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Nano ZnO/PES Ultrafiltration Membrane for Stripped Sour Water Treatment

Sherif M. Elsherbini[1*], Marwa S. Shalaby[2], Ebrahiem E. Ebrahim[1], Hassan A. Farag[3]

[1]*Chemical Engineering Department, Faculty of Engineering, Minia University, Egypt"*

[2]*Chemical Engineering Department, Engineering Research and Renewable Energy Institute, National Research Centre (NRC), Egypt"*

[3]*Chemical Engineering Department, Faculty of Engineering, Alexandria University, Egypt"*

Abstract

The depletion of freshwater resources and the increasing environmental concerns associated with wastewater discharge have necessitated the development of sustainable water management strategies in various industries, including oil refineries. This paper investigates the potential of ultrafiltration (UF) membrane treatment for the reuse of stripped sour water, a challenging wastewater streams generated during the oil refining process. The study aims to assess the effectiveness of ultrafiltration membranes made of polyether sulfone (PES) with Nano zinc oxide and others without in improving the quality of stripped sour water to meet reuse standards within oil refineries. Benefits and challenges associated with ultrafiltration membrane treatment are examined, including the positive impacts on water resource conservation, environmental sustainability, and regulatory compliance. The fundamentals of ultrafiltration are addressed, including the mechanisms responsible and the various membrane configurations used to treat wastewater. Issues of fouling and membrane integrity are as well dealt with and techniques to reduce these problems are mentioned. This study paper contains case studies and research findings from an oil refinery that underwent a pilot for ultrafiltration membrane treatment of stripped sour water that will provide an additional advantage and allow the use of the treated water in different sections of the refinery areas instead of clean condensate and service water. These treatment are likely to have a number of effects including; decreased overall water utilization and enhance water conservation by the refinery. The paper will end with future views and research methodology in order to improve the durability and adequacy of ultrafiltration membrane treatment for stripped sour water and its reuse in oil refineries and adds to the growing pool of knowledge on sustainable water management in the oil refining industry. The findings from the study offer useful insights to the operators, researchers and policymakers who are focused on reducing environmental impacts and on achieving effective water resource utilization.

Keywords: ultrafiltration membrane; fresh water deficiency; polyether sulfone membranes ; sour water treatment; NanoZn & fouling resistance.

1. Introduction:

In oil refineries, significant amounts of sour water are generated as a byproduct of various processes, such as desalting, sour water stripping, and hydro-processing. Sour water is characterized by high concentrations of hydrogen sulfide (H_2S), phenol, ammonia, and chlorides, making it a challenging wastewater stream to manage [1]. Traditionally, this stripped sour water has been directed towards the sour water stripping treatment (SWS) unit for to give the possibility to be directed to wastewater treatment plants [2] or to be discharged into water bodies, leading to environmental concerns and economic losses due to the loss of valuable water resources. The discharge of untreated or poorly treated stripped sour water poses several problems. Firstly, the high concentrations of contaminants, especially H_2S, can lead to adverse environmental effects, including water pollution and damage to aquatic ecosystems [3]. Additionally, the economic loss of valuable water resources, coupled with the increasing scarcity of freshwater, necessitates the development of efficient treatment technologies to enable the reuse of stripped sour water within the refinery.

The environmental impacts of untreated or inadequately treated stripped sour water are significant. H_2S, a toxic and corrosive gas [4], contributes to the formation of acid rain and can have detrimental effects on human health and the environment. Phenol, ammonia, and chlorides also pose environmental risks, including toxicity to aquatic life and disruption of ecosystems. Furthermore, the discharge of untreated or poorly treated sour water can result in the contamination of surface and groundwater sources, further exacerbating water scarcity issues. From an economic perspective, the loss of valuable water resources represents a significant financial burden for oil refineries. Freshwater consumption for cooling towers, process requirements, and other operations is substantial, driving up costs and straining local water supplies. By effectively treating and reusing stripped sour water, refineries can reduce their reliance on

*Corresponding author e-mail: engineer_sherif_sherbo@yahoo.com (Sherif Mohammed El Sherbini)
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freshwater sources, leading to cost savings and improved sustainability [5].

Specification of Stripped water produced after the treatment in the sour water stripping units can be as follows; H_2S 10 ppm, NH_3 50 ppm maximum are the design parameters, also phenols and chlorides can be present with a different figures depending on the feed to the sour water treatment units and the amount present in the crude oil processed.

