Evaluation of laboratory submerged membrane bioreactor and reverse osmosis system for treating textile wastewater and reuse

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Abstract. This study aims to assess the overall performance of a membrane bioreactor and reverse osmosis membrane for the treatment of textile effluent as well as to investigate their ability in meeting the water reuse standards. The laboratory-scale MBR-RO units were fed with textile wastewater, and the MBR effluent performance was evaluated through water quality for the parameters like total suspended solids (TSS), chemical oxygen demand (COD), and colour. The results reveal that the MBR system yields good quality permeate water. We obtained 99%, 90.3%, and 82.5% (average) reduction of TSS, COD, and colour, respectively, with this system. Moreover, the MBR technology is highly effective for pre-RO treatment. We also studied the impact of pressure and temperature applied to the RO membrane on the efficiency for eliminating TDS, COD, colour, and the permeate flux. The results demonstrated that the applied pressure positively affected while the feed temperature negatively affects the overall removal efficiency. This study confirms that the feed temperature, besides pressure, have a positive effect on the flux for an RO system.

1. Introduction
Water is the main source of humans on Earth. It is well characterized as a neutral liquid. One of the most difficult problems faced recently is the rarity of water supplies due to the growing demands on account of the population rise and the prosperity of industries. The textile industry is one of the most water-consuming industries [1 - 4]. Textile industry doesn't only consume huge amounts of water but also produces massive volumes of toxic, highly colored, low bio-degradable wastewater, which if inappropriately is discharged, can damage the natural water environment [5 – 8]. Textile wastewater includes high concentrations of sluggish or non-biodegradable organic materials and inorganic chemical substances such as pigments, dyes, and heavy metals along with a range of pollutants like surfactants, enzymes, salts, and agents (both oxidizing and reducing). These pollutants cause fluctuating pH, accumulation of suspended solids, robust colour, high temperature, and increased chemical oxygen demand of the wastewater [2, 8, 9]. Industrial activities are the foremost severe contributing factor to the environmental contamination issues through the discharge of wastewaters to receiving water bodies. Due to the increasingly restrictive quality of effluents needed by water authorities, in addition to the increasing shortage of fresh water, it has become critical to treat textile
effluents for reuse [10]. The conventional treatment methods for treating textile effluent before their discharge into receiving water bodies include physical, biological, and chemical treatments. Of these, the biological method involves activation of sludge for good COD reduction; however, this method is inefficient in colour treatment due to the utilization of non-biodegradable dyes and it doesn't also reduce the water salinity. On other hand, the physical and chemical methods can fully eliminate colouring and lower the amount of suspended, dissolved, colloidal, and non-settleable materials from water via chemical coagulation, followed by the gravity settling. However, chemical methods possess the significant disadvantages of difficult in managing the chemical and physical sludge resultant from the process, the high cost of chemical, and the reduced removal efficiency of the soluble COD and salinity. Other techniques such as electrochemical treatment, chemical oxidation by ozone, or a combination of UV-radiation, H2O2 and ozone are promising alternative for improving the treatment method of textile effluent, albeit these techniques are very expensive and they do not also remove the water salinity [11 - 13]. Membrane processes can be successfully utilized not only for the production of purified water but also for the recycling of specific pollutants in industrial effluents via effective separation. Membrane separation process is thus one of the most promising methods that has recently gained popularity for wastewater reclamation because of its high efficiency, ease, and low cost of operation. Furthermore, membrane bioreactors (MBRs) that combine activated sludge system with membrane separation process offer some benefits rather traditional activated sludge, it is what permits the higher biomass concentration and a sensible separation with no need of a clarifier. In addition, in terms of industrial wastewater, membrane technology provides a sensible solution to meet the stringent discharge limits as well as the option to recycle the textile wastewater by yielding high-quality treated water [10].

In the present study, the feasibility of integrating the technique of MBR with reverse osmosis (RO) technique is investigated for effluent treatment at AL-Kut Textile Plant (KTP).

