the laboratory as shown schematically in figure 1 and pictured in figure 2.
- Feed solution is prepared in the 25-liter vessel and then the outlet valve of

the feed vessel is opened to let the solutions fill the whole pipes of the system. The feed water is drawn from the vessel by means of a centrifugal pump to pass through filters (5 μm and 1 μm) then the water introduced into the RO elements by means of a high-pressure pump. Through RO element, water transports from the inlet stream across the salt rejecting membrane and into the product.

- Sets of tests are done and the different concentrations of feed water are putted in the feed vessel and the readings for rejected stream and produced stream are recorded. Also effect of the operating temperature is studied.
- Other sets of tests are done by the recycle mode where the rejected stream is recycled to the feed vessel and the reading is recorded for known periods of time.
- The Gravimetric Method is used to determine sulphate ion in the feed permeate and reject streams. The titration is used to determine total hardness, calcium, magnesium, and chloride ions in the feed permeate and reject streams (David, 2000, Jeffery et al., 1989, Aparna, 2013).
- Osmotic pressure of a solution is related to its dissolved solute concentration and is calculated from van't Hoff equation:

$$\pi = \Phi iRT \sum X_i$$

Where: π is the osmotic pressure (kPa), Φ is the osmotic coefficient, i is the number of dissociated ions per molecule (van't Hoff factor), T is the temperature (K), R is the universal gas constant and $\sum X_i$ is the concentration of all dissolved salts (kgmol/m^3). The van't Hoff factor is introduced to cover deviations from ideal solution behavior that include finite volume occupied by solute molecules and their mutual attraction as in van der Waals attraction. For all solutes Φ depends on the substance and on its concentration. As the concentration of any solute approaches zero its value of Φ approaches 1. In ideal solution, $\Phi = 1$ (Robertus, 2006 and Mohammed, 2008).

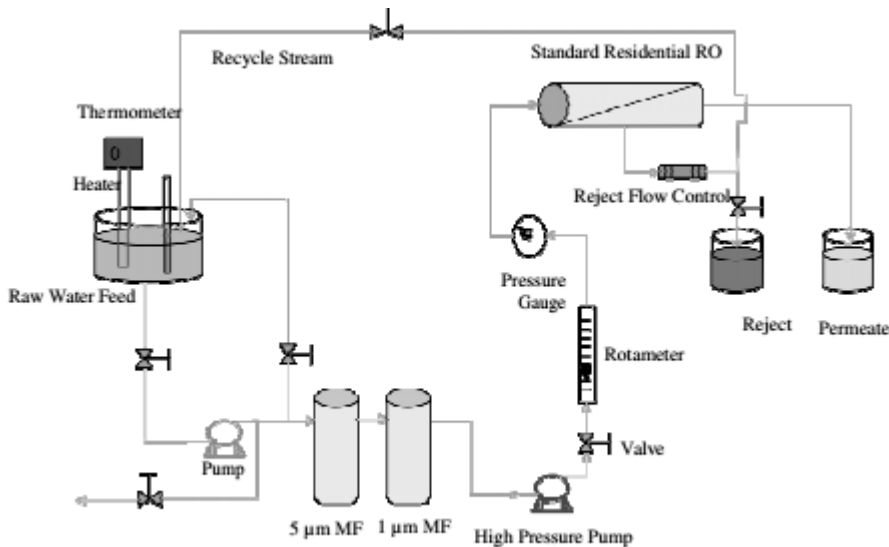


Figure 1: Schematic Diagram of RO Separation Process

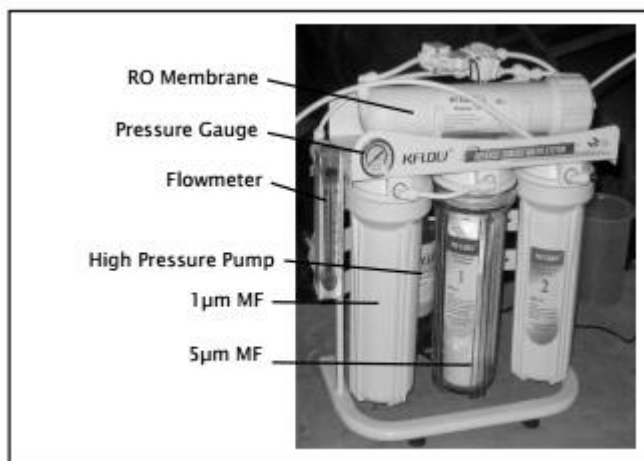


Figure 2: Experimental System of RO Membrane Separation Process Results and Discussion

Results and Discussion

In the present work, the parameters such as turbidity, total suspended solids (TSS), total dissolved solids (TDS), concentrations of studied components, and temperature are studied with their ranges in Third River water. In the Reverse Osmosis (RO) membrane technology experiment with recirculation mode, the time parameter reaches to (50 min) where the difference between operating pressure and osmotic pressure became very small then the process is stopped.

Coagulation and Flocculation

1. Effect of Coagulant Dosage on Turbidity Removal:

The effect of different coagulants dosages (Alum, FeCl_3 and Polyelectrolyte) on turbidity removal from Third River water is shown in figures 3, 4, and 5 for initial turbidities of 30, 50 and 100 NTU respectively. These figures show that the optimum dose for alum was 40, 45, and 50 ppm for 30, 40, and 100 NTU initial turbidity respectively. Meanwhile, for ferric chloride it was 20, 25, and 30 ppm and for polyelectrolyte 6, 8, and 10 ppm for 30, 50, and 100 NTU initial turbidity respectively. A similar observation was noticed in the experimental study of Hasan et al., 2010 and Kadhum et al., 2011.

