# Application of RO System to Desalinate Brackish Surface Water in Southern Iraq

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**Abstract**
Brackish surface water desalination is a primary path to relieve the shortage of useable water. The application of reverse osmosis (RO) membrane technology to desalinate the surface water in southern Iraq has recently increased due to the fresh water scarcity for drinking water to meet local needs in this region. Several studies by using simulated brackish surface water which represented the same quality of the water of this region have been conducted. In this study, actual samples of brackish surface water from three locations (Al-Jeweber, Al-Hadam and Al-Masheb) which are, respectively, located in the southern provinces of Iraq (Thi-Qar, Maysan and Basrah) were used as a feed water to conduct several desalination experiments. These feed waters were used to run a pilot scale of spiral wound reverse osmosis (RO) membrane system. The purpose of this research is to study main parameters of RO membrane system as a result of the application of this technology to desalinate the brackish surface water of the Iraqi marshes. The changes of the flow and quality of the permeate and concentrate of the RO membrane system with time were investigated. In addition, salt rejection by the RO membrane including total dissolved solid (TDS), electrical conductivity (Ec), total hardness (TH), sodium (Na), potassium (K), carbonate ($CO_3$), bicarbonate ($HCO_3$), alkalinity (Alk.), chloride ($Cl^-$), total organic carbon (TOC), nitrite ($NO_2$), nitrate ($NO_3$), phosphate ($PO_4$), sulfate ($SO_4$), iron (Fe) and zinc (Zn) were also studied . Moreover, the effect of the pretreatment on the water quality that is used as feed water for the RO system was included in this study. The results showed that 95.9% to 98% of total dissolved solids (TDS) removal percentage was attained for all runs conducted for the three selected sites. In addition, a wide range of permeate water flux which was (0.3442 – 1.3042) Lpm/$m^2$ was achieved. Moreover, pretreatment unit results showed that 90.67%, 93.9%, and 97.32% of turbidity reduction and 50.8%, 60%, and 71.7% of total organic carbon (TOC) reduction of the feed water of the three selected locations were achieved.
**Keywords:** Brackish water, Desalination, RO membrane, Salt rejection.

## 1. Introduction

Water is considered to be a valuable asset for human life. The lack of clean water resources is a grand issue in modern society (Marry, and Hoek, 2011; Elimelech, and Phillip, 2011). The clean water scarcity as well as the social excesses on fresh water sources has increased fresh water sources pollution. The problem of shortage in drinking water for human is resulted from the huge population growth which caused continous increase in water demand. (Kummu et al., 2016)

One of the benefits of using salty water such as seawater or brackish water as a source for drinking water is that this kind of water is sustainable. In other words, this method preserves more fresh water for future uses for next generations. Water sustainability can be defined as supplying or being able to be supplied with water for life or, perhaps more precisely, as the continual supply of clean water for human uses by using different water desalination technologies for water purification. (Oyoh, 2016)

These technologies of water desalination include thermal distillation technology, membrane technology, ion exchange, freezing desalination, geothermal desalination, solar desalination, and others (Oyoh, 2016; Chaudhry, 2013). In the 1970s, exploration began into using membranes for water desalination to separate salt from water (Sagle and Freeman, 2005). Membranes technologies such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO) and electrodialysis (ED) are considered a real solution to produce clean water for human consumption from seawater and brackish water (Bremere et al.,2001). Because of the high efficiency of the RO membrane, it is considered as the most important desalination technology (Malaeb, and Ayoub, 2011). Therefore, RO membrane technology applications have significantly increased the amount of suitable water for human consumption (Shon et al. 2013). A study of Cong (2018) aimed at using advanced reverse osmosis technology to increase its efficiency of brackish water desalination, the advance reverse osmosis showed most potential because of its advancement in RO membrane performance. Brackish water desalination processes focused on the importance of the pretreatment stage which considered the critical role of removing source water constituents (Henthorne and Boysen, 2015). Reverse osmosis (RO) technique is currently considered the most important desalination technology to desalinate the seawater and brackish water (Lee et al., 2011; Kurihara and Takeuchi, 2018 ).

MF membranes which have the largest pore size (1 to 10 μm) are typically operated at low pressures to reject large particles and various microorganisms such as colloids and bacteria. UF membranes have pore sizes of 0.01 to 0.1 µm , remove large organic molecules such as protein and viruses. NF membranes are a relatively recent development in membrane technology with characteristics that fall between ultrafiltration and reverse osmosis (RO) (Erikson, 1988; Conlon and Clellan, 1989; Li et al., 2008; Sachit, 2013).

Water quality of Iraqi marshes sites have high concentrations of TDS, ranging from over 500 to 2,500 mg/L and can be considered as a major source for surface brackish water (UNEP, 2009). In the last ten years, taking advantage of the widely available of the brackish surface water in the marshes, several RO desalination plants were established in the southern provinces of Iraq (Thi Qar, Maysan and Basrah).

The main aim of this research was to study the performance of the RO membrane technology to desalinate the brackish surface water of the southern Iraqi marshes in terms of permeate quality and quantity and membrane salt rejection. Actual samples of water rather than simulated water, which were conducted by several researchers, were used in this study in order to investigate the effect of all constituents of the water on the RO membrane fouling and performance.

## 2. Material and methods

### 2.1. Feed water

The surface water of three sites in southern provinces of Iraq were selected to represent the feed water of several experiments of RO membrane system in this study. These sites represented Al-Jeweber, Al-Hadam and Al-Mashab sites in Thi -Qar , Maysan and Basrah provinces respectively . One of the reasons behind selecting these water analyses is that their locations represent nearly all the area of the marshes because they were located in three southern provinces-Iraq. In addition, these three sites were chosen in different places that have different sources of water. Moreover, the concentration of the constituents of water quality of these sites varied from high levels to low levels. The location of the selected sites are shown in Figure (1). The first location is Al-Jeweber which is located in Thi Qar province. The source of the water of the Al-Jeweber marsh is Euphrates River. The water quality of this location had a TDS range from 1686 mg/L to 2380 mg/L as reported by UNEP (2007). However, the TDS of the water of this location, which was measured in this study, was 1836.4 mg/L. This means that the TDS of raw water within the limits reported by UNEP (2007). The second location is Al-Hadam which is located in Maysan province. The source of the water of the Hadam marsh is Tigris River. The water quality of second location had a TDS range from 1144mg/L to 1270mg/L as reported by UNEP (2007). However, the TDS of raw water of this location, which was measured in this study, was 1946.14 mg/l which was higher than the limits reported by UNEP (2007). The third location of this study is Al-Masahab which is located in Al-Basrah province. The source of the water of the Al-Basrah marsh is Tigris River. The water quality of this location had a TDS range from 2411 mg/L to 2750 mg/L as reported by UNEP (2007). However, the TDS of the water of this location, which was measured in this study, was 3866.6 mg/L. It was also higher than the limits reported by UNEP (2007). From the concentrations of the TDS reported by UNEP (2007) and the measured in this study, it can be noted that the salinity of the water marshes has increased during the last few years. The reason behind the increase in the water salinity of this region is the low level of the water in Tigris and Euphrates rivers.

Periodically, samples of raw surface water of 250 liters were brought from the selected sites and used during the experimental periods (December 2016 to June 2017). The raw water samples were taken from the intakes before the entry of the water to the existed desalination RO plants at a volume of 250 liters from each site. The water physical and chemical properties of the three sites were measured and tested as shown in Table (1).

### 2.2. Pretreatment of raw water samples

After the raw water samples were brought from the selected three sites, they were subjected to the pretreatment stage. The brackish surface raw water filtered by using three steps of microfiltration (MF). The first stage consisted of a 5 micron cartridge while the second and the third stages consisted of two cartridge filters with 1 micron as shown in Figure (2). The purpose of using the pretreatment was to rid of the materials that could damage the RO membrane. The turbidity of the sample before and after the pretreatment was frequently measured and recorded. The required turbidity of the feed water of the RO system is less than 0.5 NTU (Zirakrad at el., 2013; Kucera, 2010).

