Evaluation of the Performance of MBR-RO Technology for Treatment of Textile Wastewater and Reuse

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Abstract. This study aims to evaluate the performance of membrane bioreactor (MBR) followed by the membrane of reverse osmosis (RO) for textile wastewater treatment and reuse. Firstly, study of the effect of hydraulic retention time (HRT) and the concentration of mixed liquid suspended solids (MLSS) on the removal efficiency of chemical oxygen demand, colour and turbidity were achieved by MBR system. The results showed that the MBR technology became increasingly effective in the treatment of textile wastewater with increasing HRT and MLSS concentrations. The highest removal efficiencies were 86.7%, 77.67% and 96.74% for COD, colour and turbidity, respectively when HRT = 2 days, while the highest removal efficiencies were 88.34%, 83.7% and 97.9% when HRT = 2.5 days. The second step was studying the effect of operating pressure and RO feed temperature on the removal efficiency of COD and colour of the RO system. MBR effluent has been treated with RO membrane to remove the remaining pollutants. The results showed that, the increasing of the pressure and decreasing of the temperature have a positive effect on removal efficiency. The maximum removal efficiencies obtained for COD and colour were 99.3% and 99.8% respectively at a pressure of 10 bar and 25 °C RO feed temperature.

Keywords: Textile effluent, Treatment, MBR-RO. Permeate water, Reuse

1. Introduction
Textile industries are one of the most water-intensive industries in different stages of textile processing, thus they are the largest producers of wastewater polluted by colours, textile auxiliaries, toxic chemicals and resistant to biological treatment methods [1]. Textile industries consume roughly 0.2 to 0.5 m³ of water per kg of the ultimate product [2].

Water resources have turned into an issues operational and ecological. Wastewater treatment and recycling have become an active tool for sustainable industrial development programs [3]. Reuse and decentralization will be fundamental for addressing human requirements for water and sanitation in developing and developed nations. Rigorous environmental legislation has increased the intensity, potency, and variety of treatment technologies in order to treat and reuse the water in several industrial processes.

MBR technology is one of the most advanced processing techniques used recently for the treatment of wastewater and reuse. MBR is a mix of the traditional biological sludge process and membrane separation process, this technique is characterized by increasing in a suspended biomass, with membranes systems of microfiltration or ultrafiltration. Membrane bioreactors can either be in-series or
submerged, where the submerged MBR is better because it requires less energy than the in-series MBR [4]. The membrane includes an important and effective function in the removal of suspended solids and industrial dyes utilized in textile processing [5]. There are four sorts of membranes: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO), respectively. A large portion of these membranes is produced using artificial organic polymers. Membranes (MF and UF) are made of a similar material yet the contrast between them is the variety in pore sizes and techniques of their preparation [6]. While RO membranes are manufactured either from polysulfone coated with aromatic polyamides or cellulose acetate [7]. UF or MF membrane is applied to the treatment of secondary effluents before treatment via the reverse osmosis unit, wherein (UF or MF) membrane is used to eliminate suspended solids and colloids, while RO membrane is used to remove the dissolved solids, organic and ionic materials. MBR-RO technique is used to treat industrial wastewater and recycling [8]. The objective of the present study is to, evaluate the performance of MBR-RO system in the removal of textile wastewater.

2. Materials and Methods

2.1. Wastewater source

The wastewater used in the laboratory experiments was taken from the wastewater collection tank of Al-Kut Textile Factory, Wasit Governorate, Iraq. The collection tank receives the wastewater from all sections of the weaving and knitting factory, and the pumps were designed to raise the wastewater from this tank to a higher altitude and pumping it to tanks of primary settling, neutralization, aeration, secondary settling, etc. The samples of textile effluent were tested in the laboratory to determine the physicochemical characteristics of wastewater as shown in Table (1).

| Parameters | Unit | Value       |
|------------|------|-------------|
| COD        | mg/l | 280-300     |
| TSS (mg/l) | mg/l | 200-250     |
| PH         | -    | 8±0.5       |
| Colour     | Pt-Co| 350-450     |
| TDS (mg/l) | mg/l | 700-800     |
| EC         | μS/cm| 1455-1602   |
| DO         | mg/l | 1.6-1.8     |
| Turbidity  | NTU  | 85-100      |

2.2. Operating conditions

The effluent of wastewater treatment plant was treated by using the MBR technology followed by the RO membrane as shown in Figure 1.
2.2.1. MBR pilot unit.