Colloidal particles in nature normally carry charges on their surface, which lead to the stabilization of the suspension. By addition of some chemical dose, the surface property of such colloidal particles can be neutralized and precipitated so as the turbidity can be decreased until the all colloidal particles are neutralized and precipitated where the minimum turbidity can be obtained. Any more addition of the chemicals dose leads to increase the turbidity because there are no charged colloidal particles to neutralize with. These excess chemicals stay in the water as suspension and increase turbidity.

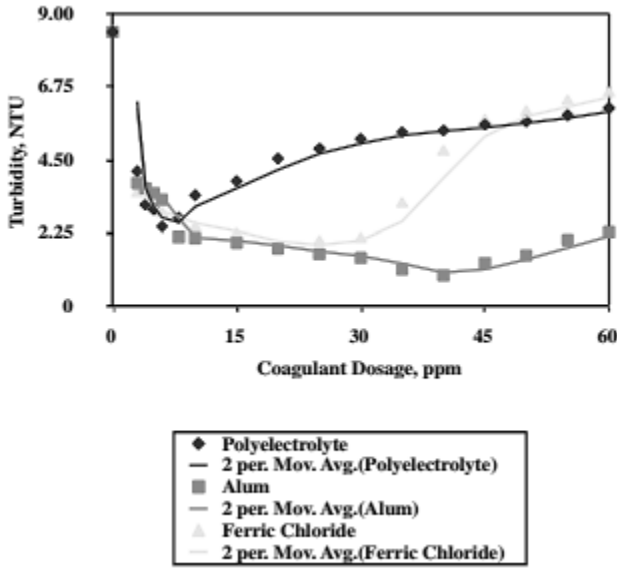


Figure 3: Effect of Coagulant Dosage on Turbidity removal (Coagulation Time 2 min (100 rpm), Flocculation Time 30 min (25 rpm), Settling Time 30 min, Initial Turbidity = 30 NTU, pH = 8.2)

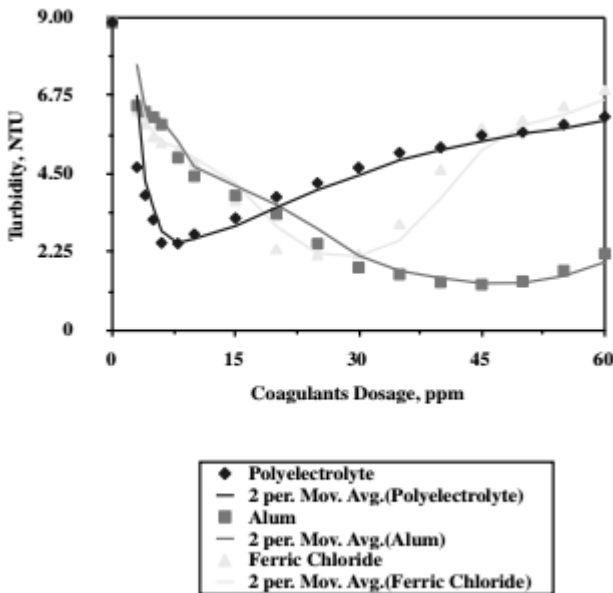


Figure 4: Effect of Coagulants Dosage on Turbidity Removal (Coagulation Time 2 min (100 rpm), Flocculation Time 30 min (25 rpm), Settling Time 30 min, Initial Turbidity = 50 NTU, pH = 8.2)

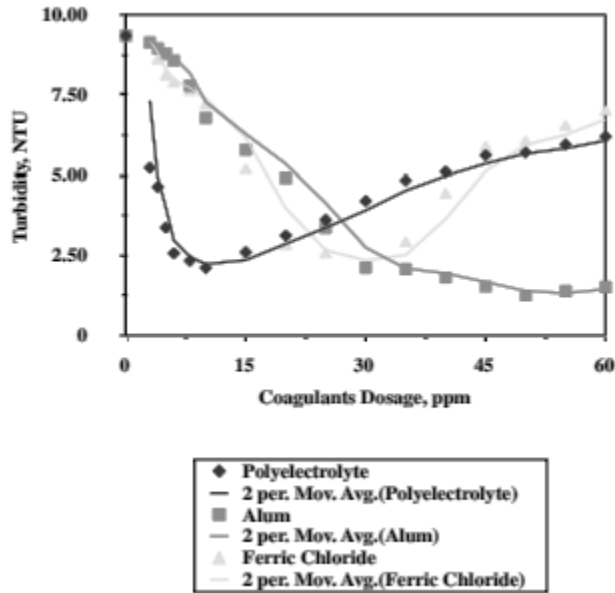


Figure 5: Effect of Coagulants Dosage on Turbidity Removal (Coagulation Time 2 min (100 rpm), Flocculation Time 30 min (25 rpm), Settling Time 30 min, Initial Turbidity = 100 NTU, pH = 8.2)

2. Effect of Speed and Time on Turbidity Removal

Figures 6, 7, and 8 show the effect of speed of the second step (flocculation step), time of the second step, and settling time on turbidity removal respectively for the same initial turbidity concentration (30 NTU) of water from Third River. In these experiments, the optimum speed of second step was (25 rpm) for both of alum (40 ppm), ferric chloride (20 ppm) and polyelectrolyte (6 ppm). While the optimum time of the second step was (30 min) for both of alum (40 ppm), ferric chloride (20 ppm) and polyelectrolyte (6 ppm) and of settling was (30 min) for both of alum (40 ppm), ferric chloride (20 ppm) and polyelectrolyte (6 ppm). A similar observation was noticed in the experimental study of James et al., 2004.

