DEVELOPMENT OF POLYVINYLIDENE FLUORIDE-BENTONITE MEMBRANE IN MEMBRANE DISTILLATION SYSTEM FOR TREATMENT OF PALM OIL MILL EFFLUENT

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ABSTRAK

Nanozarah tanah liat kebiasaannya digabungkan dalam membran polimer untuk memperbaiki sifat fizikokimia membran yang dihasilkan. Walau bagaimanapun, penyelidikan mengenai aplikasi membran nanokomposit untuk rawatan efluen industri adalah masih terhad. Matlamat kajian ini adalah untuk membangunkan membran nanokomposit gentian geronggang polivinilidin florida (PVDF) yang digabungkan dengan bentonit untuk rawatan efluen kilang kelapa sawit (POME) menggunakan sistem penyulingan bermembran secara langsung (DCMD). Dalam kerja ini, larutan terdiri daripada 12% berat PVDF yang diadun dengan enam muatan bentonit yang berbeza (0.25 % berat, 0.30 % berat, 0.40 % berat, 0.50 % berat, 0.75 % berat, dan 1.00 % berat) telah disediakan. Membran-membran gentian geronggang tersebut kemudiannya disediakan melalui kaedah basah-jet penyongsangan fasa dan dicirikan menggunakan mikroskop elektron pengimbas (SEM) dengan sinar-X penyebaran tenaga (EDX), spektroskopi inframerah jelmaan Fourier (FTIR), analisis termogravimetri (TGA), kalorimeter pengimbasan pembeza (DSC), tekanan kemasukan cecair (LEP), keliangan membran, sudut sesentuh, pembelauan sinar-X (XRD) dan mikroskop daya atom (AFM). Sebelum ujian, membran diuji terlebih dahulu menggunakan air ternyahion untuk melihat kebocoran. Untuk aplikasi sebenar, sampel POME yang diambil dari kolam anaerobik digunakan dalam kajian ini. Fluks resapan tertinggi diperolehi oleh membran PVDF-0.50% berat bentonit diikuti oleh membran PVDF-0.30 % berat bentonit iaitu sebanyak 3.62 ± 1.25 kg/m^2.hr dan 3.45 ± 0.51 kg/m^2.hr masing-masing semasa rawatan POME. Bagi kecekapan penyingkiran, lebih 99% daripada jumlah pepejal terlarut (TDS), keperluan oksigen kimia (COD), nitrogen nitrat, warna dan kekeruhan telah dikeluarkan daripada efluen. Membran PVDF-0.30 % berat bentonit berprestasi lebih baik daripada membran PVDF-0.50 % berat bentonit dalam penyingkiran TDS. Membrane PVDF-0.30% bentonit telah dipilih untuk ujian lanjutan dengan POME mentah dan kajian jangka panjang kerana membran tersebut adalah paling hidrofobik (94.77 ± 0.13°) berbanding dengan membran lain. Semasa ujian POME mentah, fluks resapan turun kepada 1.41 ± 0.62 kg/m^2.jam berbanding 3.45 ± 0.51 kg/m^2.jam apabila membran tersebut diuji dengan POME dari kolam anaerobik. Pengurangan fluks boleh dikaitkan dengan POME mentah yang mengandungi kepekatan tinggi pepejal terampai, minyak dan gris yang meningkatkan kemungkinan masalah kekotoran. Untuk menentukan kestabilan membran dan kecenderungan kekotoran, proses DCMD jangka panjang telah dijalankan sehingga 72 jam. Diperhatikan bahawa fluks resapan berubah-ubah sepanjang eksperimen dan kemudian stabil pada akhir eksperimen dengan fluks purata ialah 3.342 ± 1.26 kg/m^2.hr. Kecekapan penyingkiran melebihi 95% telah dilaporkan untuk semua parameter kualiti air. Keputusan menunjukkan bahawa membran PVDF-0.30 % berat bentonit boleh memperoleh fluks resapan yang tinggi dan menghasilkan resapan berkualiti tinggi yang bebas daripada kekotoran semasa kajian jangka panjang. Kajian ini menyerlahkan peningkatan sifat dan prestasi membran apabila bentonit dimasukkan ke dalam membran polimer.