Membrane Systems [6] for Treating H_2S, Phenol, Ammonia, and Chlorides: Ultrafiltration membrane systems have emerged as a promising technology for the treatment of stripped sour water in oil refineries. These membranes effectively remove contaminants such as H_2S, phenol, ammonia, and chlorides, allowing for the production of treated water that meets reuse standards. The efficiency of removal achieved by ultrafiltration membranes depends on multiple factors, including membrane characteristics, operating parameters, and the presence of coexisting contaminants. Studies have demonstrated high removal efficiencies for H_2S, phenol, ammonia, and chlorides, making ultrafiltration membrane treatment an attractive option for the effective remediation of stripped sour water. By employing advanced membrane systems, oil refineries can achieve significant improvements in the quality of stripped sour water, enabling its safe reuse within the refinery and minimizing environmental impacts.

Ultrafiltration (UF) membrane technology has shown a promise treatment of sour water in oil refineries. UF membranes with their pore size range of 1-100 nm can effectively remove suspended solids, colloidal particles, and large molecular weight compounds. Integrating nanotechnology, specifically nano zinc, into the UF membrane system offers potential advantages. Nano zinc particles possess antimicrobial properties and catalytic activity, which can enhance the removal of contaminants and mitigate fouling issues in the membrane system [7].

This paper aims to present the design and implementation of a sour water treatment system utilizing UF membranes integrated with nano zinc particles [8] and without by using the phase inversion process which is the key technique for making membranes. The phase inversion process can be simplified by that it starts with a polymer solution spread on a base material. This film is then dipped in a bath with chemicals that make the polymer separate into a porous structure. After washing and drying, the membrane is ready. Additional treatments can be applied to improve its performance for specific uses like adding a nano zinc material that will enhance the membrane properties that will mentioned later.

The study will focus on the removal efficiency of H_2S, phenol, ammonia, and chlorides, as well as the potential benefits and challenges associated with this innovative approach. The experiments were conducted using spiral wound modules polyether sulfone (PES) ultrafiltration membranes [9] to be easily up-scaled (semi pilot unit) on continuous mode. Fouling studies were conducted to evaluate operation continuity and maintenance cycles for this system and involved back wash of the membranes in some cases to recover the membrane activities again.

2. Materials and Methods:

2.1 Materials and implementation of UF-Based System:

Polyether sulfone (PES) with a molecular weight of 537,420, type ULTRASON 6020, was supplied by BASF, Germany. N-Methyl-2-pyrrolidone (NMP) with a purity of 99%, having a molecular weight of 99.13, was supplied by Sigma Aldrich, USA. Additionally, PVP (Poly Vinyl Pyrrolidone) with a molecular weight of 10,000 was provided by Loba Chemie, India.

2.2 Preparation of UF Membranes:

The UF membranes was fabricated with the PES as the base polymer in the membrane casting solution and kept constant at 19 wt. %, reagent grade N-Methyl-2-pyrrolidone (NMP) was used as a solvent .The solution was then cast onto a porous polymer PVP [10] (Poly Vinyl Pyrrolidone) as the non-solvent; pore forming additives [11] in the casting solution. Nano Zinc oxide was added to the polymeric dope solution casted and then rolled to [12] be nominated as M02, and without the zinc nano material will be nominated as M01.

Using a doctor-blade casting knife, the polymer solution was casted, coagulated and stored as a thin supported membrane sheet in preservative solution [13]. UF membranes were prepared by the phase-inversion technique [14] and aimed to produce tight UF membranes suitable for the ultrafiltration of stripped sour water, enabling efficient removal of contaminants and facilitating water reuse in oil refineries.

2.3 Fabrication of UF Module 1812*:*

The UF membranes module 1812 (size: 1.8 x 12 in) was fabricated in the lab of the National Research Centre (NRC) by the coagulation [15] and washing processes. The membrane sheets were cut into appropriate and rolled the membrane into a spiral wound shape with a thickness of 0.3 mm and then placed between spacers and permeate collection tubes. The assembly was tightly sealed to ensure proper fluid flow through the membrane surface while preventing bypass. The fabricated UF module 1812 consisted of multiple membrane sheets arranged in a parallel configuration to maximize the membrane area.

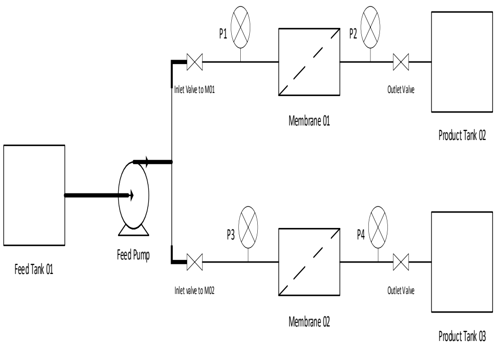

Fig. 1. Membrane filtration module

The PES (Mixed Matrix Membrane with Nano Zinc) modules were prepared, casted and rolled spiral to form 1812 modules and put in a housing with a pump up to 8 bars for filtration purposes. The whole system with spiral wound modules were prepared by the Flat Sheet Membrane Group in National Research Centre (NRC). The filtration system consists of 3 tanks one for feed and the other two for products of each membrane and one pump for pumping the inlet stripped water towards UF membranes [16]. The experiments were conducted with two different modules (two UF membrane) each with area 0.55 m^2; one with zinc nano particles and the other without as blank one, pressure gauges were supplied to measure the pressure before and after each membrane as represented in Fig. 1.

