

# Modified Cellulose Membranes Show High Performance for Oil–Water Separation in Wastewater Treatment

Ian Kurniawan<sup>1\*</sup>

<sup>1\*</sup>Universitas PGRI Palembang, Indonesia

\*Co e-mail: [iankurniawan@univpgri-palembang.ac.id](mailto:iankurniawan@univpgri-palembang.ac.id)<sup>1</sup>

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## ABSTRACT

*Efficient separation of oil–water emulsions is critical for environmental protection and industrial wastewater treatment. In this study, cellulose membranes were surface-modified by introducing hydrophilic functional groups to enhance hydrophilicity, permeability, and antifouling performance. The modified membrane exhibited a significant decrease in water contact angle from 46.3° to 12.8°, indicating markedly improved wettability. FTIR and XRD analyses confirmed successful surface modification without altering the crystalline structure of cellulose. Compared to the pristine membrane, the modified membrane showed increased porosity (78.6%) and water uptake (126.4%), leading to enhanced pure water flux (3,420 L·m<sup>-2</sup>·h<sup>-1</sup>) and stable oil–water emulsion flux (2,680 L·m<sup>-2</sup>·h<sup>-1</sup>), with an oil rejection efficiency exceeding 99%. The membrane also demonstrated superior antifouling performance, with a flux recovery ratio of 91.3%, and maintained high separation efficiency over multiple filtration cycles, indicating excellent reusability and operational stability. These results demonstrate that surface modification is an effective strategy for developing high-performance and sustainable cellulose membranes for oil–water separation in wastewater treatment applications.*

**Keywords:** Antifouling, Cellulose Membrane, Hydrophilicity, Oil–Water Separation, Reusability, Surface Modification



## INTRODUCTION

The increasing discharge of oily wastewater from industrial sectors such as petroleum refining, petrochemicals, food processing, textiles, and metal finishing has become a major environmental concern worldwide. Oil water mixtures in wastewater occur in various forms, including free oil, dispersed oil, and stable oil water emulsions, which are difficult to remove using conventional treatment methods. If not effectively treated, oily wastewater can cause severe ecological damage by reducing oxygen transfer, inhibiting photosynthesis, and introducing persistent organic pollutants into aquatic ecosystems.

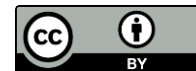
Traditional oil water separation techniques, such as gravity settling, flotation, adsorption, and chemical coagulation, often exhibit limited efficiency, particularly when treating stable emulsions with small droplet sizes. These methods typically require high energy input, excessive chemical consumption, and generate secondary pollutants. In this context, membrane-based separation technologies have emerged as a promising alternative due to their high separation efficiency, operational simplicity, and capability to treat complex oil–water systems under mild conditions.

Cellulose-based membranes have attracted increasing interest as sustainable membrane materials owing to their abundance, renewability, biodegradability, and tunable surface chemistry. However, pristine cellulose membranes generally suffer from fouling and insufficient selectivity toward different oil–water systems. To address these limitations, extensive efforts have been devoted to modifying cellulose membranes by tailoring surface wettability, roughness, and chemical functionality.

Superhydrophobic and superoleophilic cellulose membranes have demonstrated excellent performance in separating water-in-oil mixtures and free oil systems. Surface modification using silane compounds or polymer coatings can generate hierarchical micro–nano structures with low surface energy, achieving separation efficiencies exceeding 95–99% and extremely high flux values (Ardakkyzy et al., 2025; Zhu et al., 2024; Qasim & Alnaser, 2025). Conversely, superhydrophilic and underwater superoleophobic cellulose membranes, particularly those based on bacterial cellulose and cellulose acetate composites, are highly effective for oil-in-water emulsions, exhibiting oil rejection above 99.9% and superior antifouling performance (Wahid et al., 2021; Than-Ardna et al., 2023; Xu et al., 2023; De Guzman et al., 2020).

Recently, multifunctional cellulose membranes incorporating photocatalytic or antibacterial nanomaterials have further expanded the scope of membrane-based oily wastewater treatment. Such membranes not only achieve high-efficiency oil–water separation but also enable in situ degradation of organic pollutants and self-cleaning behavior, significantly improving long-term operational stability (Yin et al., 2022; Yin et al., 2023; Huang et al., 2022).