### 2.3. Pilot scale RO membrane system

The pilot scale RO membrane system was used to carry out the experimental works of this study. It consists of main units; supply unit and RO system unit. The supply unit consists of three tanks. The first tank (B1) with volume of 5 L is used to collect the permeate water, while the second tank (B2) with a volume of 100 L is used to supply the feed water to the RO membrane system. The second tank has a stirring machine to make sure of homogenous raw water solution. In addition, the unit has a third tank (B3) which is dedicated to the rinsing process after finishing the experimental processes. The second main part is the RO system unit. This unit consists of several parts such as pump and engine, pulsation damper, and display and control elements. A specific setting was adopted in opening and closing the valves and taps in order to operate the RO membrane experiments. A schematic diagram of the used pilot scale of the RO system is shown in Figure (3). In addition, the specifications of used RO membrane system are illustrated in Table (2).

### 2.4. Experimental procedures

Before running the experiments, a cleaning process was conducted to the RO membrane system processes using distilled water for several times. This step was done to remove the deposited foulants on the RO membranes from previous experiments. Two types of chemical cleaning processes were conducted for the fouled RO membrane. The chemicals which were used in the cleaning were sodium hydroxide 0.1 % and citric acid 2%. The system was rinsed by distilled water after each chemical cleaning stage. Figure (4) shows the steps of the chemical cleaning of the fouled RO membrane. All the RO membrane experiments were conducted according to the schematic diagram shown in Figure (5).

### 2.5. Measurements of water parameters

Water quality parameters were measured before and after the pre-treatment process. Measurements were also done for produced water (permeate) and rejected water (concentrated water) from the laboratory reverse osmosis system during different intervals .The water parameters that were measured are pH, water temperature (T),total dissolved solid (TDS), electrical conductivity(Ec), total hardness (TH), sodium (Na), potassium (K), carbonate ($CO_3$), bicarbonate ($HCO_3$), alkalinity (Alk.), chloride (Cl), total organic carbon (TOC), nitrite ($NO_2$), nitrate ($NO_3$), phosphate ($PO_4$), sulfate ($SO_4$), iron (Fe), and zinc (Zn).

## 3. Results and discussion

### 3.1. Raw brackish surface water characterization

As previously mentioned, the used water in all laboratory experiments were the raw surface water supplied from three selected locations in southern of Iraq. Table (3) illustrates the measured water quality characteristics which are; pH of 7.7, 7.8, and 8.03; total dissolved solid (TDS) of 1836.4, 1946.14, and 3866.6 mg/l; electrical conductivity (Ec) of 2722.8 µs/cm, 2874.83 µs/cm, and 5750 µs/cm; total organic carbon (TOC) of 6.1, 26.8, and 5.9 mg/L; turbidity of 10.4, 15.6, and 20 NTU; alkalinity of 202.2, 213, and 372 mg/l; and total hardness of 600, 632, and 800 mg/L as $CaCO_3$ for Thi-Qar (Jewber), Maysan (Hadam), and Basrah (Mashab) sites, respectively.

In addition, the measured concentrations of the anions which are $SO_4$, $NO_3$, $NO_2$ and $PO_4$ were, respectively, 680 mg/L, 3.74 mg/L, 1.3 mg/L and 2.9 mg/L for Jeweber site; 550 mg/L, 3.1 mg/L, 1.2 mg/L and 2.4 mg/L for Hadam site; and 850 mg/L, 3.5 mg/L, 1.4 mg/L and 2.45 mg/L for Mashab site. While, the concentrations of the cations which are Na, Ca, Mg, Fe, Zn were, respectively, 220.8 mg/L, 321 mg/L, 279 mg/L, 0.082 mg/L and 0.18 mg/L for Jeweber site; 233 mg/L, 337.69 mg/L, 294.3 mg/L, 0.4421 mg/L and 0.07 mg/L for Hadam site; and 350 mg/L, 364.5 mg/L, 435.48 mg/L, 0.169 mg/L and 0.09 mg/L for Mashab site. Moreover, chloride ion concentrations were 265, 350, and 341 mg/L for the three mentioned sites. The measured physical and chemical properties values are consistent with many studies conducted for the same area (UNEP, 2009; Al Mayyahi and Al Asadi, 2017; Al-Karaghouli and Kazmerski, 2011).

### 3.2 Pretreatment effects

The pretreatment unit for the raw water samples significantly reduced the turbidity of the feed water. In general, employing the MF membrane as a pretreatment unit for the raw feed water to operate the RO membrane system has increased the permeate flux (Sowgath and Mujtaba, 2017; TSG, 2017; Nitto, 2017; Sachit, 2013). In the absence of pre-treatment for the feed water that has high turbidity blockage of the porosity of the membranes used in reverse osmosis may occur (Gaid, 2011).

Table (4) shows that the turbidity of the raw water was reduced by 90.67 %, 93.9 % and 97.32 % for Thi-Qar, Maysan and Basrah locations respectively after pre-treatment. Moreover, the concentration of total organic carbon (TOC) was decreased by 50.8%, 60% and 71.7% for same locations, respectively. Increasing of organic fouling of the membrane has negative impact on the water productivity of the membrane (Kucera, 2010; Dow, 2004). Since the pretreatment reduced the TOC concentration to less than 3 mg/L, employing the pre-treatment of the raw water is an important factor.

The Langelier Saturation Index (LSI) values of raw water after pretreatment process for Al-Jeweber, Al-Hadam and Al-Mashab were -0.1962, -0.2458 and -0.1395 respectively. The negative values of the LSI referred to that the raw water is unsaturated with respect to calcium carbonate which indicates that scaling on the membrane surface is going to be least (Al-Ghamdi, 2017; Yasmine et al., 2012). According to the results, the scaling of the calcium carbonate may be low. In addition, Table (4) shows that the values of other parameters decreased at different ratios depending on the nature of raw water quality and operational conditions during laboratory work of experiments. In other words, the results pointed out the role of pretreatment in minimizing the deposition of various fouling on the RO membranes.

### 3.3. Cleaning of fouled RO membrane

The cleaning process of the used membrane was tested by using the water sample of Al-Hadam site. The results showed that the permeate water flux in the three experiments (0.8525-0.425), 0.999 -0.892) and (1.9208-1.6625) when cleaning with distilled water, basic solution and citric acid solution, respectively as shown in Table (5).

Moreover, chemical cleaning results showed that the permeate flow rate increased by 49% when sodium hydroxide solution 0.1% (NaOH) was used. The permeate increased from 0.697 L/min to 1.37 L/min. However, when citric acid solution2% ($C_6H_8O_7$) was used, the permeate flow rate increased by 79%. The permeate flow rate increased from 0.51 L/min to 2.3987 L/min as shown in Table (6).

### 3.4. Analysis of the RO performance of the three locations

A total of 9 runs of a pilot scale RO membrane system were implemented by using the water samples brought from the three selected sites as shown in Diagram (1). Run number, location of feed water, permeate flux range, and total permeate flux drop as well as total time of each run are included in Table (7).

Generally, the data analysis showed a gradual decrease in the permeate water flux of the three sites. The range of the permeate flux for the three locations was different for all runs. For example, the permeate flux for run 4 which is conducted with the feed water sample of Thi-Qar location ranged from 0.61416 to 0.5258 Lpm/m². However, the permeate flux for run 7 which is conducted with the feed water sample of Maysan location ranged from 0.5183 to 0.34583 Lpm/m². On the other hand, the permeate flux for run 10 which is conducted with the feed water sample of Basrah location ranged from 1.3042 to 1.0741 Lpm/m². The decreasing ratio were generally ranged from 6.667% to 43.42% for the three water locations. The permeate flow rate declined over time due to the continuous fouling accumulation on membranes surfaces which were used in the three locations.

#### 3.4.1. Run 4 (Thi-Qar site)

First sample, which was brought from Thi-Qar, was used to run the first experiment by using the laboratory scale of RO system. The permeate flow was recorded with the time of the experiment. Figure (6. a) shows the relationship between the permeate flow and the time of run 4. From Figure (6. a), it can be noted that the permeate started at a flow rate of 0.737 l/min and declined to reach 0.631 l/min at the end of the run .The drop of permeate flow ratio was 14.38%.