The MBR system consists of a reactor tank made of Plexiglas with a height of 40 cm and a diameter of 16.5 cm, an operating volume of 8L. The hollow fibre ultrafiltration membrane modules were installed inside the bioreactor, the membrane filtration precision is 0.01 μm and the effective surface area is 0.8 m², the UF membrane characteristics are summarized in Table (2). Air diffuser was installed under the reactor to perform the ventilation required and to maintain the dissolved oxygen concentration in a biological reactor greater than 5 mg / l. The reactor temperature was set at 25 ± 1 ° C. The wastewater was fed inside the reactor by the peristaltic pump with two flow rates of 0.166 and 0.133 l / h. The permeate was withdrawn from (MBR) by using a peristaltic pump and it was stored in the storage tank. The permeable flux ranged from 0.173 to 0.205 L / m² h when the HRT was 2 days and ranged from 0.14 to 0.164 L / m² h when the HRT was 2.5 days. The sludge retention time (SRT) was determined within 32 days. The mixed liquid is withdrawn daily to maintain the MLSS concentration between 2000 - 2500 mg / L. The negative pressure gauge was installed on the draw line between the reactor and the peristaltic pressure pump and the manual pressure data were recorded at the end of each filtration process, and the membrane pressure ranged (TMP) from 0.05-0.3 bar. At the end of each experiment, the sludge is withdrawn from the bioreactor, the reactor is washed with distilled water and the membrane was cleaned with an anti-scalant solution to remove the waste layer created on membrane fibres. The MBR operating characteristics are summarized in Table (3) as adopted by [10].
Table 2. Characteristics of UF membrane.

| Parameter Process          | Unit   | Value   |
|----------------------------|--------|---------|
| Maximum Pressure           | MPa/PSI| 0.4/58  |
| Maximum Operating Temperature| °C      | 5-40    |
| Material                   |        | Hollow fibre |
| Effective membrane area    | m²     | 0.8     |
| Filtration precision       | μm     | 0.01    |

Table 3. The operating conditions of MBR system.

| Parameters          | Unit | Average value |
|---------------------|------|---------------|
|                     |      | Run1  | Run2  |
| Mode of operation   |      | Continuous | Continuous |
| Inflow              | L/day | 4     | 3.2   |
| Permeate flux       | L/m²/day | 3.94 | 3.149 |
| (HRT)               | day   | 2     | 2.5   |
| (SRT)               | day   | 32    | 32    |
| (MLSS)              | mg/L  | 2200 ± 50 | 2500±50 |
| MLSS temp.          | °C    | 25 ± 1 | 25 ± 1 |
| DO                  | mg/L  | 5.5 ± 0.2 | 6.5 ± 0.5 |
| PH                  |       | 7.4 – 8.4 | 7.4 – 8.4 |

2.2.2. RO membrane pilot unit.

The MBR effluent was treated with RO membrane to produce higher quality water. The RO membrane was used as a type of "spiral wound membrane filtration unit". Two pressure gauges and two flow meters were used. Pressure difference was applied across the RO membrane to study the impact of pressure on the removal efficiency. The pressures applied on the reverse osmosis membrane were 2, 4, 6, 8 and 10 bar. Two temperature tests 25±1°C and 37±1°C were tested to compare the efficiency of RO membrane treatment in summer and winter. The RO membrane was cleaned at the end of each experiment using a pump with a low pressure (Ritek diaphragm pump USA with workflow 28 LPH). The RO membrane characteristics are summarized in Table (4).

Table 4. Characteristics of RO membrane.

| Parameter Process          | Unit            | Value       |
|----------------------------|-----------------|-------------|
| Maximum Operating Pressure | Bar             | 10          |
| Maximum Operating Temperature| °C              | 45          |
| pH range                   | -               | 2-11        |
| Membrane type              | -               | Spiral-wound element with polyamide thin-film composite membrane |
| Effective membrane area    | m²              | 0.37        |
| Minimum salt rejection     | -               | 96%         |
| Manufacturer               | -               | Film Technology Corp. USA |
2.3. Analytical methods

Laboratory analysis was performed to determine the characteristics of MBR influent, MBR and RO effluent. The flux of the MBR effluent is calculated by collecting water in a volumetric flask and analysed by analytical equipment. MLSS concentration was determined using the standard APHA 2540E method. The DO concentration was determined using a dissolved oxygen meter, and the PH meter (WTW – Germany) is used to determine the PH. The turbidity meter (WTW–Germany) is used to determine the turbidity. COD concentration and colour are determined using spectrophotometric (Spectro Direct-Lovibond) tests. Finally, the efficiency of removal (% R) is calculated for all species, as shown in the equation below [11].