2.4 Evaluation and testing of Modules:

The UF-based system for sour water treatment was implemented using the fabricated UF module 1812. The system included a feed tank for the stripped sour water, a pump for pressurizing the feed, and the UF module 1812 for separation of contaminants. The system was operated under controlled conditions, including feed flow rate, pressure, and temperature, to achieve optimal performance. The permeate (treated water) was collected, while the retentate (concentrated contaminants) was let to be deposited on the membrane surface in order cleaning in a [17] backwash process involving changing in the flow directions as to be implemented with a clean condensate source.

2.5 Characterization methods for ultrafiltration Membranes:

The UF membranes were characterized using various analytical techniques to assess their performance and the removal efficiency of contaminants from the treated stripped sour water, also the characterization [18] involves surface morphology like SEM test, hydrophilicity, contact angle test, mechanical strength, and surface topography. These characteristics are crucial for effective sour water treatment, as they contribute to enhanced fouling resistance, water permeability, and overall membrane performance.

❖ *Characterization techniques for Membrane analysis:*

➢ Scanning Electron Microscopy (SEM):

It is a high-resolution imaging technique used to analyze the surface morphology and microstructure of materials, including membranes. It utilizes a directed electron beam to scan the surface of the sample. SEM is used to obtain relevant data on membrane surface topography. Parameters include pore size and distribution. It enables membrane defect detection, surface roughness, and structure.

➢ Contact Angles:

It is a reliable and common method to measure the surface energy and wettability of a membrane .This approach drops a liquid droplet over the surface of the matrix and measures the angle formed between the solid matrix and the contour of the droplet. The contact angle shows the interfacial tension of the solid matrix with liquid at that endpoint and gives an idea about the contact angle. The high values of contact angles mean less wettability, whereas the low value indicates better wetting and surface energy.

➢ Mechanical Strength:

It is an indicator of the capacity of a membrane to resist stress, strain, and other exogenous forces without deformation or damage. There are several methodologies to evaluate the mechanical strength of a membrane including tensile testing, burst testing, and flexure testing, and more. The tensile strength and elongation at the break and burst pressure, and modulus of rupture are variables of these tests that indicate the membrane's response to physical strain or swell.

➢ Atomic Force Microscopy (AFM):

Is a high-resolution imaging technique that provides detailed information about the surface topography and properties of materials, including membranes. AFM uses a sharp probe with a nanoscale tip to scan the membrane surface, detecting surface features and forces at the atomic scale. It can provide information about surface roughness, porosity, and even molecular interactions on the membrane surface. AFM can also be used to measure mechanical properties such as Young's modulus and adhesion forces.

These characterization techniques are valuable for understanding the structural, surface, and mechanical properties of membranes, which are crucial for optimizing their performance and assessing their suitability for specific applications.

❖ *Analytical techniques for treated water:*

Ammonia concentration in the treated water was measured using **UOP 740** [19] method which is represented by a colorimetric measurement of the absorbance of the colored complex at a specific wavelength using a spectrophotometer. Ammonia removal efficiency was calculated by comparing the concentration of ammonia in the feed and permeate.

Phenol concentration was determined using techniques like high-performance liquid chromatography (**HPLC**) or spectrophotometry [20]. Phenol removal efficiency was calculated based on the comparison of phenol concentrations in the feed and permeate.

Chlorides concentration in the treated water was determined using **UOP 456** [21] method in various samples. Potentiometric titration is a technique used to determine the concentration of a specific analytic by measuring the electrical potential difference between two electrodes in a solution techniques. The removal efficiency of chlorides was calculated by comparing the chloride concentrations in the feed and permeate samples, providing a percentage removal based on the difference in concentrations.

Hydrogen Sulfide concentration was typically measured using gas chromatography or colorimetric APHA 4500 S2 [22] method after measuring the wavelength of the colored compound which is formed by absorbing of the hydrogen sulfide into the reagent which is (zinc acetate or lead acetate). The removal efficiency of H_2S was determined by comparing the H_2S concentration in the feed and permeate.

