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Evaluating Laboratory Side-stream Membrane Bioreactor and Nanofiltration System for Treating Domestic Wastewater and Reuse

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Abstract

This paper presents Membrane Bioreactor (MBR) and Nanofiltration (NF) systems as alternative and effective approaches for treatment and reusing domestic sewage. The goal is to investigate the general performance of a membrane bioreactor and nanofilteration membrane ability to satisfy water reuse requirements using water quality index such as total suspended solids (TSS), chemical oxygen demand (COD), and ammonia (NH_3). The findings show that the MBR system produces high-quality permeating water. TSS, COD and NH_3 rejection rates were 99%, 90.3%, and 82.5% (on average). In addition, MBR technology is quite successful as a pre-NF treatment. We also evaluated how pressure and temperature affect the effectiveness of the NF membrane removal of TDS, COD, ammonia, and permeating flux. The results showed that the applied pressure has a favorable impact on the total removal rate; however, the feeding temperature has a negative impact. The feeding temperature, in addition to pressure, has a good influence on the flux of the NF system.

Keywords: Domestic sewage, Treatment, MBR-NF. Permeating Flux, and Reuse.

الخلاصة: يقدم هذا البحث نظام المفاعل الحيوي الغشائي **(MBR)** ونظام الترشيح النانو **(NF)** كطرق بديلة وفعالة لمعالجة وإعادة استخدام مياه الصرف الصحي المنزلية. الهدف هو التحقيق في الأداء العام للمفاعل الحيوي الغشائي وقدرة غشاء الترشيح النانو على تلبية متطلبات إعادة استخدام المياه باستخدام مؤشر جودة المياه مثل إجمالي المواد الصلبة العالقة **(TSS)** والطلب الكيميائي للأكسجين **(COD)** والأمونيا **(NH3).** تظهر النتائج أن نظام **MBR** ينتج مياه نفاذة عالية الجودة. كانت معدلات رفض المواد الصلبة الذائبة ، و **COD** ، والأمونيا 99 في المائة ، و 90.3 في المائة ، و 82.5 في المائة (في المتوسط). إضافة إلى ذلك، فإن تقنية **MBR** ناجحة تمامًا كعلاج ما قبل **NF.** قمنا أيضًا بتقييم كيفية تأثير الضغط ودرجة الحرارة على فعالية إزالة غشاء **NF** من المواد الصلبة الذائبة ، و **COD** ، والأمونيا ، والتدفق النافذ. أظهرت النتائج أن الضغط المطبق له تأثير إيجابي على معدل الإزالة الكلي؛ ومع ذلك، فإن درجة حرارة التغذية لها تأثير سلبي. درجة حرارة التغذية، بالإضافة إلى الضغط، لها تأثير جيد على التدفق لنظام **NF**

1. INTRODUCTION

Because of industrialization and tremendous economic development in several emerging nations over the last three decades, the environment has degraded greatly, and water requirements have risen rapidly as people consume huge amounts of water for everyday industrial and household usage. Domestic sewage is the water that is being used by a community and includes any contaminants that have been added to it within that time. Untreated sewage has a significant detrimental influence on the environment and human health, in addition to worsening water scarcity. Wastewater that has been treated can be utilized for a variety of purposes, including landscape irrigation [1, 2, and 3].

As a result, everyone has concentrated their efforts on how to fix these problems, particularly when traditional treatments have proven ineffective or inefficient. Membrane separation has emerged as one of the most promising remedy technologies for treating and reusing municipal wastewater, and has recently gained popularity. Because recovered water is accessible near urban areas where water provider dependability is most essential and water is more costly, wastewater recycling has become a major option for the environment and economic water maintenance. It saves clean water, is ecologically benign, and cost effective [4, 5, 6, 7, 8], and [9].

The membrane bioreactor (MBR) is a combination of the biological activated sludge process and MF/UF (pore sizes ranging from 0.05 to 0.4 µm) membrane separation, offering significant advantages over traditional wastewater treatment techniques including less sludge formation, a minor footprint, high permeating efficiency, simplicity of handling, and low cost [10, 11].