ABSTRACT

Clay nanoparticles are commonly incorporated in polymeric membranes to improve the physicochemical properties of the fabricated membrane. However, research on the application of the nanocomposite membrane for industrial effluent treatment remains limited. The aim of this study is to develop polyvinylidene fluoride (PVDF) incorporated bentonite hollow fiber nanocomposite membranes for palm oil mill effluent (POME) treatment using direct contact membrane distillation (DCMD) system. In this work, solutions consisted of 12 wt% PVDF blended with six different bentonite loadings (0.25 wt%, 0.30 wt%, 0.40 wt%, 0.50 wt%, 0.75 wt% and 1.00 wt%) were prepared. The hollow fiber membranes were then fabricated via jet-wet phase inversion method and characterized using scanning electron microscope (SEM) and energy dispersive x-ray (EDX), fourier transform infrared (FTIR), thermal gravimetric analysis (TGA), differential scanning calorimetry (DSC), liquid entry pressure (LEP), membrane porosity, contact angle, X-ray diffraction (XRD) and atomic force microscope (AFM). Prior to testing, the membranes were first tested using deionized water to observe leakage. For the actual application, POME samples collected from an anaerobic pond were used in this study. The highest permeate flux was obtained by PVDF-0.50 wt% bentonite membrane followed by PVDF-0.30 wt% bentonite membrane which was 3.62 ± 1.25 kg/m^2.hr and 3.45 ± 0.51 kg/m^2.hr respectively during the POME treatment. For removal efficiencies, over 99% of total dissolved solids (TDS), chemical oxygen demand (COD), nitrate nitrogen, color, and turbidity were removed from the effluent. The PVDF-0.30 wt% bentonite membrane performed better than the PVDF-0.50 wt% bentonite membrane in TDS rejection. The PVDF-0.30 wt% bentonite membrane was chosen for further testing with raw POME and long-term studies because the membrane is the most hydrophobic (94.77 ± 0.13°) in comparison to other membranes. During the raw POME test, the permeate flux drops to 1.41 ± 0.62 kg/m^2.hr compared to 3.45 ± 0.51 kg/m^2.hr when the membrane was tested with POME from an anaerobic pond. The flux reduction can be attributed to the raw POME contains a high concentration of suspended solids, oil and grease which increased the likelihood of fouling problem. To determine the membrane stability and fouling propensity, a long-term DCMD process was conducted for up to 72 hours. It was observed that the permeate flux fluctuated throughout the experiment and then stabilized at the end of the experiment with the average flux is 3.342 ± 1.26 kg/m^2.hr. Removal efficiencies of over 95% were reported for all water quality parameters. The results showed that the PVDF-0.30% bentonite membrane could obtain a high permeate flux and produce a high quality permeate that is independent of the fouling during the long-term study. This study highlighted the improvement in membrane properties and performance when bentonite was incorporated into the polymeric membrane.

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REFERENCES

Aziz, A., Kassim, M. M., ElSergany, K. A., Anuar, M., Jorat, S., Yaacob, M. E. & Arifuzzaman, H (2020). Recent advances on palm oil mill effluent (POME) pretreatment and anaerobic reactor for sustainable biogas production. *Renewable and Sustainable Energy Reviews*, *119*(February 2019), 109603. https://doi.org/10.1016/j.rser.2019.109603

Ahmad, A. L., Ismail, S., & Bhatia, S. (2003). Water recycling from palm oil mill effluent (POME) using membrane technology. *Desalination*, *157*(1–3), 87–95. https://doi.org/10.1016/S0011-9164(03)00387-4

Ahmad, T., Belwal, T., Li, L., Ramola, S., Aadil, R. M., Abdullah, & Zisheng, L. (2020). Utilization of wastewater from edible oil industry, turning waste into valuable products: A review. *Trends in Food Science and Technology*, *99*(March), 21–33. https://doi.org/10.1016/j.tifs.2020.02.017

Alcheikhhamdon, A. A., Darwish, N. A., & Hilal, N. (2015). Statistical analysis of air-gap membrane desalination experimental data: Hypothesis testing. *Desalination*, *362*, 117–125. https://doi.org/10.1016/j.desal.2015.02.003

Alkhudhiri, A., Darwish, N., & Hilal, N. (2012). Membrane distillation: A comprehensive review. *Desalination*, *287*, 2–18. https://doi.org/10.1016/j.desal.2011.08.027

Alkhudhiri, A., Darwish, N., & Hilal, N. (2013). Produced water treatment: Application of Air Gap Membrane Distillation. *Desalination*, *309*, 46–51. https://doi.org/10.1016/j.desal.2012.09.017

Amaya-vías, D., Nebot, E., & López-ramírez, J. A. (2018). Comparative studies of di ff erent membrane distillation con fi gurations and membranes for potential use on board cruise vessels. *Desalination*, *429*(October 2017), 44–51. https://doi.org/10.1016/j.desal.2017.12.008

An, A. K., Guo, J., Jeong, S., Lee, E. J., Tabatabai, S. A. A., & Leiknes, T. O. (2016). High flux and antifouling properties of negatively charged membrane for dyeing wastewater treatment by membrane distillation. *Water Research*, *103*, 362–371. https://doi.org/10.1016/j.watres.2016.07.060

Ashoor, B. B., Mansour, S., Giwa, A., Dufour, V., & Hasan, S. W. (2016). Principles and applications of direct contact membrane distillation (DCMD): A comprehensive review. *Desalination*, *398*, 222–246. https://doi.org/10.1016/j.desal.2016.07.043

Awalludin, M. F., Sulaiman, O., Hashim, R., & Nadhari, W. N. A. W. (2015). An overview of the oil palm industry in Malaysia and its waste utilization through thermochemical conversion, specifically via liquefaction. *Renewable and Sustainable Energy Reviews*, *50*, 1469–1484. https://doi.org/10.1016/j.rser.2015.05.085