These analytical techniques provided quantitative data on the effectiveness of the UF-based system in removing chlorides, NH_3, phenol, and H_2S from the stripped sour water. The described materials and methods were employed to prepare UF membranes with PES with and without Nano Zinc, fabricate UF module 1812, implement the UF-based system for sour water treatment, and characterize the membranes' performance in terms of chlorides, NH_3, phenol, and H_2S removal from the treated stripped sour water.

3. Results and Discussion:

3.1 Characterization of Membrane:

3.1.1. Scanning Electron Microscopy (SEM):

SEM analysis was performed to examine the surface morphology and structure of the UF membranes with PES Nano Zinc. The SEM images provided information about the membrane's pore size, surface roughness, and overall integrity. The results showed that the membranes exhibited a dense and uniform surface with well-defined finger-like or sponge-like structures.

The presence of Nano Zinc particles within the membrane matrix could be observed, indicating their successful incorporation. SEM analysis for membrane 01 and membrane 02 confirmed the successful fabrication of membranes with desired surface characteristics, see Fig. 2 which represents PES membrane no.01 without Nano Zinc particles and Fig. 3 which represents PES membrane with Nano Zinc particles.

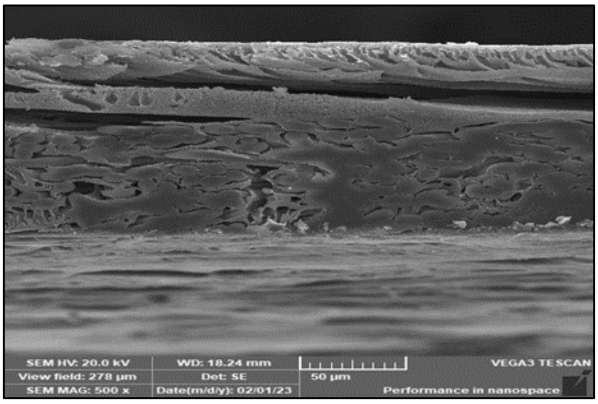

Fig. 2. SEM analysis pore size for membrane 01

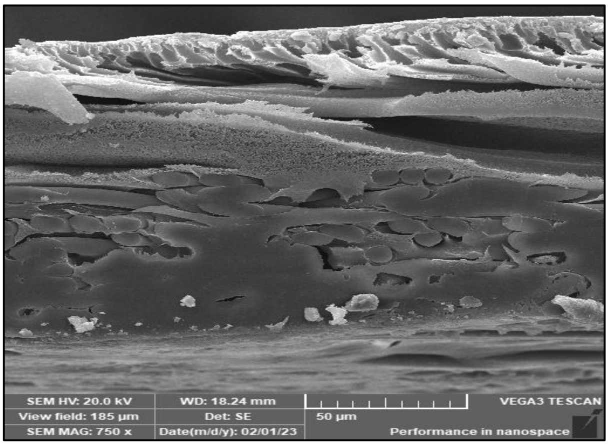

Fig. 3. SEM analysis pore size for membrane 02

1.1.1. Contact Angles:

Contact angle measurements were conducted to evaluate the hydrophilicity [23] of the UF membranes. The contact angle represents the wetting behavior of a liquid droplet on the membrane surface. Lower contact angles indicate higher hydrophilicity [24], facilitating better water permeability and reduced fouling potential. The results showed that the UF membranes with PES Nano Zinc exhibited relatively low contact angles than without the Nano Zinc, indicating their hydrophilic nature, see Fig. 4 and Fig. 5. This hydrophilicity is attributed to the presence of Nano Zinc, which can enhance the membrane's affinity towards water and improve its fouling resistance.