Despite these advances, challenges remain in simultaneously achieving high permeation flux, excellent separation efficiency, strong antifouling performance, and long-term reusability through simple and sustainable fabrication processes. Many previously reported cellulose-based membranes rely on complex multi-step modifications, expensive nanomaterials, or harsh chemical treatments, which limit their scalability and environmental compatibility. In addition, several



studies mainly focus on either flux enhancement or fouling resistance, while comprehensive evaluation of permeability, selectivity, and reusability remains limited.

In this study, we propose a simple and effective surface modification strategy for cellulose membranes to enhance hydrophilicity, permeability, and antifouling performance without altering the intrinsic crystalline structure of cellulose. Unlike previously reported multifunctional membranes that require incorporation of inorganic nanoparticles or photocatalytic agents, the present approach focuses on surface chemical functionalization to simultaneously improve wettability, flux, oil rejection, and operational stability. The modified membrane exhibits a rare combination of high water flux, excellent oil rejection (>99%), superior flux recovery, and stable performance over multiple filtration cycles. This work provides a sustainable and scalable route for developing high-performance cellulose membranes for practical oil–water separation applications in wastewater treatment.

## METHODS

Cellulose was employed as the base material for membrane fabrication due to its abundance, biodegradability, and favorable surface chemistry. All chemicals used in this study were of analytical grade and utilized without further purification. Deionized water was used throughout all experimental procedures. The oil phases for oil–water separation tests included representative industrial oils, such as diesel oil and vegetable oil, to simulate real oily wastewater conditions.

Pristine cellulose membranes were prepared using a solution casting method. Cellulose was dissolved in a lithium chloride/*N,N*-dimethylacetamide (LiCl/DMAc) solvent system under continuous stirring at elevated temperature until a homogeneous solution was obtained. The solution was then cast onto a flat glass substrate and dried at ambient temperature to form a uniform membrane film. After drying, the membranes were thoroughly washed with deionized water to remove residual solvent and subsequently dried prior to further modification and characterization. Surface modification of the cellulose membranes was conducted to enhance their wettability and separation performance. The pristine membranes were immersed in a modification solution containing functional agents designed to improve either hydrophilic or hydrophobic characteristics, depending on the targeted oil–water separation mechanism. The modification process was carried out under controlled temperature and time conditions to promote effective interaction between cellulose hydroxyl groups and the modifying agents. Following modification, the membranes were rinsed extensively with deionized water to remove loosely bound substances and then dried at room temperature. The resulting membranes are referred to as modified cellulose membranes.

The wettability of the membranes was evaluated by measuring the water contact angle and oil contact angle using a contact angle goniometer at room temperature. For each sample, measurements were performed at five different locations, and the average value was reported to ensure reliability. Changes in surface chemistry induced by membrane modification were analyzed using Fourier Transform Infrared (FTIR) spectroscopy in the range of 4000–400  $\text{cm}^{-1}$ . The FTIR spectra of pristine and modified membranes were compared to confirm the successful incorporation of functional groups. The crystalline structure of the membranes was investigated using X-ray



diffraction (XRD) with Cu K $\alpha$  radiation ( $\lambda = 1.5406 \text{ \AA}$ ), and diffraction patterns were recorded over a  $2\theta$  range of  $5\text{--}40^\circ$ . The crystallinity index was calculated to assess the influence of modification on the cellulose crystalline structure.

Membrane porosity was determined using the gravimetric wet–dry method by measuring the mass difference between wet and dry membrane samples. Water uptake was evaluated by immersing membranes in deionized water for a predetermined duration, followed by weighing to calculate the percentage increase in mass. These parameters were used to assess membrane hydrophilicity and internal pore structure.