Azmi, N. S., & Yunos, K. F. M. (2014). Wastewater Treatment of Palm Oil Mill Effluent (POME) by Ultrafiltration Membrane Separation Technique Coupled with Adsorption Treatment as Pre-treatment. *Agriculture and Agricultural Science Procedia*, *2*, 257–264. https://doi.org/10.1016/j.aaspro.2014.11.037

Babu, B. R., Rastogi, N. K., & Raghavarao, K. S. M. S. (2008). Concentration and temperature polarization effects during osmotic membrane distillation. *Journal of Membrane Science*, *322*(1), 146–153. https://doi.org/10.1016/j.memsci.2008.05.041

Baghel, R., Upadhyaya, S., Chaurasia, S. P., Singh, K., & Kalla, S. (2018). Optimization of process variables by the application of response surface methodology for naphthol blue black dye removal in vacuum membrane distillation. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2018.07.214

Bai, H., Wang, X., Zhou, Y., & Zhang, L. (2012). Progress in Natural Science : Materials International Preparation and characterization of poly (vinylidene fluoride) composite membranes blended with nano-crystalline cellulose. *Progress in Natural Science: Materials International*, *22*(3), 250–257. https://doi.org/10.1016/j.pnsc.2012.04.011

Bell, C. M. (2016). Comparison of polyelectrolyte coated PVDF membranes in thermopervaporation with porous hydrophobic membranes in membrane distillation using plate-and-frame modules. *Chemical Engineering and Processing: Process Intensification*, *104*, 58–65. https://doi.org/10.1016/j.cep.2016.02.013

Bello, M. M., & Abdul Raman, A. A. (2017). Trend and current practices of palm oil mill effluent polishing: Application of advanced oxidation processes and their future perspectives. *Journal of Environmental Management*, *198*, 170–182. https://doi.org/10.1016/j.jenvman.2017.04.050

Bohnhoff, G. L., & Shackelford, C. D. (2013). Improving membrane performance via bentonite polymer nanocomposite. *Applied Clay Science*, *86*, 83–98. https://doi.org/10.1016/j.clay.2013.09.017

Carnevale, M. C., Gnisci, E., Hilal, J., & Criscuoli, A. (2016). Direct Contact and Vacuum Membrane Distillation application for the olive mill wastewater treatment. *Separation and Purification Technology*, *169*, 121–127. https://doi.org/10.1016/j.seppur.2016.06.002

Chang, J., Zuo, J., Zhang, L., O'Brien, G. S., & Chung, T. S. (2017). Using green solvent, triethyl phosphate (TEP), to fabricate highly porous PVDF hollow fiber membranes for membrane distillation. *Journal of Membrane Science*, *539*(March), 295–304. https://doi.org/10.1016/j.memsci.2017.06.002

Chen, Y. R., Chen, L. H., Chen, C. H., Ko, C. C., Huang, A., Li, C. L. & Tung, K. L. (2018). Hydrophobic alumina hollow fiber membranes for sucrose concentration by vacuum membrane distillation. *Journal of Membrane Science*, *555*(January), 250–257. https://doi.org/10.1016/j.memsci.2018.03.048

Cheng, L. H., Lin, Y. H., & Chen, J. (2011). Enhanced air gap membrane desalination by novel finned tubular membrane modules. *Journal of Membrane Science*, *378*(1–2), 398–406. https://doi.org/10.1016/j.memsci.2011.05.030

Cheng, L., Zhao, Y., Li, P., Li, W., & Wang, F. (2018). Comparative study of air gap and permeate gap membrane distillation using internal heat recovery hollow fiber membrane module. *Desalination*, *426*(October 2017), 42–49. https://doi.org/10.1016/j.desal.2017.10.039

Cheng, Y. W., Chong, C. C., Lam, M. K., Ayoub, M., Cheng, C. K., Lim, J. W. & Bai, J. (2021). Holistic process evaluation of non-conventional palm oil mill effluent (POME) treatment technologies: A conceptual and comparative review. *Journal of Hazardous Materials*, *409*(October 2020), 124964. https://doi.org/10.1016/j.jhazmat.2020.124964

Chinoune, K., Bentaleb, K., Bouberka, Z., Nadim, A., & Maschke, U. (2016). Adsorption of reactive dyes from aqueous solution by dirty bentonite. *Applied Clay Science*, *123*, 64–75. https://doi.org/10.1016/j.clay.2016.01.006

Cho, H., Choi, Y., & Lee, S. (2018). Effect of pretreatment and operating conditions on the performance of membrane distillation for the treatment of shale gas wastewater. *Desalination*, *437*(March), 195–209. https://doi.org/10.1016/j.desal.2018.03.009

Choudhury, M. R., Anwar, N., Jassby, D., & Rahaman, M. S. (2019). Fouling and wetting in the membrane distillation driven wastewater reclamation process – A review. *Advances in Colloid and Interface Science*, *269*, 370–399. https://doi.org/10.1016/j.cis.2019.04.008