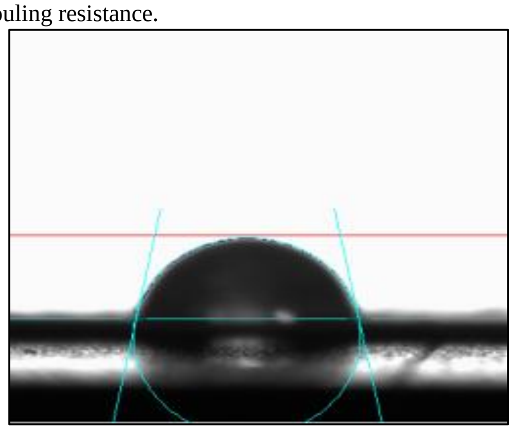

Fig. 4. Contact angle 79° measurement of membrane 01 for PES without Nano Zinc

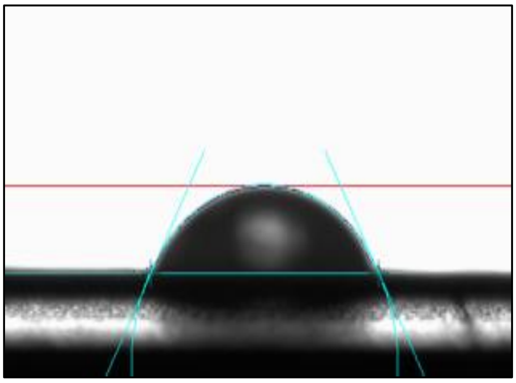

Fig. 5. Contact angle 59° measurement of membrane 02 for PES with Nano Zinc

1.1.2. Mechanical Strength:

The mechanical strength of the UF membranes was assessed to ensure their durability and resistance to handling stresses during operation. Tensile strength and elongation at break were measured to evaluate membrane integrity [25]. The results indicated that the UF PES membranes with and without Nano Zinc possessed sufficient and approximately equal mechanical strength to withstand typical operational conditions. The incorporation of Nano Zinc particles did not compromise the membrane's mechanical properties, or we can say that the affect was negligible ensuring their reliability in practical applications, see Table 01.

Table 1 Mechanical strength for membrane 01and 02

Mem brane No.	Test Method	Sample Name	Elongation (%)	Tensile strength (MPa)
1	Mechanical	M01	41.2	42.2
2		M02	31.5	39.9

1.1.3. Atomic Force Microscopy (AFM):

AFM analysis was conducted to evaluate the surface topography and roughness of the UF membranes as present in Fig. 6 and Fig. 7, which provides high-resolution imaging, allowing for the visualization of nanoscale features and surface irregularities. The AFM images revealed a relatively smooth and uniform membrane surface with minimal roughness. This smooth surface can reduce the likelihood of fouling and promote efficient water permeation [26]. This was further evidenced by measuring the contact angle, indicating that the membrane's enhanced hydrophilicity is linked to the inclusion of Nano Zinc. This addition improves the membrane's water affinity and resistance to fouling.

The presence of Nano Zinc particles on the membrane surface could be observed in membrane no2, indicating their distribution and potential contribution to the membrane's performance. The characterization results demonstrated that the UF membranes with PES Nano Zinc exhibited desirable surface morphology, hydrophilicity [27], mechanical strength, surface topography with a higher roughness than without, and low cost in compare with other nano materials like TiO_2. These characteristics are crucial for effective sour water treatment, as they contribute to enhanced fouling resistance, water permeability, and overall membrane performance.

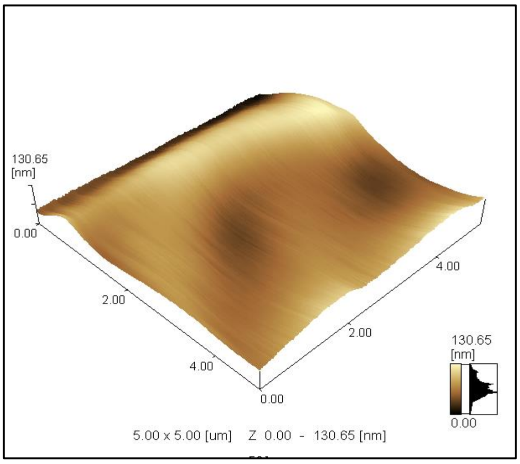

Fig. 6. AFM 3D image for membrane 01 layers structure

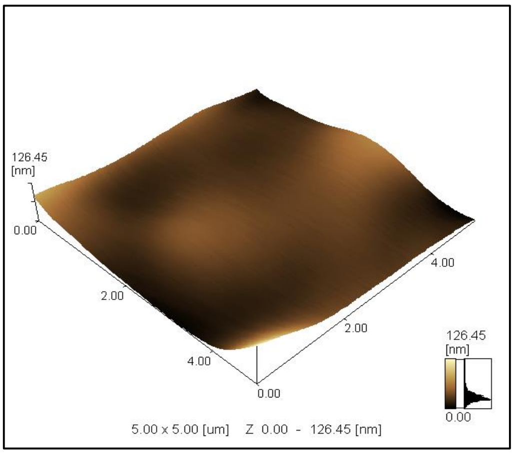

Fig. 7. AFM 3D Image for membrane 02 layers structure

The successful incorporation of Nano Zinc within the membrane matrix [28] offers additional benefits, such as antimicrobial properties, which can further enhance the membrane's performance and fouling resistance [29]. Overall, the characterization results support the suitability of the UF membranes with PES Nano Zinc for sour water treatment applications, highlighting their potential in achieving efficient and sustainable water treatment in oil refineries.