2. Materials and Methods

2.1. The experimental system and conditions
The pilot plant unit used in this study consists of a MBR bioreactor system and an RO system (Figure 1). The bioreactor tank had an operating volume of 8 L (dimensions, 40 cm height and 16.5 cm diameter). The UF membrane was made of polyvinylidene fluoride with a precision of filtration (0.01 μm), surface area (0.8 m2) and was immersed in the bioreactor; the ultra-filtration membrane properties are summarized in Table 1. The raw wastewater provided from Al-Kut textile plant was fed into the bioreactor, wherein the organic contaminants were decomposed biologically. An air dispenser situated below the UF membrane unit provided aeration and helped blend the wastewater. The wastewater was then fed within the bioreactor via a peristaltic pump at a flow rate of 0.11 L/h. The feed pump of a similar make and model as that of the suction pump was controlled through a water level sensing element so as to preserve a stable water level within the bioreactor during the trial period. The temperature of water in the bioreactor was maintained at 25 ± 1°C using a temperature controller. Actual textile wastewater was used. The experiments were conducted at an HRT of 3 days, an SRT of 32 days, and DO concentration within the bioreactor of 7.5 ± 0.3 mg/L. Before starting the experiments, the MBR system was operated for over 3 weeks, and a stable stage was reached. Occasionally, high values of the MLSS concentration were measured, and it raised up to an estimation of around 3000 mg/L. Next, the sludge elimination was initiated to maintain the MLSS concentration at a steady value within the bioreactor. The UF membrane unit was periodically removed from the reactor tank and washed with faucet water to remove the sludge deposited on the surface of the membrane. The operation properties of the MBR are given in Table 2, as adopted by [14].
Table 1. Properties of the UF membrane.

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

Table 2. The running conditions of the MBR system.

| Parameters       | Average value |
|------------------|---------------|
| Mode of operation| continuous    |
| Permeate flux    | 0.136 L/m²/day|
| Inflow           | 2.67 L/day    |
| (SRT)            | 32 day        |
| (HRT)            | 3 day         |
| MLSS temp.       | 25 ± 1 °C     |
| (MLSS)           | 3000 ± 100 mg/L|
| PH               | 7.4-8.4       |
| DO               | 7.5 ± 0.3 mg/L|

In the RO system, the RO membrane served as a spiral-wound membrane filtration unit that includes 2 pressure gauges and 2 flow meters. Different intensity of pressures (2, 4, 6, 8, and 10 bars) were applied over the RO membrane for the study of its effect on the elimination efficiency. Similarly, 2 temperature tests (25 ± 1°C and 37 ± 1°C) were used to evaluate RO membrane performance in the winter and summer seasons. The membrane unit was cleaned after each test using the Ritek Diaphragm low pressure pump (workflow 28 LPH). Table (3) shows the properties of the RO membrane.

Table 3. Properties of the RO membrane.

| Parameter                          | Value                                      |
|------------------------------------|--------------------------------------------|
| Maximum Operating Temperature      | 45 °C                                      |
| Maximum Operating Pressure         | 10 Bar                                     |
| pH range                           | 2-11                                       |
| Effective membrane area            | 0.37 m²                                    |
| Minimum salt rejection             | 96%                                        |
| Membrane type                      | Spiral-wound element with polyamide thin-film composite membrane |
| Manufacturer                       | Film Technology Corp. USA                  |
2.2. Wastewater
The discharge of the textile effluent to the water bodies is environmentally unacceptable. It is therefore necessary to treat and reuse wastewater as a step toward preserving the water bodies of pollutants and toxic substances as well as for reducing the costs. The raw wastewater utilized in the laboratory experiments was obtained from Al-Kut Textile plant, Governorate of Wasit, Iraq. A sample textile wastewater was tested to evaluate its physicochemical properties (Table 4).