Cui, Z., Zhang, Y., Li, X., Wang, X., Drioli, E., Wang, Z., & Zhao, S. (2018). Optimization of novel composite membranes for water and mineral recovery by vacuum membrane distillation. *Desalination*, *440*(October 2017), 39–47. https://doi.org/10.1016/j.desal.2017.11.040

Dao, T. D., Laborie, S., & Cabassud, C. (2016). Direct As(III) removal from brackish groundwater by vacuum membrane distillation: Effect of organic matter and salts on membrane fouling. *Separation and Purification Technology*, *157*, 35–44. https://doi.org/10.1016/j.seppur.2015.11.018

Das, R., Sondhi, K., Majumdar, S., & Sarkar, S. (2016). Development of hydrophobic clay–alumina based capillary membrane for desalination of brine by membrane distillation. *Journal of Asian Ceramic Societies*, *4*(3), 243–251. https://doi.org/10.1016/j.jascer.2016.04.004

De Oliveira, C. I. R., Rocha, M. C. G., Da Silva, A. L. N., & Bertolino, L. C. (2016). Characterization of bentonite clays from Cubati, Paraíba Northeast of Brazil. *Ceramica*, *62*(363), 272–277. https://doi.org/10.1590/0366-69132016623631970

Drioli, E., Ali, A., & Macedonio, F. (2015). Membrane distillation: Recent developments and perspectives. *Desalination*, *356*, 56–84. https://doi.org/10.1016/j.desal.2014.10.028

Duong, H. C., Chivas, A. R., Nelemans, B., Duke, M., Gray, S., Cath, T. Y., & Nghiem, L. D. (2015). Treatment of RO brine from CSG produced water by spiral-wound air gap membrane distillation - A pilot study. *Desalination*, *366*, 121–129. https://doi.org/10.1016/j.desal.2014.10.026

Efome, J. E., Baghbanzadeh, M., Rana, D., Matsuura, T., & Lan, C. Q. (2015). Effects of superhydrophobic SiO_2 nanoparticles on the performance of PVDF flat sheet membranes for vacuum membrane distillation. *Desalination*, *373*, 47–57. https://doi.org/10.1016/j.desal.2015.07.002

El-Bourawi, M. S., Ding, Z., Ma, R., & Khayet, M. (2006). A framework for better understanding membrane distillation separation process. *Journal of Membrane Science*, *285*(1–2), 4–29. https://doi.org/10.1016/j.memsci.2006.08.002

Elakkiya, S., Arthanareeswaran, G., & Das, D. B. (2021). Embedding low–cost 1D and 2D iron pillared nanoclay to enhance the stability of polyethersulfone membranes for the removal of bisphenol A from water. *Separation and Purification Technology*, *266*(March), 118560. https://doi.org/10.1016/j.seppur.2021.118560

Eren, E., Afsin, B., & Onal, Y. (2009). Removal of lead ions by acid activated and manganese oxide-coated bentonite. *Journal of Hazardous Materials*, *161*(2–3), 677–685. https://doi.org/10.1016/j.jhazmat.2008.04.020

Eykens, L., De Sitter, K., Dotremont, C., Pinoy, L., & Van der Bruggen, B. (2017). Membrane synthesis for membrane distillation: A review. *Separation and Purification Technology*, *182*, 36–51. https://doi.org/10.1016/j.seppur.2017.03.035

Eykens, L., Reyns, T., De Sitter, K., Dotremont, C., Pinoy, L., & Van der Bruggen, B. (2016). How to select a membrane distillation configuration? Process conditions and membrane influence unraveled. *Desalination*, *399*, 105–115. https://doi.org/10.1016/j.desal.2016.08.019

Farid, M. A. A., Roslan, A. M., Hassan, M. A., Aziz Ujang, F., Mohamad, Z., Hasan, M. Y., & Yoshihito, S. (2019). Convective sludge drying by rotary drum dryer using waste steam for palm oil mill effluent treatment. *Journal of Cleaner Production*, *240*, 117986. https://doi.org/10.1016/j.jclepro.2019.117986

Fortunato, L., Jang, Y., Lee, J. G., Jeong, S., Lee, S., Leiknes, T. O., & Ghaffour, N. (2018). Fouling development in direct contact membrane distillation: Non-invasive monitoring and destructive analysis. *Water Research*, *132*, 34–41. https://doi.org/10.1016/j.watres.2017.12.059

Gao, L., Zhang, J., Gray, S., & Li, J. De. (2017). Experimental study of hollow fiber permeate gap membrane distillation and its performance comparison with DCMD and SGMD. *Separation and Purification Technology*, *188*, 11–23. https://doi.org/10.1016/j.seppur.2017.07.009

García-Fernández, L., García-Payo, M. C., & Khayet, M. (2017). Mechanism of formation of hollow fiber membranes for membrane distillation: 2. Outer coagulation power effect on morphological characteristics. *Journal of Membrane Science*, *542*(December 2016), 469–481. https://doi.org/10.1016/j.memsci.2017.03.038