It has been found that for high solids concentrations and relatively low doses, flocculation occurs rapidly, but the flocs are not stable and can be broken at moderate stirring rates so high values of turbidity are obtained. Increased mixing speed of the second step leads to low values of turbidity. Increased agitation more leads to the production of smaller flocs and the turbidity increased. By reducing the rate of stirring shortly after dosing, floc size (and settling rate) can be held at plateau levels, without subsequent decline.

Incomplete mixing of the flocculant may result in local overdosing and restabilization of a small number of particles, giving rise to a persistent haze in the water so high values of turbidity are obtained. Increased mixing time of the second step decreases values of turbidity. By continuity, the restabilization state appears for small number of particles and the turbidity increased.

Decreases settling time, allowing much higher flow rates to be treated. The electrostatic repulsive forces do not constrain the particles from approaching each other because the suspension is characterized as instable; therefore, short time period is required for settling. After this time there is no express change in turbidity recorded.

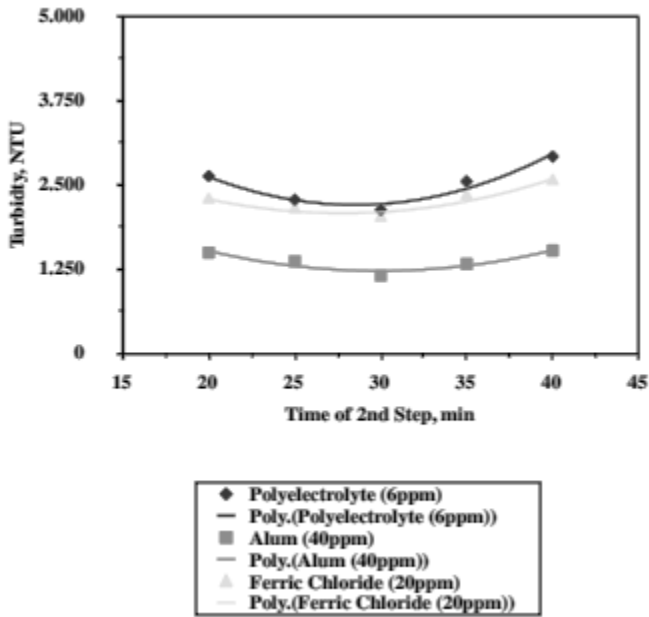


Figure 6: Effect of Speed of Second Step on Turbidity (Coagulation Time 2min (100 rpm), Flocculation Time 30 min, Settling Time 30 min, Initial Turbidity =30 NTU, pH = 8.2)

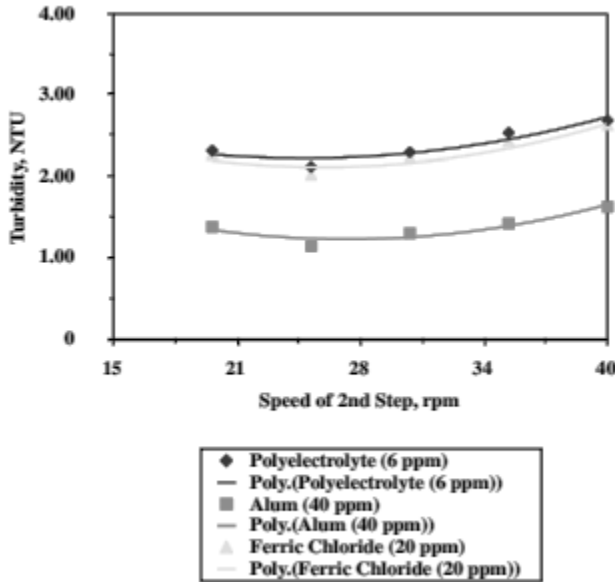


Figure 7: Effect of Time of Second Step on Turbidity (Coagulation Time 2min (100 rpm), Flocculation Speed 25 rpm, Settling Time 30 min, Initial Turbidity = 30 NTU, pH = 8.2)

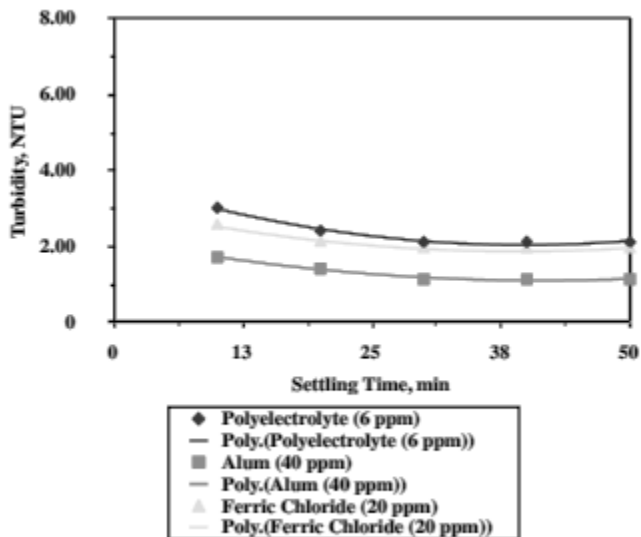


Figure 8: Effect of Settling Time on Turbidity (Coagulation Time 2 min (100 rpm), Flocculation Time 30 min (25 rpm), Initial Turbidity =30 NTU, pH = 8.2)

Microfiltration Membranes

Microfiltration (MF) membranes (5 μm & 1 μm) are used to remove the turbidity and TSS from water. The same feed water inlet into MF membranes (5 μm & 1 μm) and the results show that the quantity of the production for 5 μm MF is more than that for 1 μm MF.