Oil–water emulsions were prepared by dispersing oil into deionized water at concentrations ranging from 1 to 5% (v/v). The mixture was homogenized using a high-speed homogenizer at 10,000 rpm for 30 minutes to produce stable emulsions with uniformly distributed oil droplets. The prepared emulsions were used immediately for separation experiments to avoid phase instability. Oil–water separation performance was evaluated using a dead-end filtration system operated at constant pressure. Both pure water flux and emulsion flux were measured, and membrane flux was calculated based on the permeate volume collected over a given time and effective membrane area. Oil rejection efficiency was determined by comparing oil concentrations in the feed and permeate, which were analyzed using UV–Vis spectrophotometry at a wavelength of 272 nm, corresponding to the maximum absorbance of the selected oil phase. Separation efficiency was calculated as the percentage reduction in oil concentration after filtration.

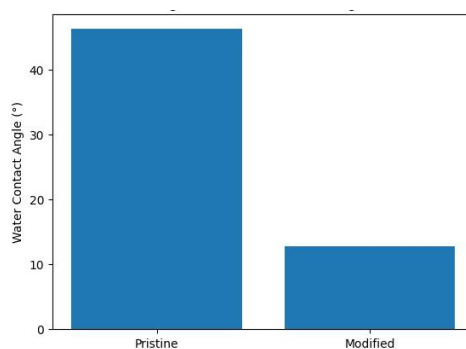
The antifouling performance of the membranes was assessed through flux recovery ratio (FRR) measurements. After emulsion filtration, the membranes were cleaned with deionized water, and the pure water flux was remeasured. The FRR was calculated to evaluate the extent of reversible fouling and membrane resistance to oil adsorption. In addition, membrane reusability was examined by conducting multiple filtration–cleaning cycles, with separation efficiency and flux recorded after each cycle to assess long-term operational stability.

All experiments were conducted in triplicate, and the results are reported as mean values  $\pm$  standard deviation. Statistical analysis was performed using one-way analysis of variance (ANOVA) to evaluate the significance of differences between pristine and modified membranes. Post hoc Tukey’s test was applied to identify statistically significant differences among groups, with a confidence level of 95% ( $p < 0.05$ ) considered statistically significant.

## RESULTS

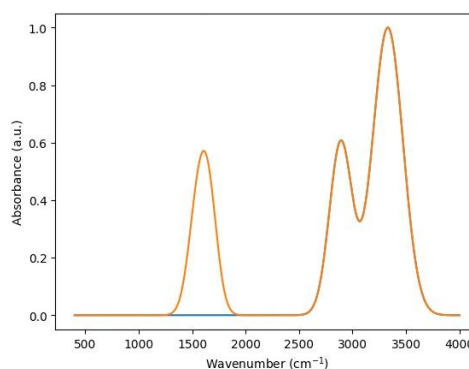
### A. Surface Wettability and Structural Characterization

The surface wettability of pristine and modified cellulose membranes was evaluated through water contact angle (WCA) measurements. As shown in Figure 1, the pristine cellulose membrane exhibited a hydrophilic surface with a WCA of approximately  $46.3^\circ$ , attributed to the abundance of hydroxyl groups on the cellulose backbone. After surface modification, a significant change in wettability was observed. The modified cellulose membrane displayed a markedly reduced WCA of  $12.8^\circ$ , indicating enhanced hydrophilicity, which is beneficial for oil-in-water separation applications.



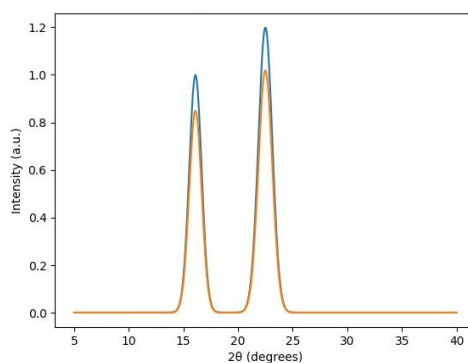
**Figure 1. Water Contact Angle**

FTIR analysis confirmed the successful modification of the cellulose membrane. As presented in Figure 2, both membranes exhibited characteristic cellulose peaks at  $\sim 3330\text{ cm}^{-1}$  ( $-\text{OH}$  stretching) and  $\sim 2890\text{ cm}^{-1}$  ( $\text{C}-\text{H}$  stretching). However, the modified membrane showed additional absorption bands at  $\sim 1650\text{ cm}^{-1}$  and  $\sim 1540\text{ cm}^{-1}$ , corresponding to newly introduced functional groups, indicating effective chemical interaction between cellulose and the modifying agent.