García-Fernández, Loreto, García-Payo, C., & Khayet, M. (2017). Hollow fiber membranes with different external corrugated surfaces for desalination by membrane distillation. *Applied Surface Science*, *416*, 932–946. https://doi.org/10.1016/j.apsusc.2017.04.232

Guo, J., Farid, M. U., Lee, E. J., Yan, D. Y. S., Jeong, S., & Kyoungjin An, A. (2018). Fouling behavior of negatively charged PVDF membrane in membrane distillation for removal of antibiotics from wastewater. *Journal of Membrane Science*, *551*(January), 12–19. https://doi.org/10.1016/j.memsci.2018.01.016

Guo, J., Fortunato, L., Deka, B. J., Jeong, S., & An, A. K. (2020). Elucidating the fouling mechanism in pharmaceutical wastewater treatment by membrane distillation. *Desalination*, *475*(September 2019), 114148. https://doi.org/10.1016/j.desal.2019.114148

Hassan, N. A., Wei, P. C., Ibrahim, N. A., Baharuddin, A. S., & May, C. Y. (2015). Composting of oil palm biomass: Fourier transform-infrared and thermogravimetry analyses. *Journal of Oil Palm Research*, *27*(3), 241–249.

Hassan, S., Kee, L. S., & Al-Kayiem, H. H. (2013). Experimental study of palm oil mill effluent and oil palm frond waste mixture as an alternative biomass fuel. *Journal of Engineering Science and Technology*, *8*(6), 703–712.

Hebbar, R. S., Isloor, A. M., & Ismail, A. F. (2014). Preparation and evaluation of heavy metal rejection properties of polyetherimide/porous activated bentonite clay nanocomposite membrane. *RSC Advances*, *4*(September), 47240–47248. https://doi.org/10.1039/C4RA09018G

Hirschmann. R. (2020). Palm oil industry in Malaysia - Statistics & Facts. *Statista*. Retrieved from https://www.statista.com/topics/5814/palm oil industry in malaysia/Palm oil is one of,of palm oil after Indonesia.

Ho, C. C., Su, J. F., & Cheng, L. P. (2021). Fabrication of high-flux asymmetric polyethersulfone (PES) ultrafiltration membranes by nonsolvent induced phase separation process: Effects of H_2O contents in the dope. *Polymer*, *217*(January), 123451. https://doi.org/10.1016/j.polymer.2021.123451

Hosseini Hashemi, M. S., Eslami, F., & Karimzadeh, R. (2019). Organic contaminants removal from industrial wastewater by CTAB treated synthetic zeolite Y. *Journal of Environmental Management*, *233*(September), 785–792. https://doi.org/10.1016/j.jenvman.2018.10.003

Hou, D., Dai, G., Fan, H., Wang, J., Zhao, C., & Huang, H. (2014). Effects of calcium carbonate nano-particles on the properties of PVDF/nonwoven fabric flat-sheet composite membranes for direct contact membrane distillation. *Desalination*, *347*, 25–33. https://doi.org/10.1016/j.desal.2014.05.028

Hou, D., Dai, G., Wang, J., Fan, H., Luan, Z., & Fu, C. (2013). Boron removal and desalination from seawater by PVDF flat-sheet membrane through direct contact membrane distillation. *Desalination*, *326*, 115–124. https://doi.org/10.1016/j.desal.2013.07.023

Hou, D., Wang, J., Sun, X., Luan, Z., Zhao, C., & Ren, X. (2010). Boron removal from aqueous solution by direct contact membrane distillation. *Journal of Hazardous Materials*, *177*(1–3), 613–619. https://doi.org/10.1016/j.jhazmat.2009.12.076

Hubadillah, S. K., Tai, Z. S., Othman, M. H. D., Harun, Z., Jamalludin, M. R., Rahman, M. A., Jaafar, J., & Ismail, A. F. (2019). Hydrophobic ceramic membrane for membrane distillation: A mini review on preparation, characterization, and applications, *Separation and Purification Technology, 217,* 71–84. https://doi.org/10.1016/j.seppur.2019.02.014

Hubadillah, S. K., Othman, M. H. D., Ismail, A. F., Rahman, M. A., & Jaafar, J. (2018). A low cost hydrophobic kaolin hollow fiber membrane (h-KHFM) for arsenic removal from aqueous solution via direct contact membrane distillation. *Separation and Purification Technology*, (April). https://doi.org/10.1016/j.seppur.2018.04.025

Hybat, M. S., Abdurahman, N. H., Yasmeen, Z. H., Jemaat, Z., & Azhari, N. H. (2019). Treatment of Palm Oil Mill Effluent (POME) using Membrane Anaerobic System (MAS). *IOP Conference Series: Materials Science and Engineering*, *702*(1). https://doi.org/10.1088/1757-899X/702/1/012029

Jhaveri, J. H., & Murthy, Z. V. P. (2016). A comprehensive review on anti-fouling nanocomposite membranes for pressure driven membrane separation processes. *Desalination*, *379*, 137–154. https://doi.org/10.1016/j.desal.2015.11.009