When the pore size of membrane was small, the quality of the production was better and the operating pressure was high, see figures 9 and 10.

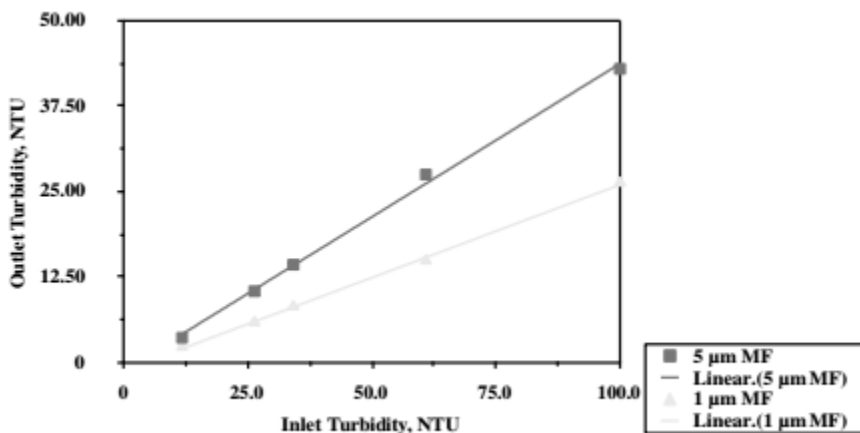


Figure 9: Effect of Feed Turbidity Change on Product Turbidity

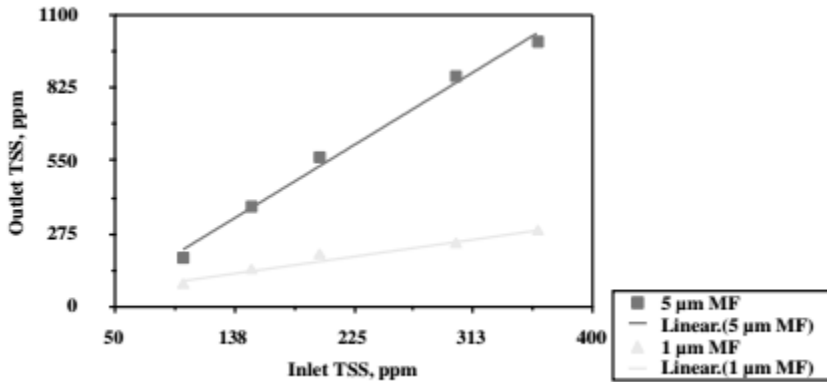


Figure 10: Effect of Feed Total Suspended Solids (TSS) Change on Product TSS

Reverse Osmosis RO Membrane Technology

1. Effect of Feed Concentration:

By increasing concentration of water feed from Third River, osmotic pressure increases, then driving force ($\Delta P - \Delta \pi$) decreases. This appears as a decrease of water flow through the membrane to 0.66 l/h at feed concentration 8170 mg/l. This is shown in figure 11. Also, figure 11 show the effect of feed concentration of Third River water on recovery where upper value of recovery percentage was 16.857 % at feed concentration 2000 mg/l and by increasing the concentration of water feed From Third River, the recovery percentage decrease until reaching to lower value 1.571 % at feed concentration 8170 mg/l according to the equation 7. By increasing feed concentration of water, solute flux increases according to the equation 6, this appears as an increase of solute concentration in the product as shown in figures 12 and 13.

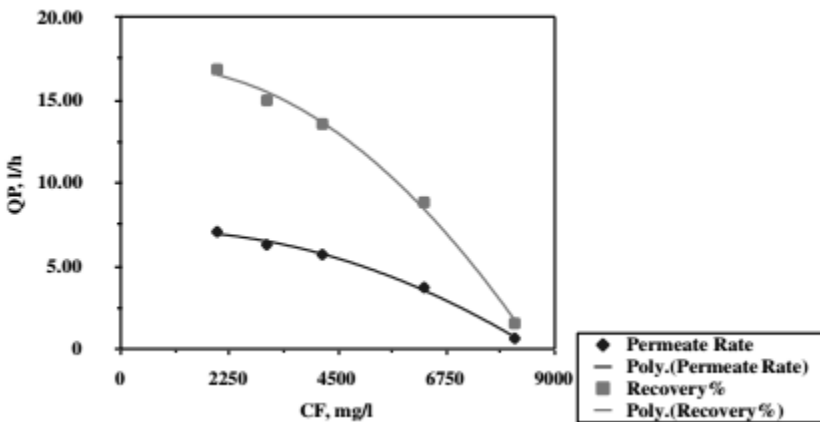


Figure 11: Effect of Feed Concentration Change on Permeate Rate and Recovery Percentage (at T = 27°C, P = 85 psi, pH = 8, QF = 421/h)