The reactor functions similarly to a standard activated sludge system, but without secondary clarification and further steps such as sand filtration. The effluent of biological activated sludge is removed using low-pressure membrane filtration techniques such as microfiltration (MF) and ultrafiltration (UF). The two most common MBR configurations are submerged (immersed) and external (side-stream) membranes [12].

The MBR system is becoming a prominent option for advanced wastewater treatment. Due to the growth of MBR, a new idea for recovering municipal wastewater has recently been suggested, which involves combining NF with MBR, with NF serving as a post-treatment approach [13].

Nanofiltration membrane uses have gained in popularity across the fields. This membrane had previously been used in filtering operations by the end of the 1980s [14]. The features of NF membranes are in between reverse osmosis (RO) and ultrafiltration (UF). They incorporate the advantages of low operating pressures with a molecular size cutoff and high permeate fluxes (less energy consumption and higher removal than reverse osmosis (RO) and ultrafiltration (UF), respectively). This has led NF to take the place of reverse osmosis (RO) in a variety of applications, including the domestic sector, municipal wastewater reclamation, drinking water purification from ground and surface waters, and RO pre-treatment [15, 16].

Although the MBR process has somewhat higher operational and capital expenses than traditional methods, it appears that the conventional treatments are upgraded even when it is successful.

It might be connected to rising water prices, increased demand for water recycling, and stricter effluent quality regulations [17].

The purpose of this study is to determine the performance of the (MBR) system in conjunction with the nanofiltration membrane (NF) in the treatment and recycling of various permeating fluxes of household wastewater based on contaminant elimination rates.

2. MATERIALS AND METHOD

2.1. The experimental set up

A MBR bioreactor and a NF system make up the pilot scale unit employed in this research (**Figure 1**). The operational volume of the reactor tank was 8.5 L (40 cm in height and 16.5 cm in diameter). The UF membrane was manufactured of polyvinylidene fluoride and it was placed outside the aeration tank with a filtration pores size of (0.01 µm) and an effective area of 0.8 m2; the ultra-filtration membrane features are mentioned in **Table 1**. The bioreactor was supplied with real wastewater from the sewer network of Al-Ezzah sewage outlet in Wasit Governorate, and it transported to the bioreactor where the organic pollutants were biologically degraded. Aeration was generated by an air dispenser located below the UF membrane unit, which also assisted in the mixing of the wastewater, also, a recirculation pump for recycling the sludge from the UF membrane to the reactor.

A peristaltic pump was used to feed the wastewater into the bioreactor at a rate of 0.11 L/h, a recycle pump to reterned the sludge back to bioreactor. The water level sensor device was used to operate the feed pump, which was of the same make and type as the suction pump, in order to maintain a constant water level within the bioreactor during the trial period. A temperature controller was used to keep the water temperature in the bioreactor at 25°C ± 1°C. The domestic wastewater tests were carried out using a two-day HRT, a 30-day SRT, and a DO level of 6.5 ± 0.5 mg/L inside the bioreactor. The MBR system had been running for nearly three weeks before the testing began in order to reach a stable state. Mixed liquid suspended solids (MLSS) concentrations were observed daily, with an estimated value of about 4000 mg/L. The sludge removal process was then started in order to keep the MLSS concentrations in the bioreactor at a constant level. To eliminate the sludge formation on the membrane's surface, the UF membrane unit was regularly cleaned. **Table 2** lists the MBR's operating characteristics, as recommended by [18, 19].

Table 1 The features of the UF membrane that were applied in this study.

Membrane type	Ultra-filter
Highest operating temperature	5 - 40 °C
Surface area of membrane	0.8 m2
membrane pore size	0.01 µm
Type the materials	Hollow fiber
manufacturers	china

Table 2 The MBR's operating conditions.

Factor	Unit	Value
Running mode	-	Continuous
Permeating flow	LMH (L/m2/h)	0.204
Feed flow	L/day	4
(HRT)	day	2
(SRT)	day	30
(MLSS)	mg/l	4000
MLSS temperature	°C	25 ± 1
DO	mg/l	6.5 ± 0.5
PH	-	7.4 - 8.4

The NF membrane operated as a plate sheet membrane-filtering unit in the NF system, which included a steel membrane cell, two pressure gauges and two flow meters. Various pressures (2, 4, 6, 8, and 10 bars) have been applied to the NF membrane to see how they affect the efficiency of removal. In the winter and summertime season, two temperature tests (25°C and 37°C) were utilized to evaluate Nano membrane performance. The Ritek Diaphragm low-pressure pump was used to clean the membrane unit after each test (workflow 28 LPH). The parameters of the NF membrane are shown in **Table 3**.