This case indicated the low efficiency of the RO system productivity of the water permeate and thus required the chemical cleaning process to remove the various fouling materials that deposited on the RO surfaces which led to the blockage of most porosity of membranes (Li et al., 2017; García et al., 2017; Cotruvo, 2004).

Figure (6. b) explains the electrical conductivity (Ec) for permeate water, concentrate water and raw water. Values of Ec varied among these water streams. Main conclusion for these values was the increasing of total dissolved solid (TDS) leading to increase electrical conductivity (Ec) (Cotruvo, 2004 ).

The electrical conductivity values of water permeate (σ per.) during the first 60 min of the run time remained constant (0.1 ms/cm) .While, at the end of the experiment, the Ec value of water permeate was increase to 0.2 ms/cm at the end time of the experiment which was 82 min. The electrical conductivity of concentrated water (σc) and raw water (σF) has the tendency to increase with run time. The electrical conductivity of concentrated water (σc) is higher than that of the raw water due to the high accumulation amount of salts in the concentrated water (Hashimoto, 2015). The difference between the initial and final values of concentrate conductivity (σc) was about (17.5 ms/cm) .

On the other hand, the salts rejection percentage was calculated by using the following formula. The ratios were ranged from 97.96% to 98.98% for run 4.

$$\text{Salt rejection } \% = \frac{\sigma f - \sigma p}{\sigma f} * 100 \qquad \ldots\ldots\ldots (1)$$

#### 3.4.2. Run 5 (Thi-Qar site)

Figure (6. c) explains the permeate flow of run 5 which started at 0.777 Lpm and continued almost at the same level for the whole run time. The high value of permeate flow was 0.883 Lpm at 40 min run times while, at the end, this value declined to reach 0.701 Lpm. On the other hand, the concentrate water flow start with 1.52 Lpm and continued at the same level to the end of the run time (1.546 Lpm).

However, Figure (6.d) displays that the permeate electrical conductivity (Ec) was 0.1 ms/cm during the 92 min of runs times and increased to 0.2 ms/cm only at end run time which was 97 min. This result indicated a good efficiency of RO membrane performance. The electrical conductivity of the concentrate (σc) and the feed water (σF) had a tendency to increase too. The salt rejection of run 5 regarding the electrical conductivity values was ranged from 98% to 99.11%.

#### 3.4.3. Run 6 (Thi-Qar site)

Figure (6.e) shows that the permeate flow started from 0.783Lpm) and continued at the same level to reach 0.731Lpm at the end of the run. In addition, Figure (6.f) shows that the electrical conductivity of permeate was

0.1 mS/cm and slightly changed to reach 0.2 mS/cm at specific run time (70 min and 75 min).While conductivity for the concentrate (σc) and feed water (σF) increased. The salt rejection based on the electrical conductivity ranged from 97. 87 % to 99.13%.

### 3.4.4. Run 7 (Maysan site)

Raw water from Hadam site was treated by the lab RO system through runs 7 to 9. Figure (7.a) shows the permeate flow for run 7 which started with 0.662 Lpm and then decreased with the time to reach 0.415 Lpm. While the concentrate flow started at 2.5 Lpm and then started oscillating to the end run time (2.707 Lpm). The electrical conductivity of permeate increased from 0.1 mS/cm to 0.4 mS/cm at the end of the run time (82min). However, conductivity for the concentrate (σc) and feed water (σF) increased dramatically due to the increasing of salts as illustrated in Figure (7.b). The salt rejection based on electrical conductivity was in the range of 98.24% to 98.64%.

### 3.4.5. Run 8 (Maysan site)

Figure (7.c) shows the permeate flow for run 8 which started at 0.51 Lpm and then increased to 0.744 Lpm. After that, the flow rate decreased and reached 0.41 Lpm at the end of the run time. While the concentrate flow started at 2.45 Lpm and then began to fluctuate between increasing and decreasing to the end time of run 8.

Overall, the electrical conductivity of the permeate increased from 0.1 mS/cm to 0.5 mS/cm at the end time of the run (96min). However, the electrical conductivity of the concentrate (σc) and the feed water (σF) directly increased as displays in Figure 7.d. Depending on the electrical conductivity, the salt rejection was ranged between 98.27 % and 98.43 %.

### 3.4.6. Run 9 (Maysan site)

The permeate water flow rate of run 9 started at 0.532 Lpm and its values remained constant until the 30th minute, and then it increased until the 50th minute (0.686 Lpm). After that, the permeate flow decreased at value of 0.401 Lpm to the end of run time. However, the concentrate flow started at 2.591 Lpm and increased to a value of 2.815 Lpm until the 70th minute and then decreased to 2.647 Lpm at the end time of the run as shown in Figure 7.e. Also, the electrical conductivity values of permeate water remained constant (0.1 mS/cm) until the 64 min of the run time, then the other values increased (0.6 mS/cm) until the end of the experiment (120min) (Figure 7.f ) .The salt rejection ratio was ranged between 98% and 97.5% depending on the electrical conductivity.

### 3.4.7. Run 10 (Basrah site)

For the feed water of Mashab site, Basrah, three runs (10 – 12) of RO pilot system were conducted. In run 10, the permeate water flow started at 1.325 Lpm and increased to 1.662 Lpm at the 90th minute. Then, it decreased to 1.541 Lpm at the end time (120 min) as shown in Figure (8.a). However, the concentrate water began at 1.639 Lpm and then decreased to 1.297 Lpm at the 100th minute. After that, it increased to 1.562 Lpm at a constant rate until the end of the run time (120 min).

Moreover, the electrical conductivity of the permeate water remained constant (0.1 mS/cm) until the 45 min of the run time, then, it increased to 0.5 mS/cm until the end of the run (120 min) as displayed in Figure (8.b). On the other hand, the salt rejection ratio was ranged between 97.63% and 97% depending on the values of the electrical conductivity.

### 3.4.8. Run 11 (Basrah site)

Figure (8.c) shows that the permeate water flow rate began at 1.503 Lpm then gradually increased to reach 1.678 Lpm until the 75th minute. Then, it decreased to 1.331 Lpm to the end of the run time (145 min). However, the concentrate water had a tendency to fluctuate during the run time (1.57 - 1.591 Lpmin). Electrical conductivity of permeate water had a constant value of 0.1 mS/cm to the 45th minute of the run time and continued to increase gradually until its value reached 0.5 mS/cm at the end of the run (145 min) .In addition, the concentrate water and feed water values were increased with the run time (Figure 8.d). The salts rejection ratios depending on the electrical conductivity values were ranged between 97.4 and 98.2%.

### 3.4.9. Run 12 (Basrah site)

Figure (8.e) shows the tendency of the permeate water flow rate (QP) of run 12 which started at 1.232 Lpm and increased with fairly constant rate until the 82 minutes to reach 1.555 Lpm. Then, the permeate flow rate gradually decreased to the end of the run time (140 minutes). The amount of produced permeate water in this run was 42 L. However, the flow of concentrate water started with 2.395 Lpm to 2.335 Lpm at end run time. Figure (8.f) illustrates the electrical conductivity of permeate water which started at 0.1 mS/cm and gradually increased until its value reached 0.3 mS/cm at the end of run time (140min). Moreover, the conductivity of concentrate water and feed water increased dramatically with the run time. The salt rejection due to electrical conductivity was ranged between 97.29% and 95.71%.

The results of the averages of salts rejection ratios as shown in Figures 9 to 11 indicated a good performance of RO membrane for the brackish surface water of the three selected water sources in this study.

The percentage of the removal of the individual ions was also calculated for all conducted runs. The concentrations of the ion for one run was calculated in the concentrate streams and the permeate carrier at the beginning, middle, and end of the run. Then, the average of the ion concentration in both concentrate and permeate channels was calculated. Each column in Figures 9 through 11 represents three runs. For example, in Figure (9), the removal percentages of sodium ion which were 97.2, 96, and 95.4% were calculated for runs 4, 5, and 6, respectively. Overall, the results showed that the rejection of the salt ions by the RO membrane for the three selected brackish surface water was significantly high.