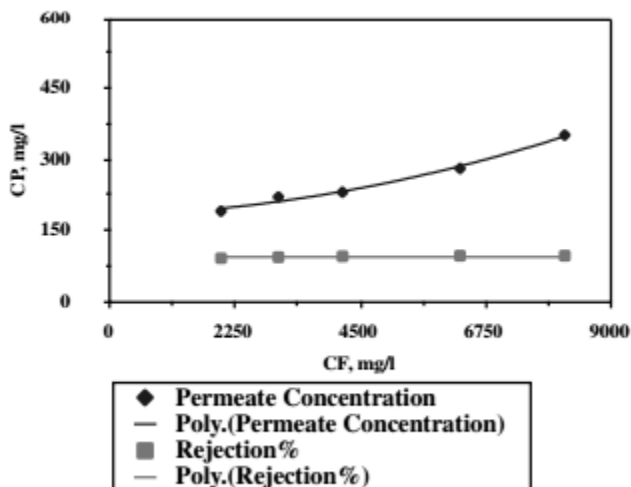


Figure 12: Effect of Feed Concentration on Permeate Concentration and Rejection Percentage (at T = 27°C, P = 85 psi, pH = 8, QF = 42 l/h)

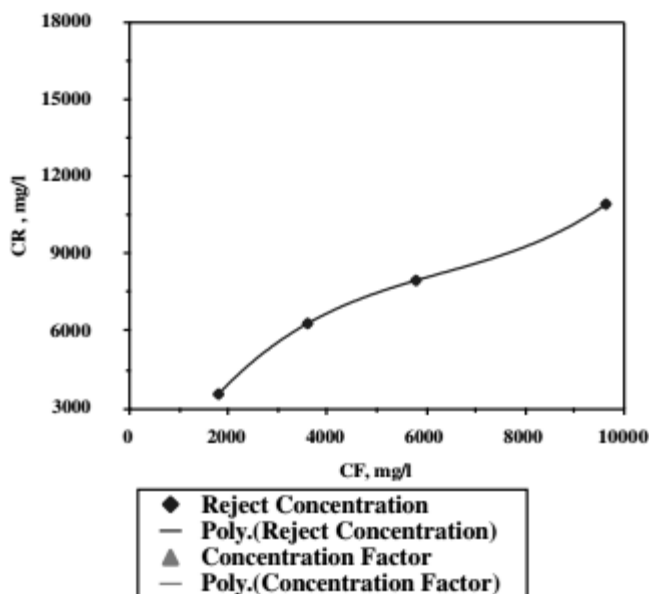


Figure 13: Effect of Feed Concentration on Reject Concentration and Concentration Factor (at T = 27°C, P = 85 psi, pH = 8, QF = 42 l/h)

Figure 14 shows that the increasing in feed concentration of Third River water leads to increased sulphate ion concentration (SO_4) (27.323 – 70.624 mg/l), TH (65 – 480 mg/l), Ca^{2+} (2 – 20 mg/l), Mg^{2+} (9 – 59 mg/l), and Cl^- (37 – 692.25 mg/l) in the permeate respectively because by this increasing in feed, solute flux increases according to the equation 6, this appears as an increase of solute concentration in the

permeate.

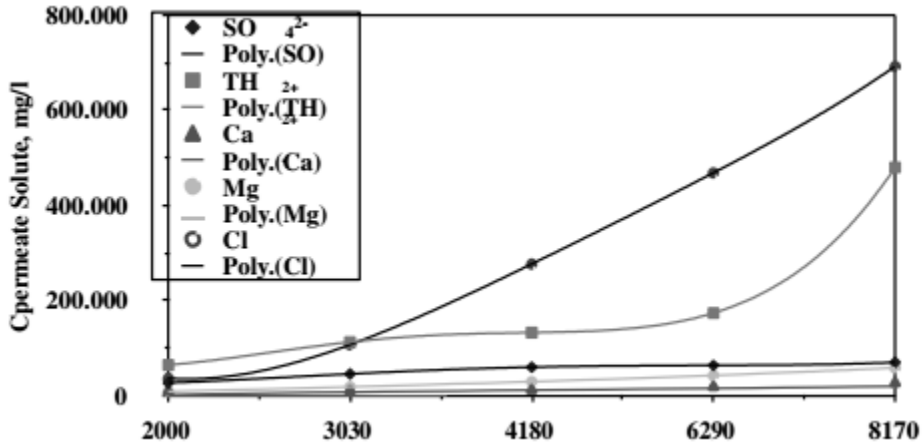


Figure 14: Effect of Feed Concentration on Solute Permeate Concentration (at T = 27°C, P = 85 psi, pH = 8, QF = 42 l/h)

Figure 15 shows the change in rejection percentage. The salts which have high molecular weight such as SO²⁻ and Ca²⁺ pass through the membrane with rejection percentage larger than salts which have low molecular weight such as Mg²⁺ for the same values of valence. For different values of valence, the salts which have high valence such as Ca²⁺ pass through the membrane with rejection percentage larger than salts which have low valence such as Cl for the same or approaching molecular weights. This relation was contingent with the equation 10.