3.2 Evaluation of UF-Based System:

3.2.1. Rejection and Permeation of Membranes:

The rejection and permeation performance of the UF membranes in the sour water treatment system were assessed over time. Two different membranes were evaluated to compare their performance:

- Membrane 01: Reference UF membrane without Nano Zinc.
- Membrane 02: UF membrane with PES Nano Zinc.

a) Effect of time on flux:

The flux, which represents the rate of water permeation through [30] the membranes, was measured over time using both membranes. The flux decline is an important parameter to monitor, as fouling can lead to reduced water permeability. An experiment was done for the flux, before applying fouling experiment, and the results showed that both membranes experienced a decline in flux over time due to fouling. However, membrane 02 exhibited a slower decline in flux compared to membrane 01, indicating its superior fouling resistance. The presence of PES Nano Zinc in membrane 02 likely contributed to its enhanced fouling resistance, allowing for sustained water permeation [31] and maintaining higher flux over time as represented in Fig.8.

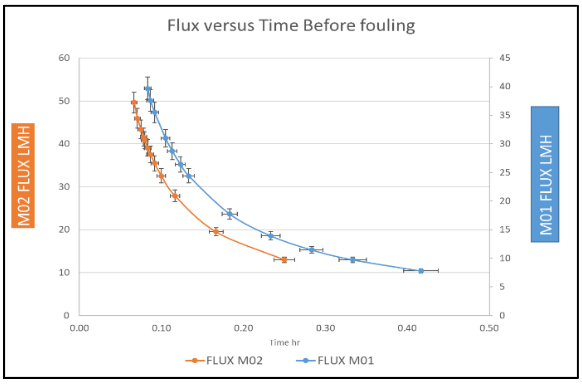

Fig. 8. Represents the flux before applying fouling Experiment

b) Effect of time on % rejection:

The rejection of contaminants, such as NH_3, phenol, chlorides and H_2S was monitored over a specific period using both membranes. The rejection percentage represents the efficiency of the membrane in removing these contaminants from the sour water feed. The results showed that both membranes exhibited high rejection rates initially, indicating their effectiveness in removing contaminants. However, over time, a slight decline in rejection was observed for both membranes due to fouling and deposition of contaminants on the membrane surface.

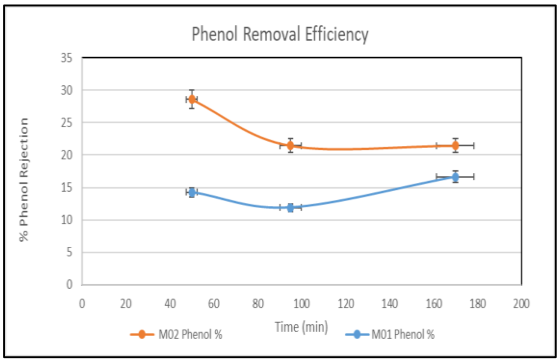

Fig. 9. Represents % phenol rejection with time

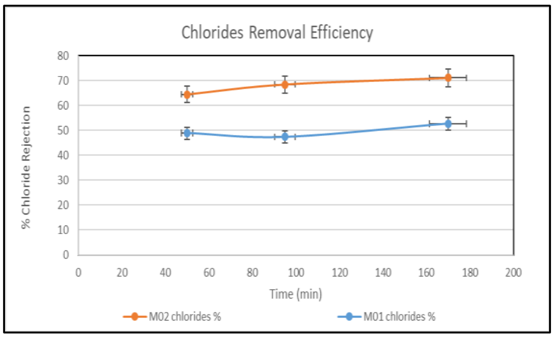

Fig. 10. Represents % chlorides rejection with time

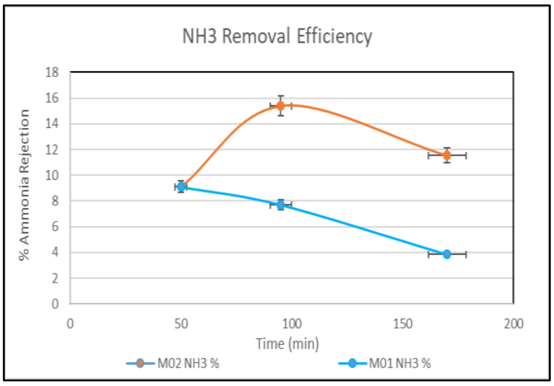

Fig. 11. Represents % Ammonia rejection with time

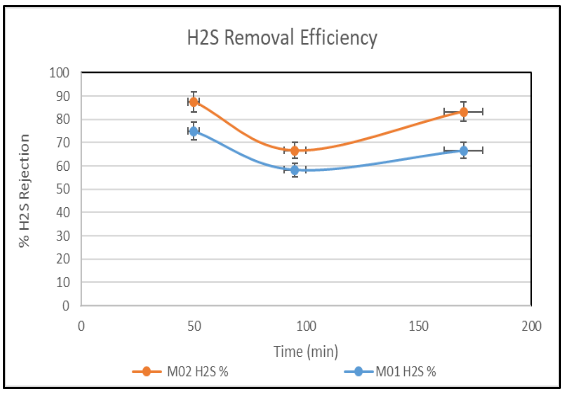

Fig. 12. Represents % H_2S rejection with time

Comparing the two membranes, membrane 02 demonstrated better long-term rejection stability compared to membrane 01, indicating its improved removal efficiency for Phenol, Chlorides, Ammonia and Hydrogen Sulfide as represented in Fig. 9, 10, 11, 12.