It is well-known that permeate water flux and salt rejections are the important parameters for RO membrane performance. Salts rejection is effected by four variable parameters including feed water pressure, feed water temperature, water recovery, and feed water salt concentration. The percentage of salts rejection which is shown in Figure 12 depended on the electrical conductivity measurements during laboratory experiments. Salts rejection ratios ranged between 93.1% and 98.7% under the same conditions (25ºC and 40 bars) for all runs (Figure 12). These results were reflected the relationship between salt rejection and permeate water flux in removing the salts ions from brackish feed water by the lab RO membrane system.

## 4. Conclusions

Actual samples of brackish water of the Iraqi marshes rather than simulated water were used to evaluate the performance of the RO membrane system as a desalination technique to produce drinkable water in the southern of Iraq. A pilot scale of RO system experiments demonstrated that high performance of this technology in terms of salt rejection and permeate water production was achieved.

Overall, 95.5% to 98% of TDS removal percentage was attained for all runs conducted with water samples of the three selected locations. In addition, wide range of permeate water flux which was 0.3442 -1.3042 Lpm/m$^2$ was achieved for the three water qualities chosen from this region. Moreover, pretreatment of the feed water is a crucial factor in minimizing the fouling material, which may lower the performance of the RO membrane, by reducing the organic materials and the turbidity of the feed water of the RO system. Using MF membrane as a pretreatment unit is highly recommended.

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**Table 1**. Raw Water quality parameters of the three study Locations.

| Location / Parameters | Al-Jewber | Al-Hadam | Al-Masahab |
|---|---|---|---|
| pH | 7.7 | 7.8 | 8.03 |
| Ec (µS/cm) | 2722.8 | 2874.83 | 5250 |
| TDS (mg/l.) | 1836.4 | 1946.14 | 3866.6 |
| Turb. (NTU) | 10.4 | 15.6 | 37.4 |
| Alkalinity (mg/l.) | 202.4 | 213 | 372 |
| Total Hardness (mg/l. as $CaCO_3$) | 600 | 632 | 800 |
| TOC (mg/l.) | 6.1 | 6.5 | 9.9 |
| $SO_4^{-2}$ (mg/l.) | 680 | 550 | 850 |
| $Cl^{-1}$ (mg/l.) | 265 | 322 | 341 |
| $Na^{+1}$ (mg/l.) | 220.8 | 233 | 350.5 |
| $Ca^{+2}$ (mg/l.) | 321 | 337.69 | 364.5163 |
| $Mg^{+2}$ (mg/l.) | 279 | 294.3 | 435.4837 |
| $NO_3^{-1}$ (mg/l.) | 3.74 | 3.1 | 3.5 |
| $NO_2^{-1}$ (mg/l.) | 1.3 | 1.2 | 1.4 |
| $PO_4^{-3}$ (mg/l.) | 2.9 | 2.4 | 2.45 |
| $K^{+1}$ (mg/l.) | 20.2 | 22 | 23 |
| $Zn^{+2}$ (mg/l.) | 0.18 | 0.07 | 0.09 |
| $Fe^{+2}$ (mg/l.) | 0.082 | 0.4421 | 0.1690 |
| Salinity (‰) | 1.3 | 1.5 | 2.4 |

**Table 2.** The specifications of RO membrane of the used lab system.

| | |
|---|---|
| **Piston pump** | Max. flow rate: 425 L/hr. |
| | Max. head: 700 m |
| **Membrane model** | Active Area = 1.2 $m^2$ |
| | Length = 500 mm |
| | Diameter = 60 mm |
| | Raw water flow rate = max 23 L/min. |
| | Material = polyamide |
| **Measuring ranges** | Retentate flow rate = 0.2 to 6 L/min. |
| | Permeate flow rate = 0.5 to 1.8 L/min. |
| | Pressure: 2 to 120 bar |
| | Temperature = 3 to 50°C |
| | Conductivity = 3 to 200 mS/cm |

**Table 3**. Brackish surface water characteristics for three southern sites.

| Location / Parameters | Location (1) Raw surface water of Thi-Qar /Al-Jewber | Location (2) Raw surface water of Maysan /Al-Hadam | Location (3) Raw surface water of Basrah /Al-Masahab |
|---|---|---|---|
| pH | 7.7 | 7.8 | 8.03 |
| Ec (μS/cm) | 2722.8 | 2874.83 | 5250 |
| TDS (mg/L.) | 1836.4 | 1946.14 | 3866.6 |
| Turb. (NTU) | 10.4 | 15.6 | 37.4 |
| Alkalinity (mg/L) | 202.4 | 213 | 372 |
| Total Hardness (mg/L as $CaCO_3$) | 600 | 632 | 800 |
| TOC (mg/L) | 6.1 | 6.5 | 9.9 |
| $SO_4^{-2}$ (mg/L) | 680 | 550 | 850 |
| $Cl^{-1}$ (mg/L) | 265 | 322 | 341 |
| $Na^{+1}$ (mg/L) | 220.8 | 233 | 350.5 |
| $Ca^{+2}$ (mg/L) | 321 | 337.69 | 364.5163 |
| $Mg^{+2}$ (mg/L) | 279 | 294.3 | 435.4837 |
| $NO_3^{-1}$ (mg/L) | 3.74 | 3.1 | 3.5 |
| $NO_2^{-1}$ (mg/L) | 1.3 | 1.2 | 1.4 |
| $PO_4^{-3}$ (mg/L) | 2.9 | 2.4 | 2.45 |
| $K^{+1}$ (mg/L) | 20.2 | 22 | 23 |
| $Zn^{+2}$ (mg/L) | 0.18 | 0.07 | 0.09 |
| $Fe^{+2}$ (mg/L) | 0.082 | 0.4421 | 0.1690 |
| Salinity (‰) | 1.3 | 1.5 | 2.4 |

**Table 4.** The results of the pretreatment process for the raw water samples of three selected locations (García et al., 2017; Nitto, 2013).

| Parameters | Limited Value | Thi-Qar | | | Maysan | | | Basrah | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Raw surface water | After pretreatment | Removal ratio % | Raw surface water | After pretreatment | Removal ratio % | Raw surface water | After pretreatment | Removal ratio % |
| Turb. (NTU) | <1 | 10.4 | 0.97 | 90.67 | 15.6 | 0.95 | 93.9 | 37.4 | 1.001 | 97.32 |
| TOC (mg/l.) | <3 | 6.1 | 3.0 | 50.8 | 6.5 | 2.6 | 60 | 9.9 | 2.81 | 71.717 |
| Langelier Saturation Index (LSI) | <0 | +0.498 | -0.1962 | | +0.6396 | -0.2458 | | +1.1152 | -0.1395 | |
| Temperture | <45 | 25 | | | 25 | | | 25 | | |
| pH | 2-12 | 7.7 | | | 7.8 | | | 8.03 | | |
| Microbes CFU/ml. | <1000 | 440 | | | 220 | | | 308 | | |

**Table 5.** Chemical cleaning experiments for reactivation the Polyamide RO membrane performance.

| Run's Number | Location | Temp. (°C) | Permeate flux range (Lpm/m²) | Total permeate flux drop(%) | Total time (min) |
|---|---|---|---|---|---|
| 1 | Maysan** | 25 | (0.999-0.892) | 10.7 | 105 |
| 2 | Maysan** | 25 | (0.8525-0.425) | 50.14 | 112 |
| 3 | Maysan** | 25 | (1.9208-1.6625) | 13.44 | 77 |

**The cleaning experiments of fouled RO membrane: run (1) after cleaning with NaOH (0.1%); run (2) after cleaning with distilled water; and run (3) after cleaning with citric acid.