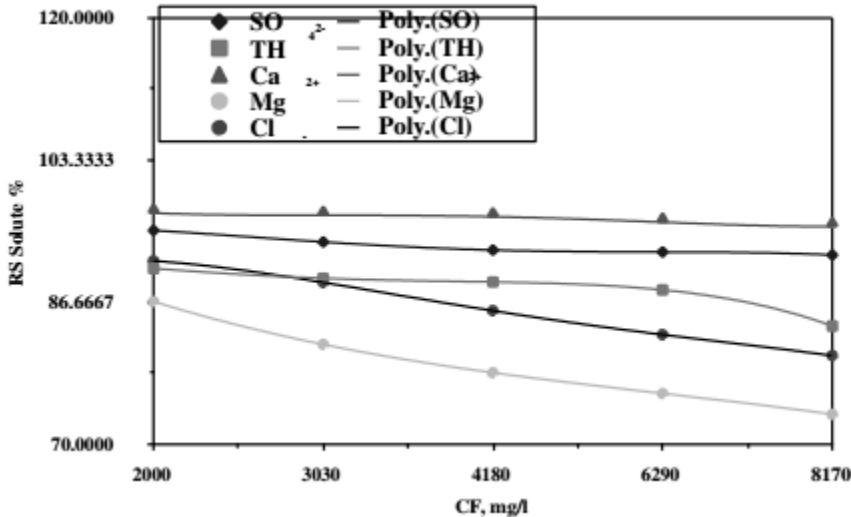


Figure 15: Effect of Feed Concentration on Solute Rejection Percentage (at T = 27°C, P = 85, pH = 8, QF = 42 l/h)

Figure 16 shows that the increasing in feed concentration of water from Third River leads to increase sulphate ion concentration (SO₄²⁻) (651.16 – 978.721 mg/l), TH (1000

– 3090 mg/l), Ca^{2+} (120 – 698 mg/l), Mg^{2+} (140 – 269 mg/l), and Cl^- (624.41 – 3920.04 mg/l) in the reject respectively because pure water transfer from feed side to the permeate side across the membrane and this leads to concentrate of solute in the reject.

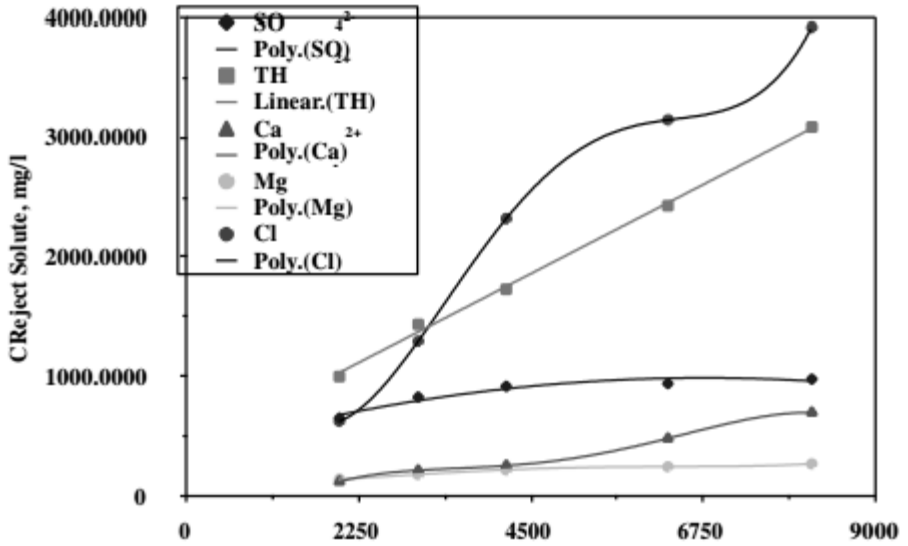


Figure 16: Effect of Feed Concentration on Solute Reject Concentration (at $T = 27^\circ\text{C}$, $P = 85$ psi, $\text{pH} = 8$, $Q_F = 42$ l/h)

The increasing in feed concentration of water from Third River leads to decrease in concentration factor for sulphate ion (SO_4) (1.168 – 1.079) TH (2.536 – 1.037), Ca^{2+} (1.714 – 1.551), Mg^{2+} (2.059 – 1.206), and Cl^- (1.43 – 1.109) according to equation 9. This is shown in figure 17.

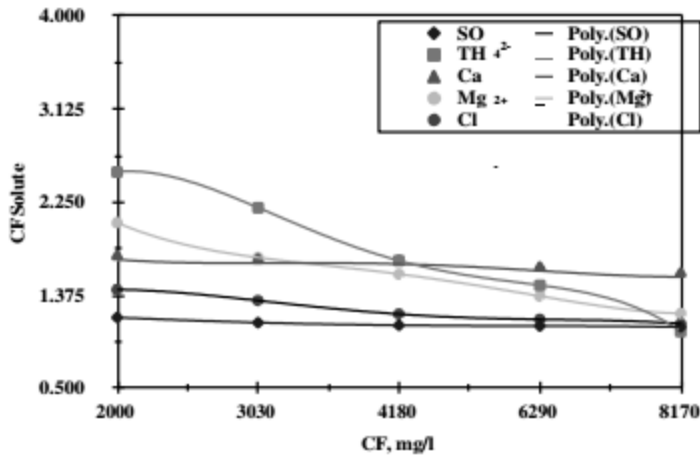


Figure 17: Effect of Feed Concentration on Solute Concentration Factor (at $T = 27^\circ\text{C}$, $P = 85$ psi, $\text{pH} = 8$, $Q_F = 42$ l/h)

Effect of Operating Temperature

Increasing of inlet operating temperature with the range of (20 – 37 °C) will increase the product rate with the range of (2.7 – 5.82 l/h) and recovery percentage of water with the range of (6.429 – 15 %). This is shown in figure 18. A change in operating temperature of feed water from Third River changes (1) the densities and viscosities of the feed, and (2) the osmotic pressure of the system. An increase of temperature increases the osmotic pressure of feed water from Third River, resulting in a decrease in the driving force ($\Delta P - \Delta \pi$). Thus while change (1) above increase the relative flow of the pure water through the membrane with increase in temperature; the change in the osmotic pressure has the opposite effect. A similar observation was noticed in the experimented study of Mohammed, 2008 and Mattheus et al., 2002.