c) Fouling Experiments:

According to the graph represented in Fig.13, the first experimental stage, the main experimental attention was paid to the filtration of stripped sour water through membranes M01 and M02. Then, in the second step, fouling was established by adding humic acid into clean condensate water; the flux rates were significantly decreased as compared with the initial measurements; membrane M01 was more influenced than M02. Subsequent to this, a backwash procedure was carried out in the next phase to enable reduction of a significant concentration of foulants on the membranes; nevertheless, the operation did not enhance the levels of the flux rates to the optimum levels. The use of stripped water as a subsequent treatment also shown moderate increase in flux, but this experiment also depicted the foulants' effects that still remained even through the treatment thus revealing that cleaning and treatment protocols can significantly affect the membrane flux rates.

Fouling experiments represented was conducted by using a humic acid of 2 gm/l concentration, used as a foulant to evaluate the fouling potential and performance of the UF-based system. In the beginning, the pure water flux (J_1) of the blends was measured. In the next step, the unit was filled with 2 gL-1 humic acid solution and permeate was collected for every 20 min interval during the period of 70 min.

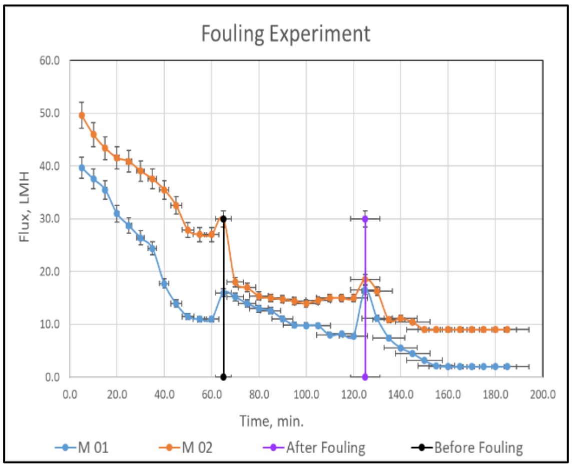

Fig. 13. Represents applying the fouling experiment and the effect of flux before and after with time.

After humic acid filtration, the blend membrane was thoroughly backwashed with Clean Condensate water for 42 min till clean water observed and finally the water flux (J_2) was measured again. The anti- fouling property was measured in terms of [32] FRR (Flux Recovery Ratio), which can be calculated using formula (1) as given below.

$$\%FRR = \frac{J2}{J1} \times 100 \quad (1)$$

In order to completely understand the fouling behavior of a blend membrane, ratios of total fouling (Rt), reversible fouling (Rr) and irreversible fouling (Rir) were calculated using equations (2)–(4) mentioned below [33] ,where the flux permeation, expressed as (J_P), occurred when the humic acid solution was used as a feed.

$$Rt\ (\%) = (1 - \frac{Jp}{J1}) \times 100 \quad (2)$$

$$Rr\ (\%) = \frac{(J2 - JP)}{(J1)} \times 100 \quad (3)$$

$$Rir\ (\%) = \frac{(J1 - J2)}{(J1)} \times 100 \quad (4)$$

The system was operated under continuous flow conditions, and fouling parameters such as flux decline, transmembrane pressure increase, and fouling layer composition were analyzed. The results indicated that both membranes experienced fouling over time, as evidenced by the decline in flux and the increase in transmembrane pressure. However, membrane 02 exhibited a lower fouling rate and a slower decline in flux compared to membrane 1. This suggests that the incorporation of PES Nano Zinc in membrane 02 contributed to its improved fouling resistance and reduced fouling propensity.

The fouling layer composition analysis revealed that membrane 02 had a thinner and more easily removable fouling layer compared to membrane 01. This observation further supports the superior fouling resistance of membrane 02, as the presence of PES Nano Zinc likely hindered the adhesion and deposition of foulants on the membrane surface. Overall, the evaluation of the UF-based system demonstrated that membrane 02 outperformed membrane 01 in terms of rejection stability, flux decline, and fouling resistance. The incorporation of PES Nano Zinc in membrane 02 enhanced its long-term performance and fouling resistance, making it a more suitable choice for efficient sour water treatment.