**Table 6**. Chemical cleaning efficiency of the fouled RO membrane.

| Cleaning Material | Membrane type | Water Quantity (L) | Run time (min) | Flow rate (QP)before Cleaning | Flow rate (QP)after Cleaning | Efficiency of Cleaning (%) |
|---|---|---|---|---|---|---|
| **NaOH (0.1%)** | **polyamide** | **60** | **105** | **0.697** | **1.37** | **49** |
| **Distilled water** | **polyamide** | **60** | **112** | **1.0477** | **1.31** | **20** |
| **$C_6H_8O_7$ ( 2%)** | **polyamide** | **60** | **77** | **0.51** | **2.3987** | **79.14** |
| **Distilled water** | **polyamide** | **For rinsing the fouled membrane after end the all runs** | | | | |

**Table 7**. Relationship between the permeate fluxes and total time of the RO membrane.

| RUN's Number | Location | Temperature (°C) | Permeate flux range (Lpm/m²) | Total permeate flux drop(%) | Total time (min) |
|---|---|---|---|---|---|
| 4 | Thi-Qar | 25 | (0.61416 -0.5258) | 14.39 | 82 |
| 5 | Thi-Qar | 25 | (0.6475-0.5841) | 9.792 | 97 |
| 6 | Thi-Qar | 25 | (0.6525-0.609) | 6.667 | 75 |
| 7 | Maysan | 25 | (0.5183- 0.34583) | 33.27 | 82 |
| 8 | Maysan | 25 | (0.425- 0.3416) | 19.62 | 100 |
| 9 | Maysan | 25 | (0.4433-0.3442) | 22.35 | 120 |
| 10 | Basrah | 25 | (1.3042-1.0741) | 17.64 | 120 |
| 11 | Basrah | 25 | (1.2525-1.1092) | 11.44 | 145 |
| 12 | Basrah | 25 | (1.0266-0.5808) | 43.42 | 140 |


**Figure 1.** The Studied locations of the selected RO plants in the Study area of Southern Iraq.

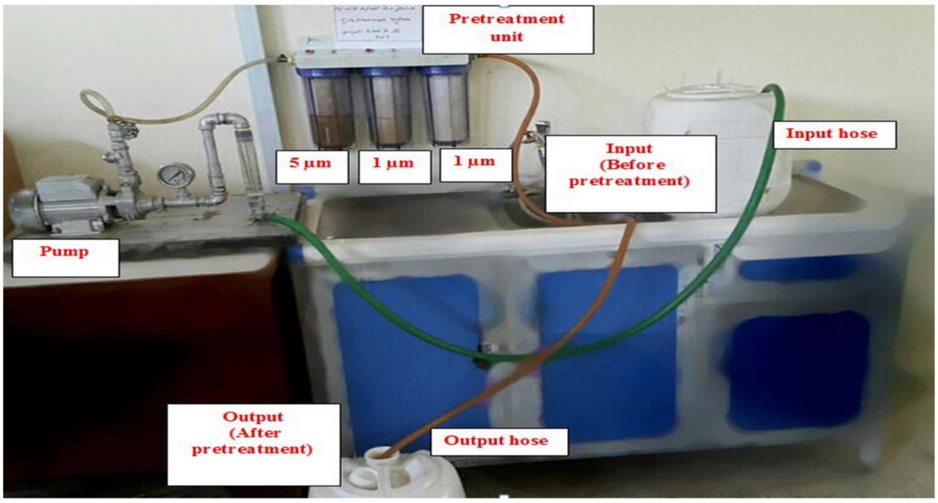
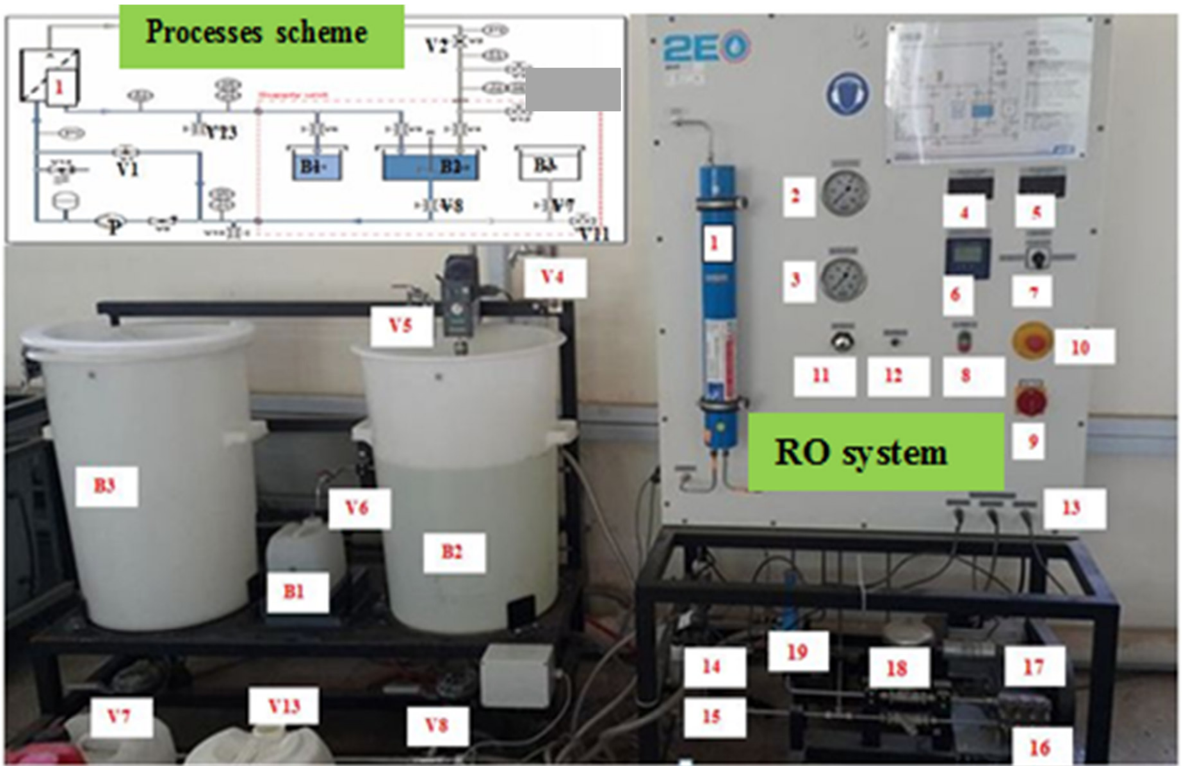



**Figure 2.** Pretreatment unit for brackish surface raw water treatment.




| | | | |
|---|---|---|---|
| 1 | Membrane module (A) | 15 | Drain valve for (Permeate, Retentate, Raw water) |
| 2 | Retentate manometer | 16 | Pump (P) |
| 3 | Raw water manometer | 17 | Engine |
| 4 | Retentate flow rate display | 18 | Pulsation damper |
| 5 | Permeate flow rate display | 19 | Safety valve |
| 6 | Conductivity measuring transducer | 20 | Tap (V4) for Retentate |
| 7 | Selector switch for measuring point of conductivity and temperature | 21 | Tap (V5) for Permeate |
| 8 | On/Off switch for pump | 22 | Tap (V6) for Permeate |
| 9 | Main switch | 23 | Raw water tank (B2) |
| 10 | Emergency off switch | 24 | Permeate tank (B1) |
| 11 | Bypass valve (V1) | 25 | Rinse water tank (B3) |
| 12 | Retentate valve (V2) | 26 | Tap (V8) with limit switch |
| 13 | Connectors for conductivity sensor | 27 | Stirring machine |
| 14 | Measuring cell with conductivity sensor(QI) | 28 | Tap (V7) with limit switch |