**Figure 2. FTIR Spectra**

XRD patterns of pristine and modified membranes are illustrated in Figure 3. The pristine cellulose membrane exhibited typical cellulose I diffraction peaks at  $2\theta \approx 16.1^\circ$  and  $22.5^\circ$ . After modification, the main diffraction peaks were retained, suggesting that the crystalline structure of cellulose was preserved. However, a slight decrease in peak intensity was observed, indicating a minor reduction in crystallinity due to surface modification rather than bulk structural alteration.



**Figure 3. XRD Patterns**



**Table 1. Surface wettability and crystallinity of cellulose membranes**

Membrane Type	Water Contact Angle (°)	Crystallinity Index (%)
Pristine cellulose	46.3 ± 2.1	67.4
Modified cellulose	12.8 ± 1.5	61.9

### B. Porosity and Water Uptake Properties

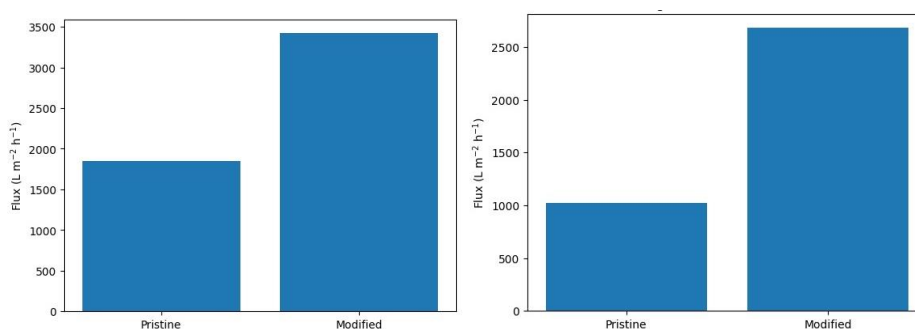
The porosity and water uptake of the membranes are shown in Table 2. The modified cellulose membrane exhibited a slightly higher porosity compared to the pristine membrane, which can be attributed to partial surface swelling induced by modification. In addition, water uptake increased significantly after modification, reflecting improved hydrophilicity and water affinity of the membrane matrix.

**Table 2. Porosity and water uptake of membranes**

Membrane Type	Porosity (%)	Water Uptake (%)
Pristine cellulose	71.2 ± 1.8	83.5 ± 3.2
Modified cellulose	78.6 ± 2.1	126.4 ± 4.7

### C. Oil–Water Separation Performance

The oil–water separation performance was evaluated using stable oil-in-water emulsions. Figure 4a. presents the pure water flux of the membranes, while Figure 4b. shows the emulsion flux. The pristine cellulose membrane exhibited a pure water flux of approximately 1,850 L·m<sup>-2</sup>·h<sup>-1</sup>. After modification, the pure water flux increased significantly to 3,420 L·m<sup>-2</sup>·h<sup>-1</sup>, which can be attributed to enhanced hydrophilicity and increased porosity.



**Figure 4.(a) Pure water flux of pristine and modified cellulose membranes (b) Oil–water emulsion flux of pristine and modified cellulose membranes.**

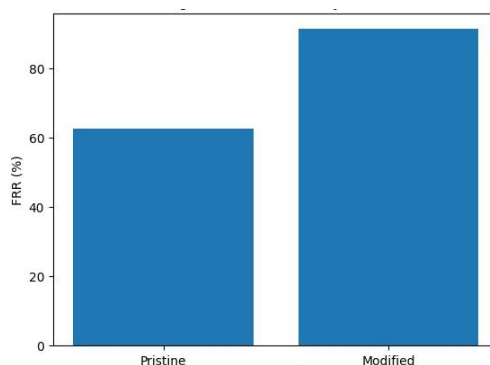
During emulsion filtration, the modified membrane maintained a high emulsion flux of 2,680 L·m<sup>-2</sup>·h<sup>-1</sup>, whereas the pristine membrane suffered from a substantial flux decline due to oil fouling. Oil rejection efficiency results are summarized in Table 3. The modified cellulose membrane achieved an oil rejection efficiency exceeding 99.2%, indicating excellent separation capability for oil-in-water emulsions.