Table 3 The NF membrane properties that were utilized in this research.

Membrane	Nanofiltration
type	PPSU 20% - PVC 6%
Provider	University of Technology, Baghdad, Iraq
Effective area of filtration (m2)	1.452*10-3
Porous media %	49.77
Thickness (µm)	86.85

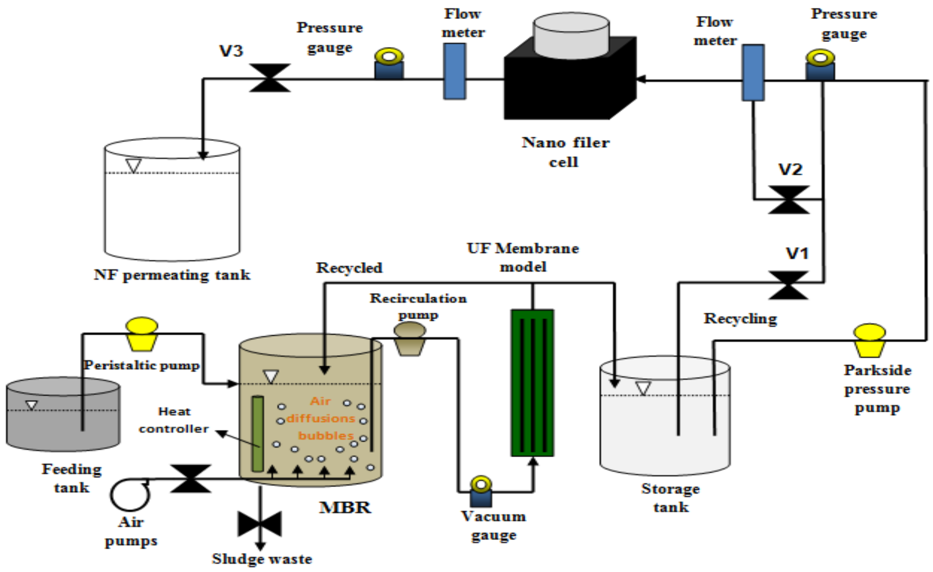

Figure 1 A MBR-NF pilot scale.

2.2. Wastewater

The actual wastewater used in the laboratory tests came from the sewer outlet of Al-Ezzah sewage plant in Wasit Governorate. The physicochemical parameters of a sample of domestic sewage were investigated in **Table 4**.

Table 4 the properties of domestic wastewater that fed the membrane.

Factors	Daily Values
COD (chemical oxygen demand)	**295-377 (mg/l)**
BOD5 (biological oxygen demand)	**260-350 (mg/l)**
TSS (total suspended solids)	**250-350 (mg/l)**
TDS (total dissolved solids)	**960-1450 (mg/l)**
EC (electrical conductivity)	**1530-1655 (µS/cm)**
DO (dissolved oxygen)	**1.4-1.8 (mg/l)**
NH3 (ammonia)	**17– 32 (mg/l)**
Turbidity	**90-200 (NTU)**
PH	**7.8 – 8 ± 0.5**

2.3. Analysis methods

Untreated wastewater was examined as MBR and NF effluent, and its qualities were investigated. The permeating flux for MBR and NF effluents was calculated by collecting water in a volumetric flask and testing it using analytical equipment. The MLSS concentration was determined using the Standard APHA 2540E technique. The DO content was calculated with the use of a DO meter. The pH was measured using a WTW pH meter (Germany). The COD levels were measured using a spectrophotometric device (Spectro Direct-Lovibond). The calculating technique for the elimination efficiency (% R) for every species is shown in Equation 1 below [20].

$$R=\frac{C_1-C_2}{C_1} \tag{1}$$

Where:
R: removal ratio,
$\mathbf{C_1}$: Feed concentration (mg/l),
$\mathbf{C_2}$: Permeate concentration (mg/l).