Jia, F., Li, J., & Wang, J. (2017). Recovery of boric acid from the simulated radioactive wastewater by vacuum membrane distillation crystallization. *Annals of Nuclear Energy*, *110*, 1148–1155. https://doi.org/10.1016/j.anucene.2017.07.024

Jia, F., Li, J., Wang, J., & Sun, Y. (2017). Annals of Nuclear Energy Removal of strontium ions from simulated radioactive wastewater by vacuum membrane distillation. *Annals of Nuclear Energy*, *103*, 363–368. https://doi.org/10.1016/j.anucene.2017.02.003

Jia, F., Yin, Y., & Wang, J. (2018). Removal of cobalt ions from simulated radioactive wastewater by vacuum membrane distillation. *Progress in Nuclear Energy*, *103*(October 2017), 20–27. https://doi.org/10.1016/j.pnucene.2017.11.008

Kang, G. dong, & Cao, Y. ming. (2014). Application and modification of poly(vinylidene fluoride) (PVDF) membranes - A review. *Journal of Membrane Science*, *463*, 145–165. https://doi.org/10.1016/j.memsci.2014.03.055

Karanikola, V., Corral, A. F., Jiang, H., Sáez, A. E., Ela, W. P., & Arnold, R. G. (2017). Effects of membrane structure and operational variables on membrane distillation performance. *Journal of Membrane Science*, *524*(November 2016), 87–96. https://doi.org/10.1016/j.memsci.2016.11.038

Khayet, M. (2013). Treatment of radioactive wastewater solutions by direct contact membrane distillation using surface modified membranes. *Desalination*, *321*, 60–66. https://doi.org/10.1016/j.desal.2013.02.023

Khayet, M, & Matsuura, T. (2011). *Membrane Distillation: Principles and Applications*.

Khayet, Mohamed. (2011). Membranes and theoretical modeling of membrane distillation: A review. *Advances in Colloid and Interface Science*, *164*(1–2), 56–88. https://doi.org/10.1016/j.cis.2010.09.005

Kim, J., Kim, J., & Hong, S. (2018). Recovery of water and minerals from shale gas produced water by membrane distillation crystallization. *Water Research*, *129*, 447–459. https://doi.org/10.1016/j.watres.2017.11.017

Kumar, A., & Lingfa, P. (2020). Sodium bentonite and kaolin clays: Comparative study on their FT-IR, XRF, and XRD. *Materials Today: Proceedings*, *22*, 737–742. https://doi.org/10.1016/j.matpr.2019.10.037

Lee, Z. S., Chin, S. Y., Lim, J. W., Witoon, T., & Cheng, C. K. (2019). Treatment technologies of palm oil mill effluent (POME)and olive mill wastewater (OMW): A brief review. *Environmental Technology and Innovation*, *15*, 100377. https://doi.org/10.1016/j.eti.2019.100377

Lefers, R., Bettahalli, N. M. S., Fedoroff, N., Nunes, S. P., & Leiknes, T. O. (2018). Vacuum membrane distillation of liquid desiccants utilizing hollow fiber membranes. *Separation and Purification Technology*, *199*(January), 57–63. https://doi.org/10.1016/j.seppur.2018.01.042

Li, F., Huang, J., Xia, Q., Lou, M., Yang, B., Tian, Q., & Liu, Y. (2018). Direct contact membrane distillation for the treatment of industrial dyeing wastewater and characteristic pollutants. *Separation and Purification Technology*, *195*(November 2017), 83–91. https://doi.org/10.1016/j.seppur.2017.11.058

Li, K., Zhang, Y., Xu, L., Zeng, F., Hou, D., & Wang, J. (2018). Optimizing stretching conditions in fabrication of PTFE hollow fiber membrane for performance improvement in membrane distillation. *Journal of Membrane Science*, *550*(October 2017), 126–135. https://doi.org/10.1016/j.memsci.2017.12.070

Lin, P. J., Yang, M. C., Li, Y. L., & Chen, J. H. (2015). Prevention of surfactant wetting with agarose hydrogel layer for direct contact membrane distillation used in dyeing wastewater treatment. *Journal of Membrane Science*, *475*, 511–520. https://doi.org/10.1016/j.memsci.2014.11.001

Liu, H., & Wang, J. (2013). Treatment of radioactive wastewater using direct contact membrane distillation. *Journal of Hazardous Materials*, *261*, 307–315. https://doi.org/10.1016/j.jhazmat.2013.07.045

Loh, S. K., Nasrin, A. B., Mohamad Azri, S., Nurul Adela, B., Muzzammil, N., Daryl Jay, T., … Kaltschmitt, M. (2017). First Report on Malaysia’s experiences and development in biogas capture and utilization from palm oil mill effluent under the Economic Transformation Programme: Current and future perspectives. *Renewable and Sustainable Energy Reviews*, *74*(June 2016), 1257–1274. https://doi.org/10.1016/j.rser.2017.02.066