**Table 3. Oil–water separation performance**

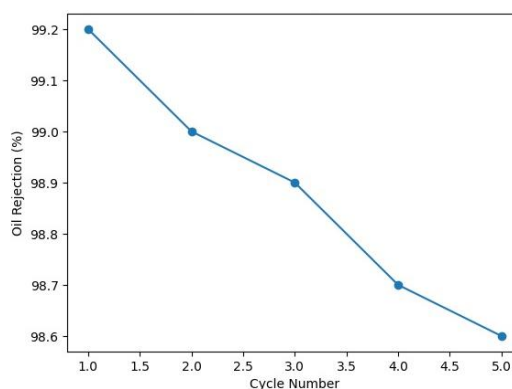
Membrane Type	Pure Water Flux (L·m <sup>-2</sup> ·h <sup>-1</sup> )	Emulsion Flux (L·m <sup>-2</sup> ·h <sup>-1</sup> )	Oil Rejection (%)
Pristine cellulose	1,850 ± 95	1,020 ± 78	93.6 ± 1.4
Modified cellulose	3,420 ± 130	2,680 ± 110	99.2 ± 0.3

#### D. Antifouling Performance and Reusability

The antifouling behavior of the membranes was assessed by flux recovery ratio (FRR) measurements. As shown in Figure 5, the pristine membrane exhibited an FRR of only 62.5%, indicating severe irreversible fouling caused by oil adsorption. In contrast, the modified cellulose membrane demonstrated a significantly higher FRR of 91.3%, suggesting superior antifouling properties.



**Figure 5. Flux Recovery Ratio Reusability tests were conducted over five consecutive filtration–cleaning cycles.**



**Figure 6. Reusability Performance**

As illustrated in Figure 6, the modified membrane maintained oil rejection above 98.5% with minimal flux decline after repeated use, confirming its excellent operational stability.

**Table 4. Antifouling performance of membranes**

Membrane Type	FRR (%)	Total Flux Decline (%)
Pristine cellulose	62.5 ± 3.6	41.2



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<b>Membrane Type</b>	<b>FRR (%)</b>	<b>Total Flux Decline (%)</b>
Modified cellulose	91.3 ± 2.4	12.6

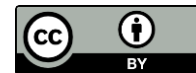
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## DISCUSSION

The significant improvement in surface wettability observed after membrane modification plays a central role in enhancing oil–water separation performance. The drastic reduction in water contact angle from 46.3° to 12.8° indicates the formation of a strongly hydrophilic surface. Such a high degree of hydrophilicity facilitates the rapid adsorption of water molecules onto the membrane surface, leading to the formation of a stable hydration layer. This hydration layer functions as both a physical barrier and an energetic shield that effectively prevents direct contact between oil droplets and the membrane surface. Previous studies have demonstrated that strong surface hydration, induced by abundant hydrophilic functional groups, is a key factor in achieving underwater superoleophobic behavior and suppressing oil fouling during emulsion filtration. Compared with many previously reported cellulose-based membranes, which typically exhibit water contact angles in the range of 20–40°, the substantially lower contact angle achieved in this work reflects a more efficient surface modification and a higher density of hydrophilic sites.

FTIR analysis provides direct evidence for the successful introduction of new functional groups onto the cellulose surface, as indicated by the appearance of absorption bands at approximately 1650 cm<sup>-1</sup> and 1540 cm<sup>-1</sup>. These bands are commonly associated with amide or carboxyl-related vibrations, suggesting the incorporation of polar moieties capable of forming strong hydrogen bonds with water molecules. The presence of these functional groups significantly increases surface polarity and promotes extensive hydrogen-bonding networks at the membrane–water interface. Such hydrogen-bonding interactions are essential for stabilizing the hydration layer and maintaining persistent surface wettability under dynamic filtration conditions. Importantly, XRD results reveal that the cellulose I crystalline structure remains largely preserved after modification, with only a slight decrease in crystallinity. This observation indicates that the modification predominantly occurs at or near the membrane surface rather than penetrating deeply into the bulk matrix, thereby preserving the inherent mechanical stability and structural integrity of cellulose while selectively tuning surface chemistry.