During the experimental run for following treatment with a NF system, the system was set to collect permeate in a beaker every 20 minutes at each employed pressure to quantify the flow using Equation 2:

$$J=\frac{Qp}{A} \tag{2}$$

Where:
J: The permeating flux ($L/m^2.h$),
Qp: The permeate flow rate per hour and
A: Active area of membrane (m^2).

3. RESULTS AND DISCUSSION

3.1. Stage1: MBR findings

Within 30 days of operating the bioreactor, a performance examination of the MBR based only on inflow and outflow quality, as well as the percentage removal of COD, NH_3, and TSS, revealed that the MBR system generated high-quality permeated water. COD concentrations, TSS, and NH3 in the MBR inflow and outflow on operation days are shown in **Figures 2 – 4**. COD and TSS influent concentrations varied from 295-377 mg/L, 17–32 mg/L, and 250-350 mg/L, respectively. The COD removal rate for the MBR system's influent and effluent is shown in **Figure 2**. The COD is the quantity of oxygen in organic matter that may be oxidized chemically in domestic sewage.

COD is significant in sewage treatment because it is a good indication of organic contaminants. As a result, COD was used as an indicator of organic contamination in this investigation. The COD level in the influent ranged from

295 to 377 mg/L, with an average of 345 mg/L, whereas the COD concentrations in the effluent varied from 34 mg/L to 46 mg/L, indicating a removal rate of > 86%. This demonstrates that the MBR system effectively removes organic components while also achieving a high level of COD removal. The substantial COD reduction shows that the membrane filtering procedure was used to reduce both biodegradable and non-biodegradable COD demands.

The inflow of NH_3 concentration is between 17 and 32 mg/l. The values of inflow and outflow of NH_3 as time-dependent are illustrated in **Figure 3**. The average NH_3 elimination rate of ammonia was 86.48%, corresponding to the effluent of NH_3, 3.5 mg/L. The high HRT resulted in higher NH_3 removal rates.

High removal rates demonstrate MBR's effectiveness in the nitrogen removal process. Due to Chen et al. [22], high MLSS concentrations increased the sludge's lifespan, allowing the approach to maintain nitrobacteria, resulting in the apparent nitrification impact.

Lastly, sludge waste was used to get rid of the majority of the non-biodegradable components. Only a small amount of non-biodegradable material persisted above the barrier. Similar results have been observed previously [23, 24]. The MBR method achieves good solids separation, as seen in **Figure 4**. TSS was removed at a rate of > 98%, resulting in MBR permeating with a TSS rate of 4.7 mg/L. The high percentage of TSS removal by the MBR suggests that the membrane was in excellent condition [21, 22, 23, 24, and 19].