**Figure 3.** A schematic diagram of the used pilot scale of the RO system.

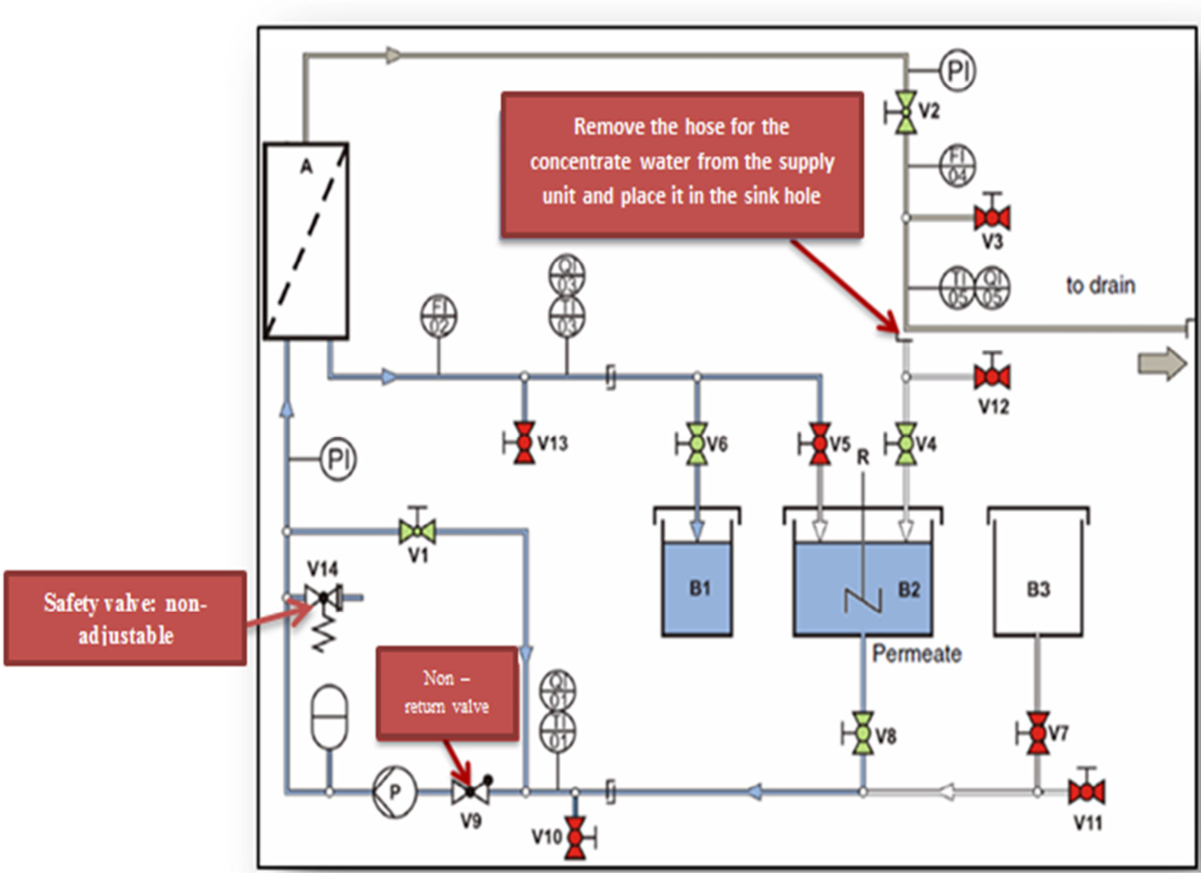



**Figure 4**. RO membrane cleaning procedure (Gunt Hamburg, 2011).

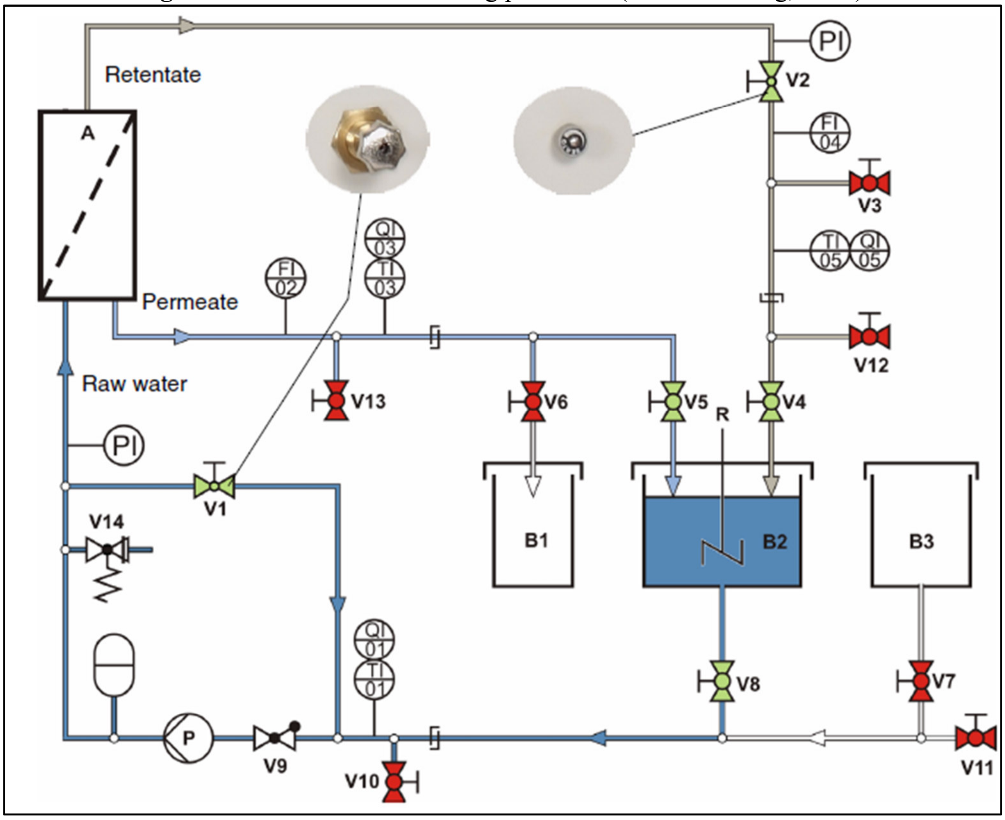



**Figure 5.** The process diagram for experimental RO operating (Gunt Hamburg, 2011).

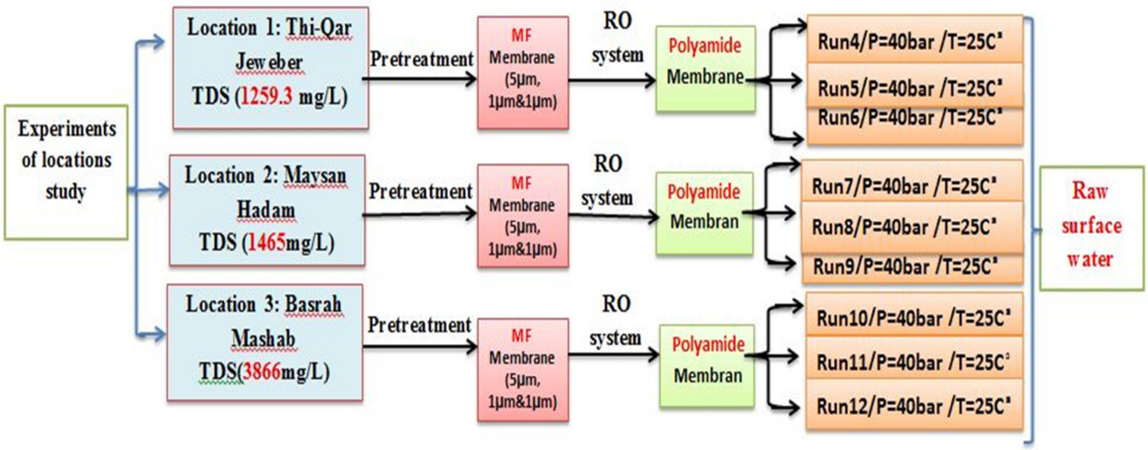