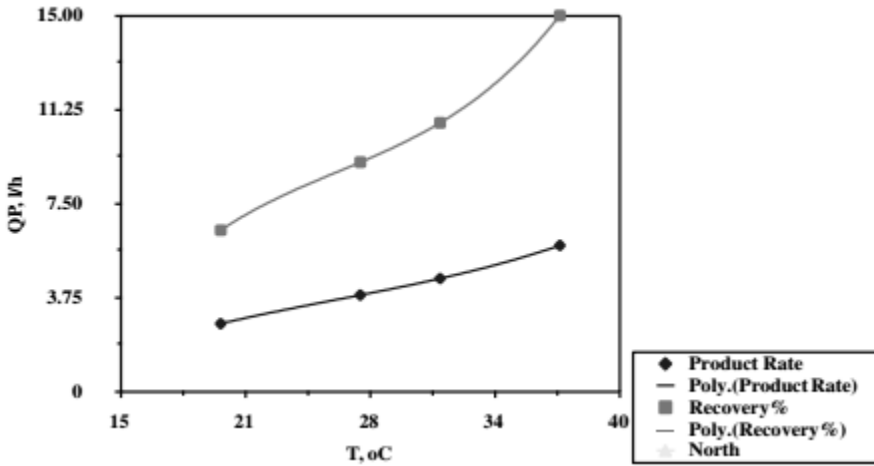


Figure 18: Effect of Operating Temperature on Product Rate Flux and Recovery (at $C_F = 3500$ ppm, $P = 85$ psi, $pH = 8$, $Q_F = 42$ l/h)

The increase of operating temperature for feed water from Third River with the range of (20 – 37°C) leads to increase the flux; this appears as an increase of salts concentrations in the product with the range of (150 – 280 mg/l). The effect of operating temperature on salts concentrations, can be explain the decreasing of rejection percentage with increase in operating temperature, see figure 19. While figure 20 show that the reject concentration and concentration factor decrease with the ranges of (2840 – 2210 mg/l) and (1.136 – 0.884) respectively with increasing temperature because the increasing of pure water passed through the membrane into permeate stream leads to decrease the salts concentration in the reject. A similar observation was noticed in the experimented study of Mohammed, 2008.

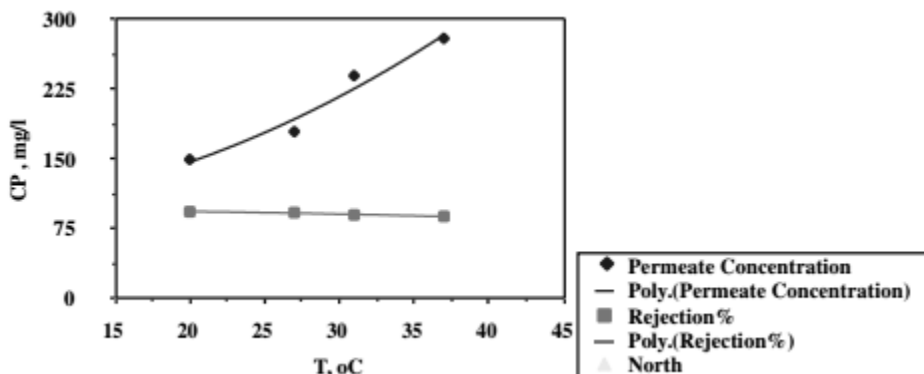


Figure 19: Effect of Operating Temperature on Product Solute Concentration and Rejection Percentage, (at $C_F = 3500$ ppm, $P = 85$ psi, $pH = 8$, $Q_F = 42$ l/h)

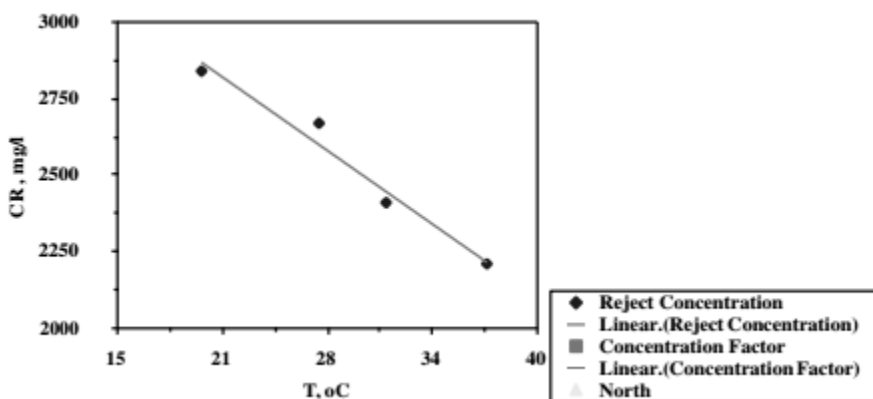


Figure 20: Effect of Operating Temperature on Reject Concentration and Concentration Factor (at $CF = 3500$ ppm, $P = 85$ psi, $pH = 8$, $Q_F = 42$ l/h)

Recirculation of Concentrate

In some experiments, the RO is used to recovery of water from effluents of Third River. The permeate is removed and the concentrate stream is recycled back to the feed vessel in order to recover high quantity from pure water. At time equal to zero, for recirculation of concentrate the operating conditions for the water from Third River with 4430 mg/l concentration were $VF = 25$ l, $QF = 50$ l/h, $T = 27^\circ\text{C}$, $P = 85$ psi.