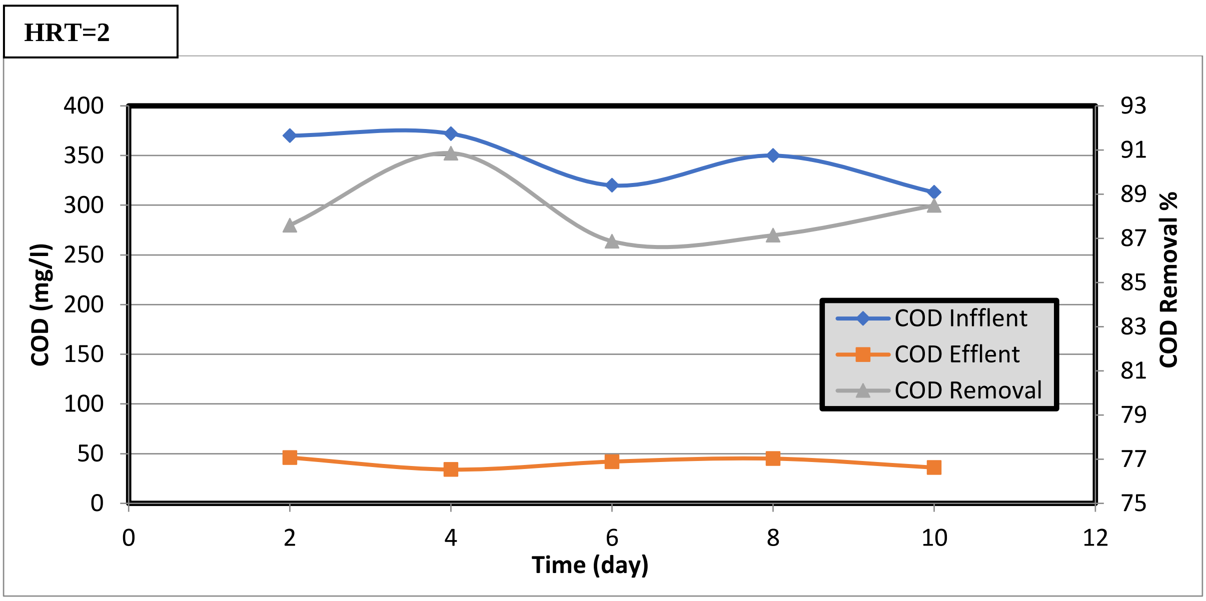

Figure 2 Concentrations of COD in and outflow as a function of time (HRT=day) and removal percentages.

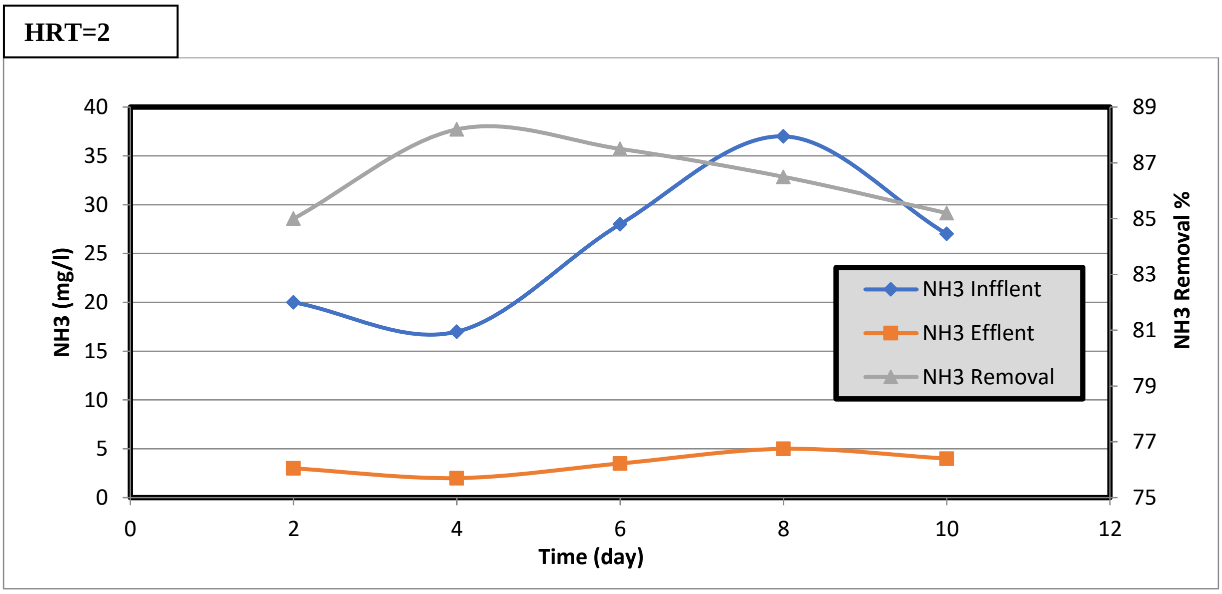

Figure 3 Concentrations of NH_3 in and outflow as a function of time (HRT=2 day) and removal percentages.