**Diagram 1.** plan of all runs carried out by the laboratory reverse osmosis system.

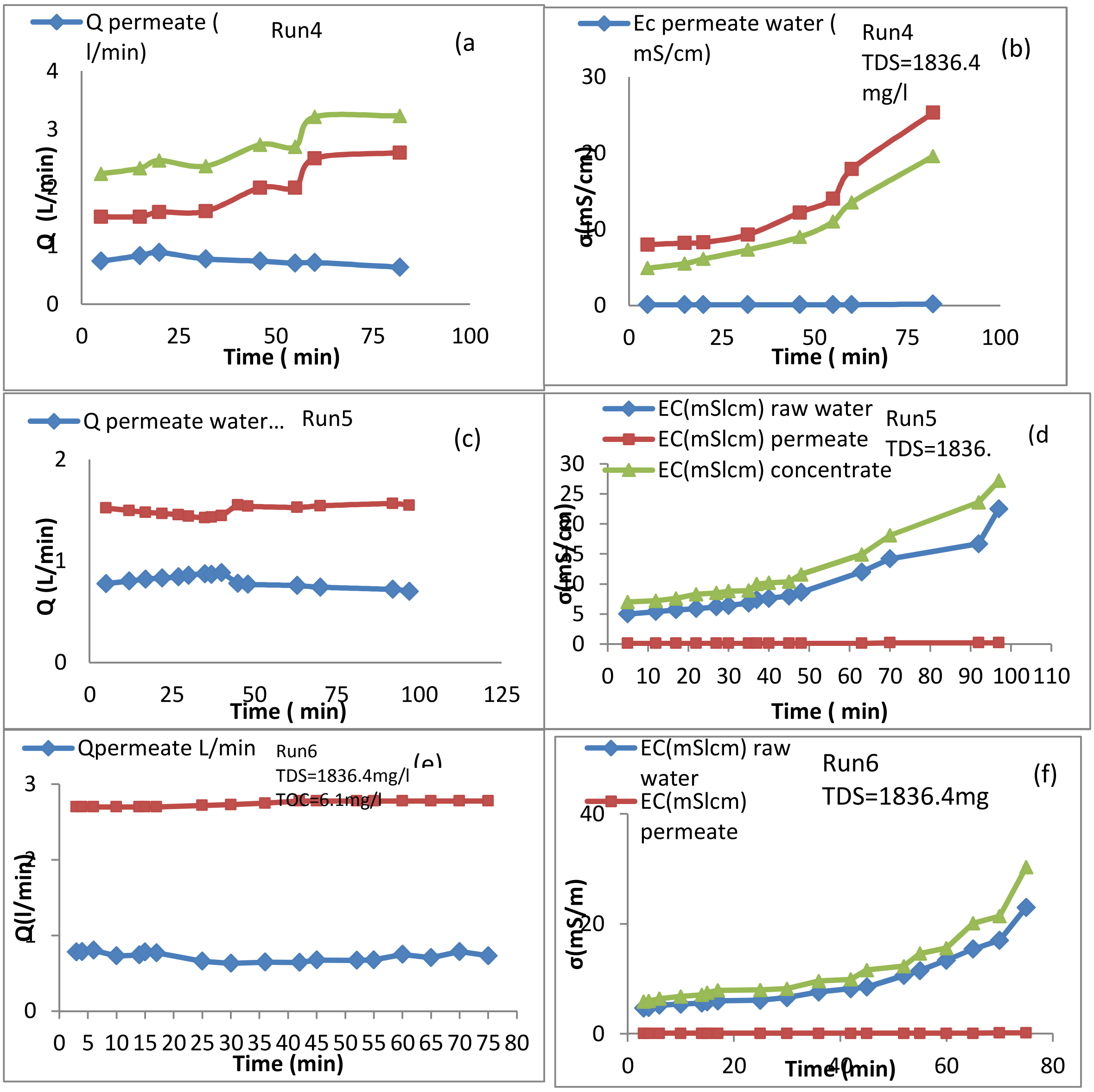



**Figure (6)**. Relationship among conductivity, flow rate and time: (a) and (b) for Thi-Qar site run 1; (c) and (d) for run 2; (e) and (f) for run 3.

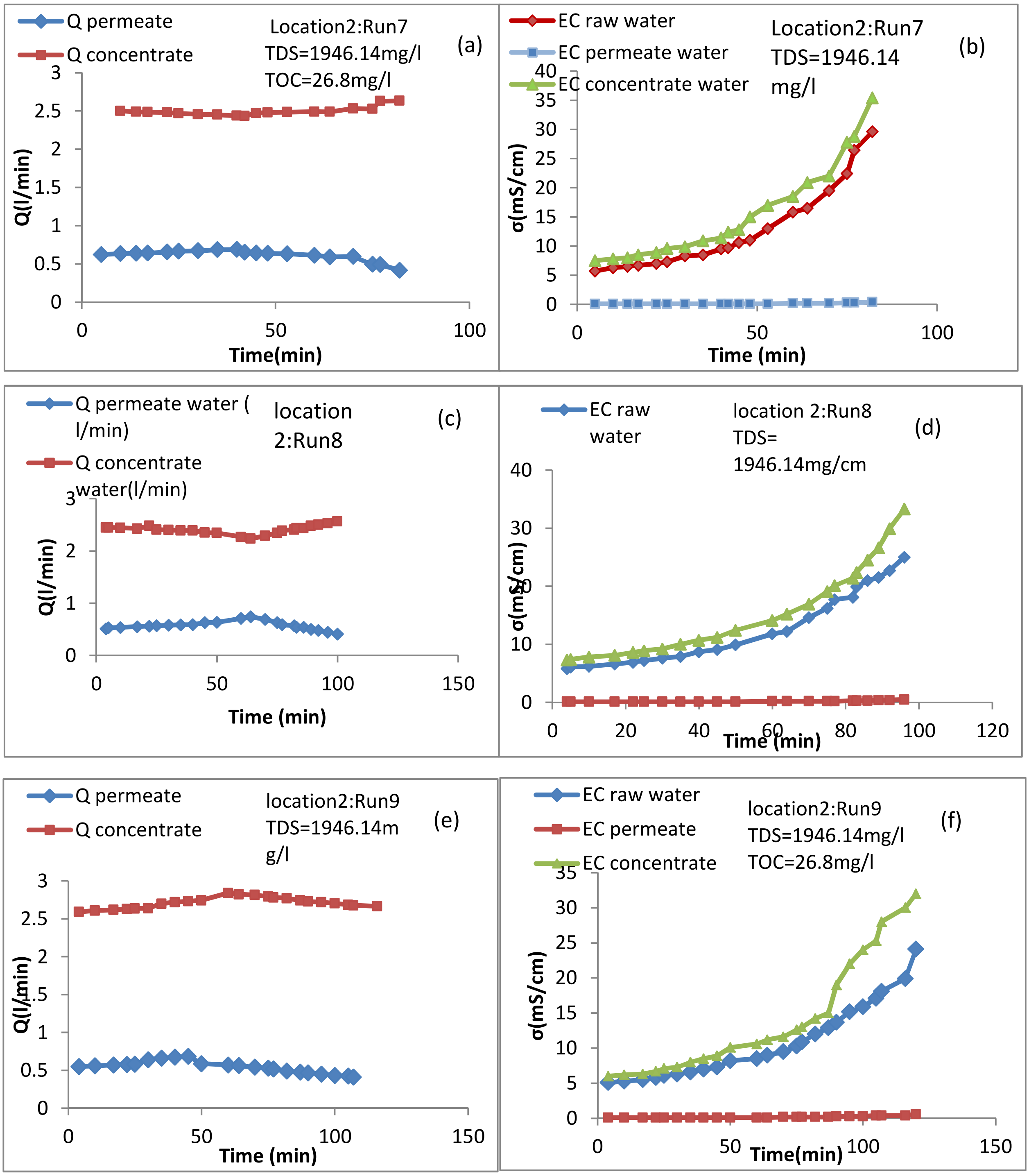



**Figure (7).** Relationship among conductivity, flow rate and time: (a) and (b) for Maysan site run 4; (c) and (d) for run 5; (e) and (f) for run 6.