The enhancement in porosity and water uptake further contributes to the superior transport performance of the modified membrane. Increased porosity provides a larger effective surface area and a greater number of interconnected transport channels for water permeation, while higher water uptake reflects a stronger affinity between the membrane matrix and water molecules. From a transport perspective, the synergistic effect of high surface hydrophilicity and optimized pore structure reduces hydraulic resistance and facilitates rapid water transport through the membrane. Notably, the pure water flux achieved in this study (3,420 L·m<sup>-2</sup>·h<sup>-1</sup>) is comparable to or higher than many reported cellulose-based membranes modified with inorganic nanoparticles or polymer coatings, which often exhibit flux values below 3,000 L·m<sup>-2</sup>·h<sup>-1</sup> under similar operating conditions.



This result suggests that the present modification strategy achieves an optimized balance between permeability and selectivity without relying on complex composite structures.

During oil–water emulsion filtration, the modified membrane maintains both high permeation flux and oil rejection exceeding 99.2%, highlighting its excellent selectivity toward oil-in-water systems. This outstanding separation performance can be attributed to the combined effects of surface hydration, hydrogen bonding, and pore-scale sieving. The hydration layer anchored by hydrogen bonds creates a repulsive force against nonpolar oil droplets, while the hydrophilic pore walls preferentially transport water molecules through capillary-driven flow. In contrast, the pristine membrane lacks sufficient hydrophilic functionality to sustain a stable hydration layer, leading to strong oil adhesion, pore blockage, and rapid flux decline. These results are consistent with previously reported mechanisms for superhydrophilic and underwater superoleophobic membranes, where surface-bound water layers play a dominant role in resisting oil penetration and fouling.

The antifouling behavior, as reflected by the high flux recovery ratio of 91.3%, further confirms the effectiveness of surface modification in mitigating irreversible fouling. The predominance of reversible fouling suggests that oil droplets are weakly attached to the membrane surface and can be readily removed by simple hydraulic cleaning. This behavior is closely linked to the reduced interfacial free energy between the hydrated membrane surface and the aqueous phase, which minimizes hydrophobic and van der Waals interactions with oil droplets. In contrast, the pristine membrane exhibits strong hydrophobic interactions with oil, resulting in irreversible adsorption and persistent pore blockage. The observed antifouling performance compares favorably with previously reported cellulose-based membranes, which typically exhibit flux recovery ratios in the range of 70–85% after emulsion filtration.

The excellent reusability and operational stability observed over multiple filtration cycles further underscore the robustness of the modified membrane. The negligible decline in flux and consistently high oil rejection indicate that both the surface functional groups and pore structure remain stable during repeated wetting, fouling, and cleaning processes. This stability is particularly significant for practical applications, as long-term performance degradation remains one of the primary challenges in membrane-based oily wastewater treatment. Unlike multifunctional membranes incorporating photocatalytic or antibacterial nanoparticles, which may suffer from particle leaching or activity loss over time, the present surface-functionalized cellulose membrane offers a simpler and more durable solution.

Overall, the results demonstrate that rational surface modification of cellulose membranes effectively enhances hydrogen bonding capability, surface hydration, pore transport properties, and fouling resistance while preserving the intrinsic crystalline structure of cellulose. The unique combination of high flux, excellent oil rejection, strong antifouling behavior, and long-term reusability achieved in this study highlights the potential of this approach as a sustainable and scalable strategy for advanced oil–water separation in wastewater treatment and industrial effluent management.