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\text{Removal Efficiency (\% R)} = 1 - \frac{\text{Permeate Concentration (mg/L)}}{\text{Feed Concentration (mg/L)}} \times 100 \quad \text{(1)}
\]

3. Results and Discussion

Sludge was initially collected from sedimentation tanks in the textile plant and transferred to the MBR tank. The MBR was operated for 30 days prior to the initiation of the experiments in order to achieve the operational conditions specified in Table 2. It was then started to withdrawal the sludge each day in order to maintain MLSS concentration in the aeration tanks. The HRT of the membrane bioreactor system was increased from 2 to 2.5 days to study the effect of HRT on the rate of removal efficiency. The change of HRT from 2 to 2.5 days, increased the removal efficiency of COD from 86.7% to 89.3%, as shown in Figures 2(a) and 2(b), and these values are satisfactory according to previous studies [12]. It has been observed that COD removal efficiencies increase with increasing HRT. The reason for the increased efficiency of COD removal with increasing HRT is that biological reactors have the ability to oxidize the organic material entering the reactor, especially at low inflow, as mentioned in previous studies [13].

![Figure 2](image-url)
Figures 3 (a) and 3 (b) showed the removal efficiency of turbidity achieved in the MBR system is to be 96.74% and 97.9% at HRT = 2 and 2.5 day, which is a good rate to remove as reported in previous studies [1]. This percentage of removal indicates that the turbidity of MBR permeate are very low, and this means that the UF membrane operates properly without any flaws during the experiment period and the produces clean water and free from impurities.

![Figure 3](image)

**Figure 3.** Turbidity in textile effluent and the MBR permeate with the time of operation and their removal percentage, at (a) HRT=2 days and (b) HRT= 2.5 days.

Figures 4 (a) and 4 (b) showed the removal efficiency of colour achieved in the MBR system is to be 77.67% and 83.7% at HRT = 2 and 2.5 day, which is consistent with previous studies [14]. Note that there is an increase in colour removal with increased HRT, because the increased of HRT leads to increased microorganisms, the function of these organisms is to absorb pollutants and colour molecules that enter MBR.
MBR effluent was treated with RO membrane unit to treat residual of pollutants to produce high-quality water that conforms to reuse standards. Figures (5) and (6) show that the minimum overall removal efficiencies achieved by RO membrane for COD and colour are 93.4% and 93%, respectively, at pressure 2 bar and RO feed temperature 37 °C, and the highest overall removal efficiency of COD was 99.3% and colour was 99.8%, at pressure 10 bar and RO feed temperature 25 °C. We note that the removal efficiencies of COD and colour increases with increasing mechanical pressure applied to the membrane. This can be attributed to the fact that increasing the mechanical pressure applied to the membrane leads to an increase in the free volume available to the active layer of the membrane, which allows components to permeate the created space and the reason for the decrease of the efficiency with high feed temperature is that the high temperature leads to an increase in the pore size of the membrane and thus allows the passage of pollutants through it, as mentioned in previous studies [9].

It is very essential to mix the MBR and RO technologies. this mixture able to achieve the highest levels of removal for COD, colour and salts to provide the production of high quality reusable water for industrial purposes. Although the MBR is extremely effective in removing industrial pollutants (COD, colour and turbidity), but it is ineffective in removing salts. As a result, it is necessary to resort to treatment with RO system to remove the remaining pollutants and achieve reuse standards. MBR and RO showed excellent performance in removing all contaminants with removal rates of more than 93% for COD and colour. And removal rates of total dissolved solids (TDS) ranged from 96-100%. This means that mixing (MBR with RO) successfully processes the textile wastewater and within the reuse specification and this also corresponds to what was mentioned in previous studies [1].

Figure 4. Colour removal with time, at (a) HRT=2 days and (b) HRT= 2.5 days.
4. Conclusion
Following the integration of the MBR and RO techniques for textile wastewater treatment, it can be concluded that the performance of these technologies are an extremely effective in the wastewater treatment and reuse. It can also be concluded that these techniques are complementary to each other in removing all organic pollutants at rates exceeding 93% for COD and colour, and exceeding 96% for total dissolved solids (TDS). MBR technology proved to be effective in removing organic pollutants, except for salts. It was observed through the results obtained that the HRT has a positive effect on the removal of organic pollutants (COD, colour and turbidity) and it was also observed that MBR technology is an extremely effective way to RO pre-treatment. It has also been demonstrated that the use of RO technology is effective in removing residual organic pollutants and salts within the required limits and the reuse specifications. The results showed that the applied pressure on the RO membrane has a positive effect on the removal efficiency, whereas the feeding temperature has an inverse effect on the removal efficiency.

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