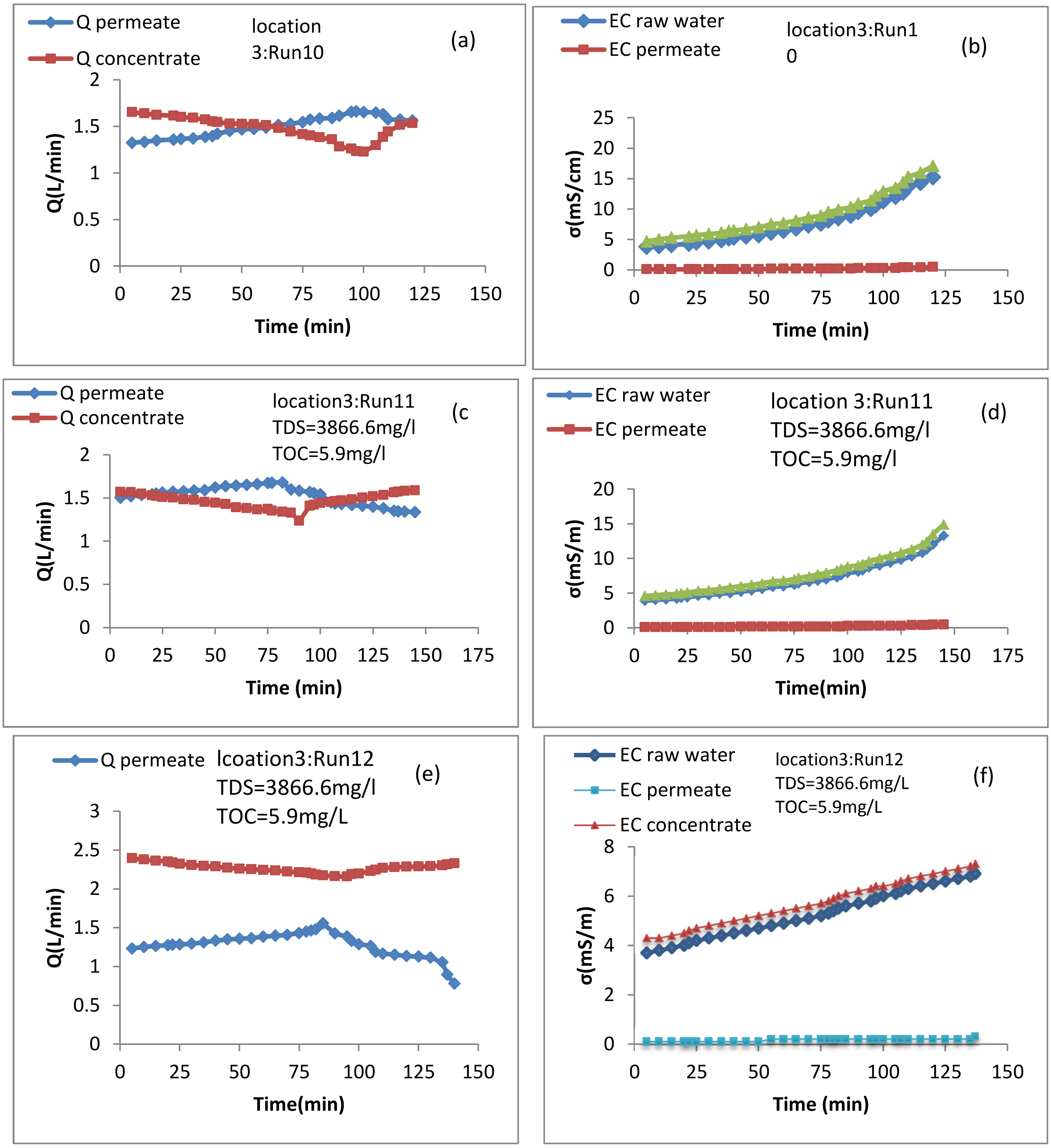
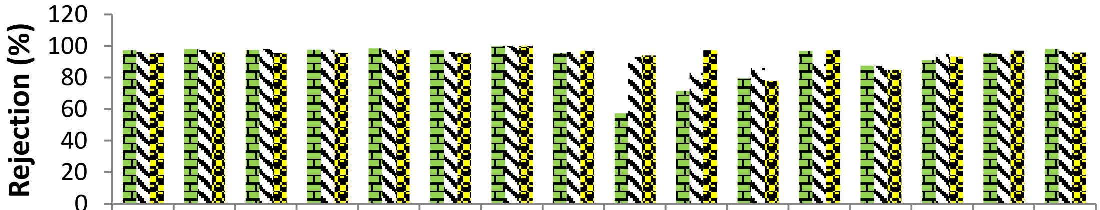
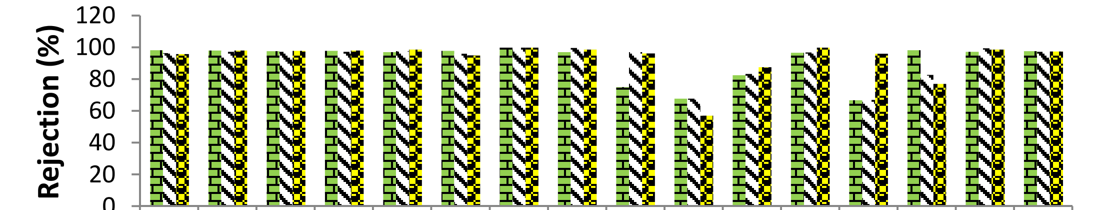



**Figure (8).** Relationship among conductivity, flow rate and time: (a) and (b) for Basrah site run 7; (c) and (d) for run 8; (e) and (f) for run 9.



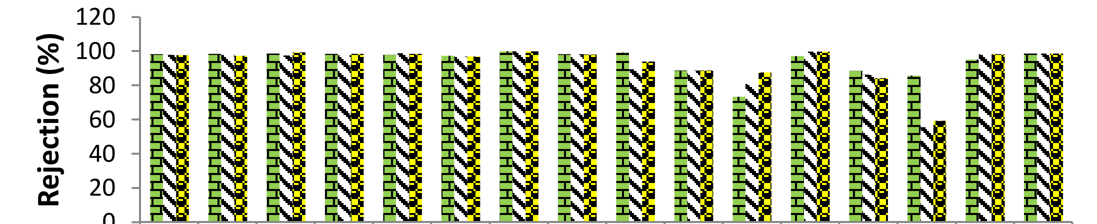

| | Na | Ca | Mg | T.H. | SO4 | Cl | CO3 | HCO3 | Fe | Zn | PO4 | K | NO3 | NO2 | ALK. | TDS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run 4 | 97.2 | 98 | 97.4 | 97.7 | 98.6 | 97.2 | 100 | 95.3 | 57.3 | 71.4 | 79.7 | 96.9 | 87.5 | 91 | 95.5 | 98 |
| Run5 | 96 | 97.6 | 98 | 97.8 | 97.6 | 96 | 100 | 96.1 | 93 | 83.1 | 86.2 | 88.5 | 87.5 | 95 | 94.8 | 96.6 |
| Run6 | 95.4 | 95.8 | 95.4 | 95.6 | 97.3 | 95.5 | 100 | 96.9 | 94 | 97.3 | 77.8 | 97.2 | 84.9 | 93.2 | 97 | 95.9 |

**Figure (9)**. The averages of salt rejection ratios within the concentrated water of the three experiments (Thi-Qar site).




| | Na | Ca | Mg | T.H. | SO4 | Cl | CO3 | HCO3 | Fe | Zn | PO4 | K | NO3 | NO2 | ALK. | TDS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run7 | 98.3 | 98.1 | 97.7 | 97.9 | 97.2 | 97.9 | 100 | 97.2 | 75 | 67.9 | 82.5 | 96.7 | 66.8 | 98.3 | 97.3 | 97.6 |
| Run8 | 96.5 | 97.3 | 97.4 | 97.3 | 97.7 | 96 | 100 | 99.8 | 97.2 | 67.9 | 83.3 | 96.8 | 66.9 | 82.7 | 99.5 | 97.2 |
| Run9 | 96 | 98.1 | 98 | 98.1 | 98.8 | 95.1 | 100 | 98.6 | 96.4 | 57.1 | 87.6 | 99.9 | 96 | 77.1 | 98.6 | 97.5 |

**Figure (10)**. The averages of salt rejection ratios within the concentrated water of the three experiments (Maysan site).




| | Na | Ca | Mg | T.H. | SO4 | Cl | CO3 | HCO3 | Fe | Zn | PO4 | K | NO3 | NO2 | ALK. | TDS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run10 | 98.3 | 98.5 | 98.7 | 98.6 | 98.1 | 97.5 | 100 | 98.4 | 99.4 | 88.9 | 73.6 | 97.2 | 88.6 | 85.9 | 95.2 | 98.8 |
| Run11 | 98 | 98.1 | 97.6 | 97.8 | 98.9 | 97.1 | 100 | 98.4 | 89.6 | 88.9 | 80.9 | 99.8 | 86.4 | 55.7 | 98.4 | 98.7 |
| Run12 | 97.9 | 97.5 | 99.5 | 98.6 | 98.5 | 97.1 | 100 | 98.3 | 94.1 | 88.9 | 87.8 | 99.9 | 84.3 | 59.5 | 98.3 | 98.8 |

**Figure (11)**. The averages of salt rejection ratios within the concentrated water of the three experiments (Basrah site).