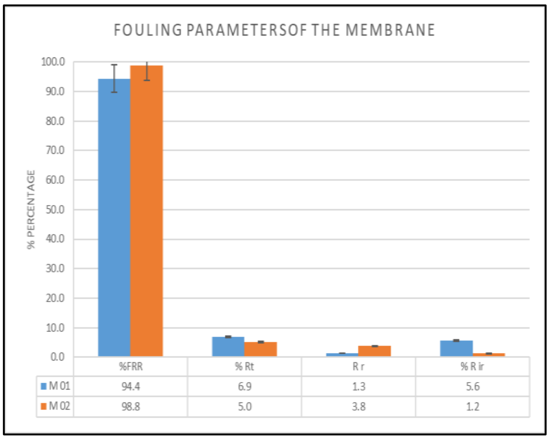

Fig.14. fouling Parameters of Membrane 01 and 02

These findings suggest that the UF-based system utilizing membrane 02 can provide sustained and reliable operation [34], with improved flux recovery ratio, contaminant rejection and reduced fouling, leading to enhanced water quality and operational efficiency in oil refineries, and this appears in Fig. 14.

It is noteworthy that several studies have been conducted on membranes such as UF, NF (Nano Filtration), and RO (Reverse Osmosis) for treating various contaminants in wastewater and sour water. Table 2 illustrates the effectiveness of contaminant removal, which varies between different membranes based on the membrane type and the nano particles utilized within them.

Table 2 Efficiency of contaminants removal for various types of membranes and nano-membranes.

Type of Membrane	**Nano Materials**	**Contaminants Removed**	**Removal Efficiency Achieved**	**References**
PSF (Polysulfone)	zinc oxide (ZnO) nanoparticles	Chemical oxygen demand (COD), Total dissolved solids (TDS)	TDS 70 %,COD 74%.	[35]
BW30 and SW30 RO Desal DK NF	N/A	Phenol, TOC, COD	RO Phenols: Up to 98%. COD,TOC: Up to 99%. NF COD < 40%	[36]
(PSf), polyacrylonitrile (PAN), polyvinyl alcohol (PVA), polyethylene (PE), polypropylene (PP) and polyvinylidene fluoride (PVDF)	carbon nanotubes (CNTs), graphene oxide (GO), metal/metal oxide nanoparticles (ZnO, TiO_2).	Heavy metals (lead, cadmium), Organic pollutants (phenols, dyes), Microbial contaminants (bacteria, viruses), COD, TDS.	90% for many contaminants	[37]
PVA)/polyamide (PA) (RO)	N/A	Phenol	Phenols: 99%.	[38]
PES with additives	Zno	Phenol, NH_3, H_2S, Chlorides	Phenols: Up to 28%. H_2S Up to 88% NH_3 Up to 15% Chlorides Up to 72%	Thesis work

4. Conclusion:

The study focused on the development and evaluation of UF membranes with PES Nano Zinc for sour water treatment in oil refineries. The characterization results demonstrated that the membranes exhibited desirable surface morphology, hydrophilicity, mechanical strength, and surface topography, indicating their suitability for the intended application. The incorporation of Nano Zinc particles within the membrane matrix provided additional benefits, such as improved fouling resistance and antimicrobial properties.

The evaluation of the UF-based system using the developed membranes revealed promising results, both membranes exhibited high initial rejection rates for contaminants, but membrane 02 demonstrated better long-term rejection stability and flux performance compared to membrane 01. The presence of Nano Zinc in membrane 02 contributed to its enhanced fouling resistance, resulting in sustained water permeation and reduced fouling propensity. Fouling experiments further supported the superior fouling resistance of membrane 02, as it exhibited a slower decline in flux and a thinner, more easily removable fouling layer.

Overall, the UF-based system utilizing membrane 02 showed potential for efficient sour water treatment, providing sustained water quality and operational efficiency in oil refineries. The study highlights the significance of incorporating innovative Nano Zinc materials in membrane development to enhance fouling resistance and improve system performance.

This application presents an example of how implementation of an advanced treatment solution embraces environmental sustainability agenda of conserving water resources enhanced by positive economic returns for the refinery business. There are specific cost benefits related to water reuse primarily based on the reduced cost of purchasing freshwater, treating wastewater, and disposing of it, which enhances organizational effectiveness as well as profitability.

5. Acknowledgments:

I would like to acknowledge the Flat Sheet Membrane Group at the National Research Centre (NRC) for supplying the PES Nano Zinc material used in this study. Their support and collaboration were instrumental in the successful development and evaluation of the UF membranes. I also extend my gratitude to my professors, doctors, research team and laboratory staff for their valuable assistance during the experimental work.

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