Table 4. The properties of textile effluent.

| Parameter | Value          |
|-----------|----------------|
| COD       | 270-285 (mg/l) |
| TSS       | 200-225 (mg/l) |
| PH        | 8±0.5          |
| Colour    | 420-445 (Pt-Co)|
| TDS       | 700-800 (mg/l) |
| EC        | 1455-1602 (μS/cm) |
| Do        | 1.6-1.8 (mg/l) |
| Turbidity | 85-100 (NTU)   |

2.3. Analytical method
The raw wastewater was tested as the effluent of MBR and RO and its properties were studied. The permeate flux for the MBR and RO effluents was estimated through accumulating water in a volumetric flask and analyzing it by using analytical gadgets. The Standard APHA 2540E method was
used to determine the MLSS concentration. The DO content was estimated by using the DO meter. The WTW pH meter (Germany) was used to determine the pH. A spectrophotometric device (Spectro Direct-Lovibond) was used to test the color and COD concentration. Equation 1 below shows the calculation method for the removal efficiency (%R) for each species [15].

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

Through the experimental operate for subsequent treatment by using RO system, the system was operated to accumulate the permeate within a beaker at every 3 min and for 30 min at every used pressure to measure the flux via the usage of Equation 2:

\[
J = \frac{Q_P}{A}
\]

Where:

\(J\): the permeate flux (L/m²·h),
\(Q_P\): the permeate flow rate per hour and
\(A\): active surface area of membrane (m²).

3. Results and Discussion

3.1. Phase 1: MBR Results

Within 30 days of running the bioreactor, the performance evaluation of the MBR based totally on the influent and effluent quality and the elimination per cent of COD, colour and TSS showed that the MBR system produced permeate water of a good quality. Figures 2–4 show COD, TSS concentration, and colour in the MBR inlet and outlet versus the operating days. The influent concentrations of COD, TSS, and colour ranged from 270 to 285 mg/L, 200–225 mg/L, and 420–445 Pt-Co, respectively. Figure (2) demonstrates the elimination efficiencies of the COD for the influent and effluent of the MBR system. The COD is the amount of oxygen in an organic matter within the textile effluent that can be oxidized chemically. COD is significant in wastewater remedy as it is a suitable indicator of the organic pollutants in wastewater. Consequently, during this study, COD was designated as an index of the organic pollution. The influent COD ranged from 270 to 285 with an average influent COD of 278.8 mg/L, while the COD concentration within the effluent ranged between 20 and 33, and, therefore, the removal rate was >85%. This showed that the MBR system created good removal of the organic components and that it was absolutely able to achieve a high elimination of COD. The high COD decrease suggests that a well biodegradable and non-biodegradable COD demand decrease was accomplished via the membrane filtration process. Finally, most of the non-biodegradable materials were eliminated via sludge wasting. Only a little fraction of the non-biodegradable material across the membrane remained. Comparable outcomes were also reported elsewhere [1]. Figure 3 shows the excellent separation of solids achieved by the MBR system. The TSS removal of >98% was achieved, leading to the MBR permeate with TSS level of <4 mg/L. The high percentage elimination of the TSS through the MBR indicates that the membrane was in an exceedingly good condition. In this study, MBR achieved the maximum removal of colour at 82.5% (Figure 4), because the colour elimination mechanism in the MBR system depends only on the biological degradation of the microorganisms inside the bioreactor. The action of these microorganisms was to absorb the incoming colour particles [1, 16, 17].
Figure 2. Concentration of COD in influent and effluent versus the operation time and removal percentage.

Figure 3. Concentration of TSS in influent and effluent versus the operation time and removal percentage.

Figure 4. Concentration of colour in influent and effluent versus the operation time and removal percentage.
3.2. Phase 2: RO Results

The permeate acquired after the treatment using the MBR technique was inside water reuse standard; however, not every parameters of the water reuse standards (as per the Iraqi Standard Law No. 25, 1967) was fulfilled. The MBR permeate skipped the water reuse standards for overall dissolved solids (700 mg/L) and colour (80 Pt-Co). Therefore, the MBR permeate could not be reused for the industrial purposes within the textile factory, particularly in the dyeing processes. Thus, additional processing was required. The RO membrane was utilized to eliminate most of the salts and the contaminants remaining within the MBR permeate. The impact of the operational pressure and feeding temperature on the elimination efficiency and permeate flux were studied.