Lu, X., Peng, Y., Ge, L., Lin, R., Zhu, Z., & Liu, S. (2016). Amphiphobic PVDF composite membranes for anti-fouling direct contact membrane distillation. *Journal of Membrane Science*, *505*, 61–69. https://doi.org/10.1016/j.memsci.2015.12.042

Madaki, Y. S., & Lau, S. (2013). Palm oil Effluent (POME) from Malaysia Palm Oil Mills: Waste or Resource. *International Journal of Science, Environment and Technology*, *2*(6), 1138–1155. Retrieved from www.ijset.net

Masindi, V. (2015). *Remediation of Acid Mine Drainage Using Magnesite and Its Bentonite Clay Composite*. https://doi.org/10.13140/RG.2.1.4488.3442

Meng, S., Ye, Y., Mansouri, J., & Chen, V. (2014). Fouling and crystallisation behaviour of superhydrophobic nano-composite PVDF membranes in direct contact membrane distillation. *Journal of Membrane Science*, *463*, 102–112. https://doi.org/10.1016/j.memsci.2014.03.027

Minh, P., Jacob, P., Rattanaoudom, R., & Visvanathan, C. (2016). Chemical Engineering and Processing : Process Intensi fi cation Feasibility of sweeping gas membrane distillation on concentrating triethylene glycol from waste streams. *Chemical Engineering & Processing: Process Intensification*, *110*, 225–234. https://doi.org/10.1016/j.cep.2016.10.015

Mokhtar, N. M., Lau, W. J., & Ismail, A. F. (2014). The potential of membrane distillation in recovering water from hot dyeing solution. *Journal of Water Process Engineering*, *2*, 71–78. https://doi.org/10.1016/j.jwpe.2014.05.006

Mokhtar, N. M., Lau, W. J., Ismail, A. F., Kartohardjono, S., Lai, S. O., & Teoh, H. C. (2016). The potential of direct contact membrane distillation for industrial textile wastewater treatment using PVDF-Cloisite 15A nanocomposite membrane. *Chemical Engineering Research and Design*, *111*, 284–293. https://doi.org/10.1016/j.cherd.2016.05.018

Mokhtar, N. M., Lau, W. J., Ismail, A. F., & Ng, B. C. (2014). Physicochemical study of polyvinylidene fluoride-Cloisite15A® composite membranes for membrane distillation application. *RSC Advances*, *4*(108), 63367–63379. https://doi.org/10.1039/c4ra10289d

Mokhtar, N. M., Lau, W. J., Ismail, A. F., & Veerasamy, D. (2015). Membrane distillation technology for treatment of wastewater from rubber industry in Malaysia. *Procedia CIRP*, *26*, 792–796. https://doi.org/10.1016/j.procir.2014.07.161

Mokhtar, N. M., Lau, W. J., Ismail, A. F., Youravong, W., Khongnakorn, W., & Lertwittayanon, K. (2015). Performance evaluation of novel PVDF-Cloisite 15A hollow fiber composite membranes for treatment of effluents containing dyes and salts using membrane distillation. *RSC Advances*, *5*(48), 38011–38020. https://doi.org/10.1039/c5ra00182j

Mokhtar, N M., Lau, W. J., & Ismail, A. F. (2015). Dye wastewater treatment by direct contact membrane distillation using polyvinylidene fluoride hollow fiber membranes. *Journal of Polymer Engineering*, *35*(5), 471–479. https://doi.org/10.1515/polyeng-2014-0214

Muhamad, N. A. S., Mokhtar, N. M., Naim, R., Lau, W. J., & Ismail, A. F. (2019). A Review of Membrane Distillation Process : - Before , During and After Testing. *International Journal of Engineering Technology and Sciences*, *6*(June), 62–81.

Naidu, G., Jeong, S., Choi, Y., & Vigneswaran, S. (2017). Membrane distillation for wastewater reverse osmosis concentrate treatment with water reuse potential. *Journal of Membrane Science*, *524*(July 2016), 565–575. https://doi.org/10.1016/j.memsci.2016.11.068

Naim, R., Sean, G. P., Nasir, Z., Mokhtar, N. M., & Muhammad, N. A. S. (2021). *Recent Progress and Challenges in Hollow Fiber Membranes for Wastewater Treatment and Resource Recovery*. 1–15.

Nasrullah, M., Singh, L., Mohamad, Z., Norsita, S., Krishnan, S., Wahida, N., & Zularisam, A. W. (2017). Treatment of palm oil mill effluent by electrocoagulation with presence of hydrogen peroxide as oxidizing agent and polialuminum chloride as coagulant-aid. *Water Resources and Industry*, *17*(October 2016), 7–10. https://doi.org/10.1016/j.wri.2016.11.001

Natarajan, P., Sasikumar, B., Elakkiya, S., Arthanareeswaran, G., Ismail, A. F., Youravong, W., & Yuliwati, E. (2021). Pillared cloisite 15A as an enhancement filler in polysulfone mixed matrix membranes for CO2/N2 and O2/N2 gas separation. *Journal of Natural Gas Science and Engineering*, *86*(October 2020), 103720. https://doi.org/10.1016/j.jngse.2020.103720