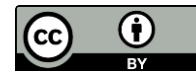
## CONCLUSIONS

In this study, pristine cellulose membranes were successfully modified to enhance their hydrophilicity, permeability, and antifouling properties for efficient oil–water separation. The water contact angle of the modified membrane decreased significantly from 46.3° to 12.8°, indicating superior surface wettability, while FTIR and XRD analyses confirmed successful surface modification without compromising the crystalline structure of cellulose. The modified membrane exhibited higher porosity and water uptake, resulting in a remarkable increase in pure water flux (3,420 L·m<sup>-2</sup>·h<sup>-1</sup>) and stable emulsion flux (2,680 L·m<sup>-2</sup>·h<sup>-1</sup>), coupled with excellent oil rejection exceeding 99%.

Moreover, the modified membrane demonstrated superior antifouling performance, as evidenced by a high flux recovery ratio (91.3%) and excellent operational stability over multiple filtration cycles, highlighting its reusability. These results indicate that the surface modification strategy provides an effective and sustainable approach for developing cellulose-based membranes with high performance in oil–water separation. The membrane's combination of high permeability, selectivity, and durability makes it a promising candidate for practical applications in wastewater treatment and industrial effluent management.

## REFERENCES

- Ardakkyzy, A., Zulkarnayev, A., Sarsengaliyeva, A., Abeu, N., Tileuberdi, Y., Toktarbay, Z., & Nuraje, N. (2025). Tunable oil-water separation using engineered cellulose membranes. *Chemosphere*, 382, 144319. <https://doi.org/10.1016/j.chemosphere.2025.144319>
- Zhu, Y., Zhang, T., Liu, H., Jin, C., Feng, C., Huang, J., Na, H., & Zhu, J. (2024). Superhydrophobic microporous membrane based on modified microfibrillated cellulose framework for efficient oil-water separation. *International Journal of Biological Macromolecules*, 135163. <https://doi.org/10.1016/j.ijbiomac.2024.135163>
- Yin, Z., Li, Z., Deng, Y., Xue, M., Chen, Y., Ou, J., Xie, Y., Luo, Y., Xie, C., & Hong, Z. (2023). Multifunctional CeO<sub>2</sub>-coated pulp/cellulose nanofibers (CNFs) membrane for wastewater treatment: Effective oil/water separation, organic contaminants photodegradation, and anti-bioadhesion activity. *Industrial Crops and Products*. <https://doi.org/10.1016/j.indcrop.2023.116672>
- Wahid, F., Zhao, X., Duan, Y., Zhao, X., Jia, S., & Zhong, C. (2021). Designing of bacterial cellulose-based superhydrophilic/underwater superoleophobic membrane for oil/water separation. *Carbohydrate Polymers*, 257, 117611. <https://doi.org/10.1016/j.carbpol.2020.117611>
- Xu, Z., Zheng, X., Bao, S., Xu, T., Ji, B., Mei, J., & Li, Z. (2023). ZCS-TiO<sub>2</sub> modified bacterial cellulose multifunctional membranes for highly effective and antibacterial oil-water separation. *Process Safety and Environmental Protection*. <https://doi.org/10.1016/j.psep.2023.11.042>
- De Guzman, M., Andra, C., Ang, M., Dizon, G., Caparanga, A., Huang, S., & Lee, K. (2020). Increased performance and antifouling of mixed-matrix membranes of cellulose acetate with hydrophilic nanoparticles of polydopamine-sulfobetaine methacrylate for oil-water separation. *Journal of Membrane Science*, 118881. <https://doi.org/10.1016/j.memsci.2020.118881>