Figure 21 shows the effect of time on volume of permeate and recovery percentage. As the time increased the product rate decreased. This leads to decrease the recovery percentage according to the equation 7. Because of an increase of the feed concentration with time in the recirculation mode, the salts concentration in the product increased with the increase in operating time. This means that the rejection percentage decrease, see **figure 22**.

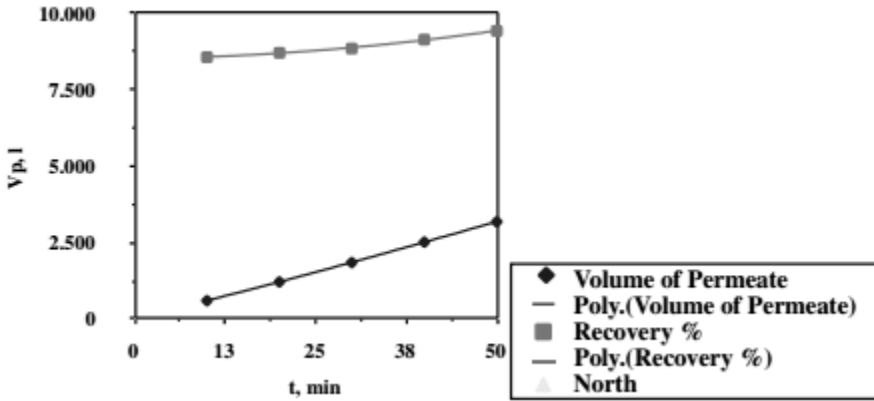


Figure 21: Effect of Operating Time on Volume of Permeate and Recovery Percentage (Recirculation of Concentrate, $V_F = 25$ l, $Q_P = 42$ l/h, $T = 27^\circ\text{C}$, $\text{pH} = 8$ and $P = 85$ psi)

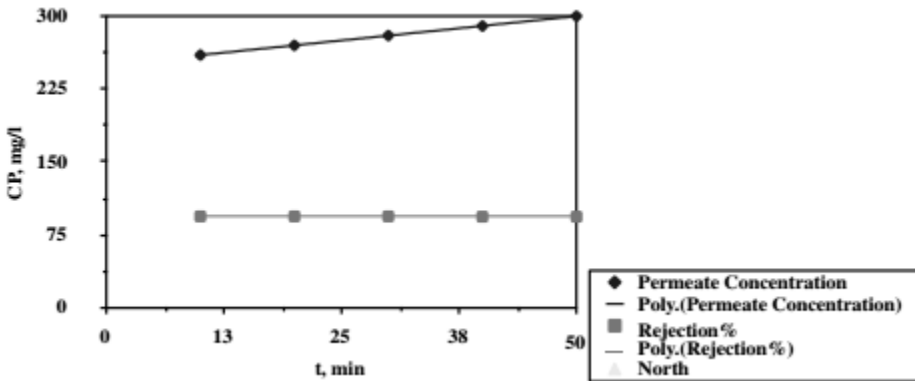


Figure 22: Effect of Operating Time on Permeate Concentration and Rejection Percentage (Recirculation of Concentrate, $V_F = 25$ l, $Q_P = 42$ l/h, $T = 27^\circ\text{C}$, $\text{pH} = 8$ and $P = 85$ psi)

Conclusion

Using conventional methods and Reverse Osmosis membranes. In coagulation/ flocculation process, optimum dosage for alum was 40, 45 and 50 ppm for 30, 50 and 100 NTU initial turbidity respectively. While, for ferric chloride it was 20, 25 and 30 ppm and for polyelectrolyte 6, 8 and 10 ppm for 30, 50 and 100 NTU initial turbidity respectively. The optimum speed of second step was 25 rpm. While the optimum time of the second step was 30 min and of settling was 30 min. For the same dosage, the ability of alum, ferric chloride and polyelectrolyte to remove the turbidity is arranged progressively as the following: Polyelectrolyte → Ferric chloride → Alum.

Microfiltration can be used to reduce the turbidity, TSS and bacteria. For the same feed, the ability of 1 μm MF membrane to remove the turbidity and TSS from water was more than that of 5 μm MF membrane. RO membrane can be used to reduce the TDS to the demand limits. The product rate of the membrane decreases with increasing feed concentration. The maximum recovery percentage (16.857 %) was at $\text{CF} = 2000$ mg/l for $P =$

85 psi, QF = 42 l/h, T = 27°C and pH = 8. Maximum component rejection percentage at P = 85 psi, QF = 42 l/h, T = 27°C and pH = 8 95.1 %, 90.647 %, 97.143 %, 86.765 %, 91.526 % for sulphate, TH, Ca²⁺, Mg²⁺ and Cl⁻ respectively. In recirculation of concentrate process, maximum value of volume of permeate is (3.186 liter) from feed vessel (25 liter) after 50 min.

Recommendations

Testing other types of membranes (e.g. cellulose acetate CA) to investigate their behavior in the same module type. Studying the effect of the pH on flux and sulphate rejection and studying the effect of fouling and cleaning of membranes in order to improve separation efficiency.

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