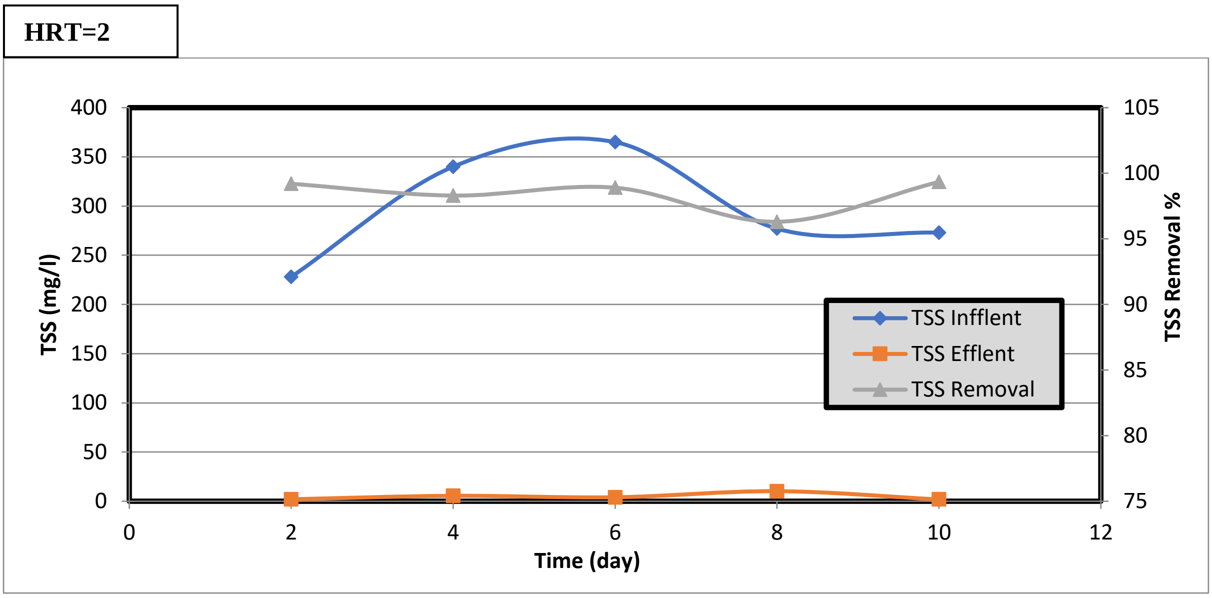

Figure 4 Concentrations of TSS in and outflow as a function of time (HRT=2 day) and removal percentages.

3.2. Stage2: NF results

The permeating obtained after processing with the MBR technology satisfied the water reuse requirement; however, not all of the water reuse characteristics (as defined by Iraqi Standard Law No. 25, 1967) were met. As a result, there was a need for further processing. Most of the salts and pollutants that remained in the MBR permeate were removed by using the NF membrane. The effect of operating pressure and serving temperature on permeated flow and elimination efficiency was investigated. The effluent MBR was corrected by treating leftover impurities with a NF membrane in order to deliver high-quality water that met reuse criteria. **Figures 5-7** show the effect of operating pressures and feeding temperatures on total COD and NH3 removal percentages, as well as permeating flow. When the working pressure was increased from 2 to 10 bars, the total elimination efficiency was raised from 95 % to 99.7 %, and 87.5 to 92.5 % respectively. The permeating flux continued to increase from 36 to 42 LMH, implying that the connection between the operational pressure and COD and NH3 removal effectiveness is proportional, as is the relationship between the operational pressure and the permeating flux. The rise in pressure across the NF membrane led to a rise in driving pressure and, as a result, decreased resistance across the membrane surface, resulting in membrane compression.

When the temperature was increased from 25°C to 37°C, the elimination rate decreases with the increasing feed temperature, with COD and NH3 removal efficiency decreasing from 96 % to 94 %, and from 87.5 to 86.4 %, respectively, at P = 2 bars, and from 99.4% to 97%, 92.5% to 90%, respectively, at P = 10 bars. While the permeating flow rose as the feeding temperature rose, it rose from 35.9 LMH to 42 LMH at P = 2 bar and from 33 LMH to 40 LMH at P = 10 bar.

The temperature of the input had an inverse connection with COD and NH3 removal efficacy, whereas the temperature of the feeding had a proportionate relationship with the permeate flux. The explanation for this is because increasing the feeding temperature causes mechanical deformation of the membrane's pore size, which causes the pore size to grow, allowing more water permeability and organic matter and salts to flow through the membrane surface [21, 25, and 26].