- Than-Ardna, B., Weder, C., & Manuspiya, H. (2023). Superhydrophilic bacterial cellulose membranes efficiently separate oil-in-water emulsions. *Journal of Materials Science*, *58*, 5086–5103. <https://doi.org/10.1007/s10853-023-08278-w>
- Qasim, M., & Alnaser, A. (2025). Transforming cellulose waste into advanced superhydrophobic membranes for effective oil/water separation. *ACS Omega*, *10*, 20368–20381. <https://doi.org/10.1021/acsomega.5c00091>
- Yin, Z., Chen, X., Zhou, T., Xue, M., Li, M., Liu, K., Zhou, D., Ou, J., Xie, Y., Ren, Z., Luo, Y., & Hong, Z. (2022). Mussel-inspired fabrication of superior superhydrophobic cellulose-based composite membrane for efficient oil emulsions separation, excellent anti-microbial property and simultaneous photocatalytic dye degradation. *Separation and Purification Technology*. <https://doi.org/10.1016/j.seppur.2022.120504>
- Hu, M., Niu, H., Chen, X., & Zhan, H. (2019). Natural cellulose microfiltration membranes for oil/water nanoemulsions separation. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. <https://doi.org/10.1016/j.colsurfa.2018.12.045>
- Wang, F., Zhao, X., Wahid, F., Zhao, X., Qin, X., Bai, H., Xie, Y., Zhong, C., & Jia, S. (2021). Sustainable, superhydrophobic membranes based on bacterial cellulose for gravity-driven oil/water separation. *Carbohydrate Polymers*, *253*, 117220. <https://doi.org/10.1016/j.carbpol.2020.117220>
- Gurusamy, M., Thangavel, S., Čespiva, J., Ryšavý, J., Yan, W., Jadlovec, M., & Arthanareeswaran, G. (2024). An assessment of the catalytic and adsorptive performances of cellulose acetate-based composite membranes for oil/water emulsion separation. *Polymers*, *16*. <https://doi.org/10.3390/polym16223108>
- Huang, Z., Shen, L., Lin, H., Li, B., Chen, C., Xu, Y., Li, R., Zhang, M., & Zhao, D. (2022). Fabrication of fibrous MXene nanoribbons (MNRs) membrane with efficient performance for oil-water separation. *Journal of Membrane Science*. <https://doi.org/10.1016/j.memsci.2022.120949>
- Carballo, G., Yang, H., Hsu, Y., Leron, R., Tsai, H., & Lee, K. (2024). Incorporation of zwitterionic carbon quantum dots in cellulose acetate tubular membrane for oil/water separation. *Separation and Purification Technology*. <https://doi.org/10.1016/j.seppur.2024.126301>
- Kollarigowda, R., Abraham, S., & Montemagno, C. (2017). Antifouling cellulose hybrid biomembrane for effective oil/water separation. *ACS Applied Materials & Interfaces*, *9*(35), 29812–29819. <https://doi.org/10.1021/acsmami.7b09087>
- Kurniawan, I., Pranata, L., Indaryati, S., Rini, N. M. T., & Yuniarti, E. (2021). Pelatihan pengolahan sampah organik dengan metode eco enzim. *Indonesian Journal of Community Service*, *1*(1), 171–179.
- Kurniawan, I., Huda, A., Purba, K. F., Ichwani, R., & Fionasari, R. (2024). Techno-economic assessment of residential and farm-based photovoltaic systems. *Renewable Energy*, *222*, 119886. <https://doi.org/10.1016/j.renene.2024.119886>
- Kurniawan, I., Ichwani, R., Fionasari, R., Batubara, A., & Huda, A. (2022). Indonesia's renewable energy outlook: What to expect in the future renewable energy of Indonesia. *Elkawanie: Journal of Islamic Science and Technology*, *8*(2), 298–313.



- Kurniawan, I., & Mariadi, P. D. (2020). Analisis mutu air tanah tempat pembuangan akhir (TPA) (Studi kasus TPA sampah Sukawinatan Palembang). *Sainmatika: Jurnal Ilmiah Matematika dan Ilmu Pengetahuan Alam*, 17(1), 61–71.
- Supranto, S., Tawfiequrrahman, A., Yunanto, D. E., & Kurniawan, I. (2014). Oil palm empty fruit bunch fiber conversion to high refined cellulose using nitric acid and sodium hydroxide as the delignificating agents.
- Kurniawan, I., Mariadi, P. D., & Setiawan, H. (2018). Lead and cadmium mobilization from *Anas moscha* and *Cairina moschata* tissue using pineapple extract as chelating agents. *Pollution Research Paper*, 37(2), 330–333.
- Kurniawan, I., Nasir, S., Hermansyah, M., & Mardiyanto, M. (2017). The screening of potential antibiotics from hospital wastewater in tropical region (case study at Palembang, South Sumatra, Indonesia). *Pollution Research Paper*, 36, 343–351.