The effluent MBR was remedied by using RO membrane to treat the residual contaminants in order to provide high-quality water that complied with the reuse standards. Figures 5-8 demonstrate the impact of the operational pressures and feed temperatures on the overall removal efficiency for COD, TDS, and colour, as well as the permeate flux when the operating pressure increased from 2 bars to 10 bars, the overall removal efficiency increased from 95% to 99.3%, 95% to 100%, and 94.3% to 100% for COD, TDS, and colour, respectively, and the permeate flux increased from 12.2 LMH to 16 LMH, indicating that the relationship between the operational pressure and the removal efficiency of COD, TDS, and colour is proportional as is that between the operational pressure and permeate flux. This result occurred because of the pressure increase over the RO membrane, which resulted in increased driving pressure and, consequently, lower resistance through the membrane surface, leading to membrane compaction.

When the temperature rose from 25°C to 37°C, the percentage removal decreased with increasing feed temperature, where the removal efficiency of COD, TDS, and colour decreased from 95% to 93.4%, 95% to 92.8%, and 94.3% to 92.5%, respectively, at P = 2 bars, and they decreased from 99.3% to 97.8%, 100% to 98.2%, and 100% to 98.2%, respectively, at P = 10 bars. While the permeate flux increased with increasing feed temperature, where the permeate flux increased from 12.2 LMH to 14.3 LMH at P = 2 bars and from 16 LMH to 18.03 LMH at P = 10 bars. The relationship between the temperature of the feed and the removal efficiency of COD, TDS, and colour was inverse, while that between the feed temperature and permeate flux was proportional. The reason for this is that an increase in the feed temperature results in mechanical deformation of the pore size of the membrane, which in turn increase the pore size and, thereby, permit water permeability to increase as well as the passage of organic matter and salts through the membrane surface [18, 19].

![Figure 5](image-url)

**Figure 5.** Effect of Operating Pressure on the Overall COD Removal at T = 25 and 37°C
Figure 6. Effect of Operating Pressure on the Overall TDS Removal at T = 25 and 37°C

Figure 7. Effect of Operating Pressure on the Overall colour Removal at T = 25 and 37°C

Figure 8. Effect of Operating Pressure on Permeate Flux at T= 25 and 37 °C

It is extremely important to combine the techniques of MBR and RO as it is capable of fulfilling the optimal rates of eliminating COD, salinity, and colour in order to yield high-quality water that can be
reused in diverse industries. Despite the fact that the MBR system is highly efficient in disposing the COD, TSS, and colour of industrial pollutants, it is ineffective in eliminating salts. Therefore, treatments with RO technique seem more promising for removing residual pollutants in order to meet the reuse quality standard. Both RO and MBR demonstrated brilliant overall performance in eliminating all pollutants, with COD elimination rate of >93% and colour and overall TDS elimination rate of 96–100%. These results imply that blending (techniques of MBR with RO) effectively works in textile wastewater treatment and yields water within reuse specification; this data agrees with those reported in a previous study [20].

4. Conclusion
Through this study, we demonstrated the effectiveness of the MBR-RO technique in eliminating pollutants from the effluent of the Kut textile factory. Several conclusions can be drawn from this study. The treatment of MBR with mixed liquid suspended solid concentration (MLSS) of 3000 mg/L provided an excellent remedy for industrial wastewater treatment. The TSS removal reached 99%, with MBR permeates of TSS levels <4 mg/L. This excellent separation of solids confirmed that it is reachable through the UF membrane. MBR demonstrated a good decrease in the biodegradable and organic matter content. The average removal of COD was 90.3%, leading to an effluent with COD of 20 to 33 mg/L, whereas, the average removal of color was 82.5%. The MBR technology has been proven to be efficient in eliminating the organic pollutants, except for salts. Notably, the MBR technology is highly effective for pre-RO treatment. The use of RO system has also proven to be efficient in eliminating the organic pollutants and salts remaining in the wastewater within the limits and specifications of reuse. The outcomes of this study demonstrated that the pressure applied to RO membrane has a positive impact, while the feed temperature has a negative impact on the removal efficiency. From the experimental outcomes, it can be seen that the feed temperature, besides pressure, positively affects the RO system flux.

5. References
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