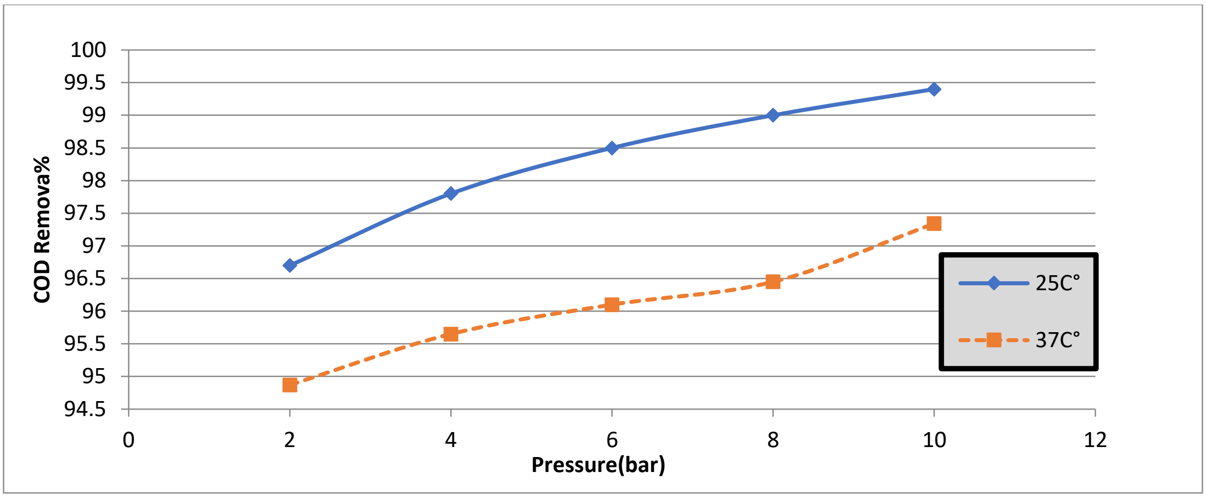

Figure 5 Effect of operational pressure on the total COD percentages, where: T = 25 and 37℃

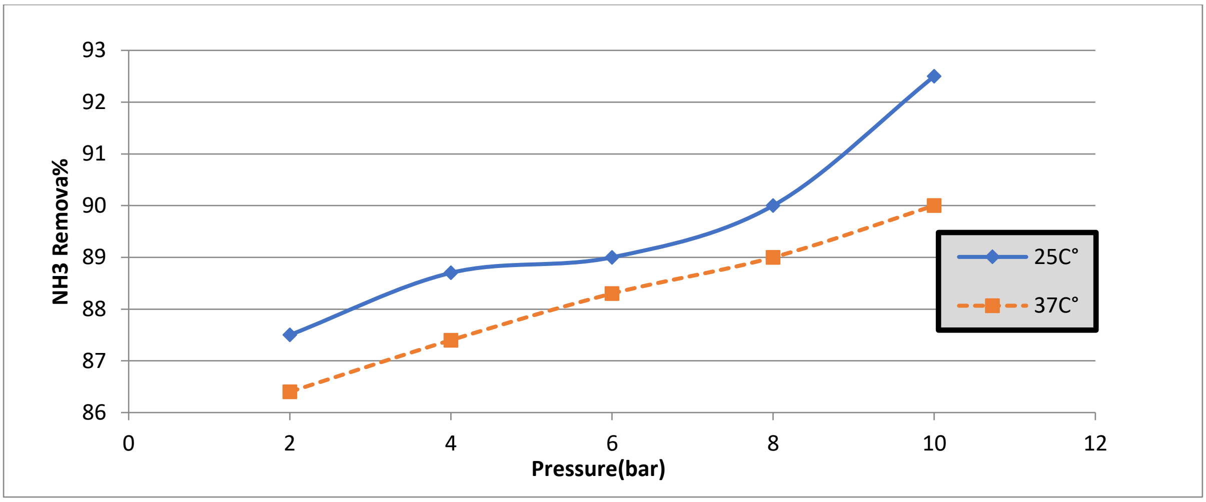

Figure 6 Effect of operational pressure on the total NH_3 elimination percentages, where: T = 25 and 37℃

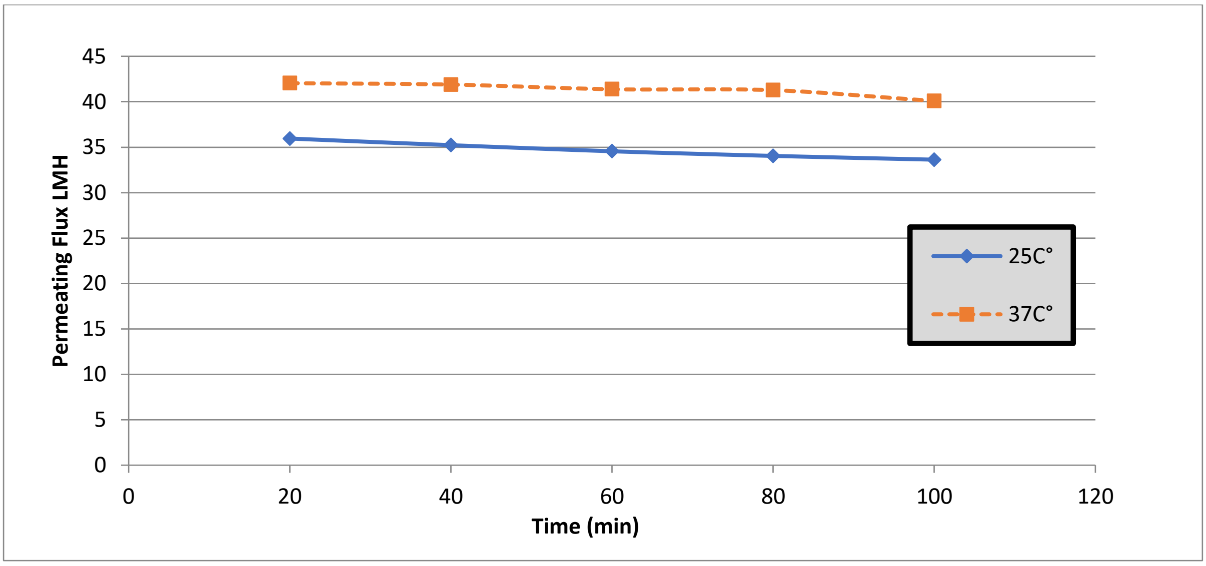

Figure 7 Effect of operational pressure on permeating fluxes, where: T = 25 and 37℃

Combining MBR and NF processes is critical because it allows for the most efficient removal of COD and NH3, resulting in high-quality water that can be recycled in a variety of industries. Although the MBR system is very good at removing COD, TSS, and NH3 from industrial pollutants, treatments appear to have a better chance of eliminating remaining contaminants and meeting the reuse quality criterion. Both NF and MBR had excellent overall performance in terms of removing all contaminants. The findings suggest that combining (MBR with NF methods) is successful in domestic wastewater treatment and produces water that meets reuse specifications; these findings are consistent with those published in prior research [19, 21, 27].

4. CONCLUSION

We proved the efficiency of the MBR-NF technology in removing contaminants from the domestic wastewater in this study. This research yielded a number of results. The treatment of MBR with 4000 mg/L of mixed liquid suspended solids (MLSS) provides an excellent solution for domestic sewage treatment. TSS removal was 99%, with TSS values of less than 4.7 mg/L in MBR permeates. This good solids separation proved that it is possible to achieve through the UF membrane.

MBR showed a significant reduction in biodegradable and organic matter content. The average COD removal was 90.3%, resulting in an effluent with COD levels ranging from 34 to 46 mg/L, while the average NH3 removal was 86%. The MBR technique has been shown to be effective at removing organic contaminants. The MBR technology, in particular, is quite successful for pre- NF treatment. The usage of a NF system has also been shown to be effective in removing organic contaminants and salts from wastewater while staying within the reuse limitations and criteria. The results of this investigation showed that the pressure given to the NF membrane has a favorable influence on the removal efficiency; however, the feed temperature has a negative impact. The experimental results show that the feeding temperature, in addition to pressure, has a favorable influence on the NF system flow.

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