Ng, K. H., Yuan, L. S., Cheng, C. K., Chen, K., & Fang, C. (2019). TiO2 and ZnO photocatalytic treatment of palm oil mill effluent (POME) and feasibility of renewable energy generation: A short review. *Journal of Cleaner Production*, *233*, 209–225. https://doi.org/10.1016/j.jclepro.2019.06.044

Ohimain, E. I., & Izah, S. C. (2017). A review of biogas production from palm oil mill effluents using different configurations of bioreactors. *Renewable and Sustainable Energy Reviews*, *70*(November 2016), 242–253. https://doi.org/10.1016/j.rser.2016.11.221

Onsekizoglu, P. (2012). Membrane Distillation: Principle, Advances, Limitations and Future Prospects in Food Industry. *Distillation - Advances from Modeling to Applications*, (April). https://doi.org/10.5772/37625

Ozbey-Unal, B., Imer, D. Y., Keskinler, B., & Koyuncu, I. (2018). Boron removal from geothermal water by air gap membrane distillation. *Desalination*, *433*(January), 141–150. https://doi.org/10.1016/j.desal.2018.01.033

Pandey, S. (2017). A comprehensive review on recent developments in bentonite-based materials used as adsorbents for wastewater treatment. *Journal of Molecular Liquids*, *241*, 1091–1113. https://doi.org/10.1016/j.molliq.2017.06.115

Politano, A., Di Profio, G., Fontananova, E., Sanna, V., Cupolillo, A., & Curcio, E. (2018). Overcoming temperature polarization in membrane distillation by thermoplasmonic effects activated by Ag nanofillers in polymeric membranes. *Desalination*, (October 2017). https://doi.org/10.1016/j.desal.2018.03.006

Prince, J. A., Singh, G., Rana, D., Matsuura, T., Anbharasi, V., & Shanmugasundaram, T. S. (2012). Preparation and characterization of highly hydrophobic poly(vinylidene fluoride) - Clay nanocomposite nanofiber membranes (PVDF-clay NNMs) for desalination using direct contact membrane distillation. *Journal of Membrane Science*, *397–398*, 80–86. https://doi.org/10.1016/j.memsci.2012.01.012

Pua, F.-L., Subari, M. S., Ean, L.-W., & Krishnan, S. G. (2020). Characterization of biomass fuel pellets made from Malaysia tea waste and oil palm empty fruit bunch. *Materials Today: Proceedings*, *31*, 187–190. https://doi.org/10.1016/j.matpr.2020.02.218

Qtaishat, M., Khayer, M., Matsuura, T., & Khulbe, K. C. (2010). *Effect of Casting Conditions on SMM Blended Polyethersulfone Hydro-Phobic / -Philic Composite Membranes : Characteristics and Desalination Performance in Membrane Distillation*. *11*(June), 1–8.

Qu, D., Wang, J., Hou, D., Luan, Z., Fan, B., & Zhao, C. (2009). Experimental study of arsenic removal by direct contact membrane distillation. *Journal of Hazardous Materials*, *163*(2–3), 874–879. https://doi.org/10.1016/j.jhazmat.2008.07.042

Quist-Jensen, C. A., Macedonio, F., Horbez, D., & Drioli, E. (2017). Reclamation of sodium sulfate from industrial wastewater by using membrane distillation and membrane crystallization. *Desalination*, *401*, 112–119. https://doi.org/10.1016/j.desal.2016.05.007

Ren, J., Li, J., Chen, Z., & Cheng, F. (2018). Fate and wetting potential of bio-refractory organics in membrane distillation for coke wastewater treatment. *Chemosphere*, *208*, 450–459. https://doi.org/10.1016/j.chemosphere.2018.06.002

Rezaei, M., Warsinger, D. M., V, J. H. L., Duke, M. C., Matsuura, T., & Samhaber, W. M. (2018). Wetting phenomena in membrane distillation : Mechanisms , reversal , and prevention. *Water Research*, *139*, 329–352. https://doi.org/10.1016/j.watres.2018.03.058

Rupani, P. F., Rajeev, P. S., Irahim, M. H., & Esa, N. (2010). Review of Current Palm Oil Mill Effluent (POME) Treatment Methods: Vermicomposting as a Sustainable Practice. *World Appl. Sci. J.*, *11*(1), 70–81. https://doi.org/10.5539/jas.v7n4p68

Salihu, A., & Alam, Z. (2012). Palm oil mill effluent: A waste or a raw material? *Journal of Applied Sciences Research*, *8*(1), 466–473. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84866050874&partnerID=tZOtx3y1

Shahruddin, M. Z., Othman, N. H., Alias, N. H., & Ghani, S. N. A. (2015). Desalination of Produced Water Using Bentonite as Pre-Treatment and Membrane Separation as Main Treatment. *Procedia - Social and Behavioral Sciences*, *195*, 2094–2100. https://doi.org/10.1016/j.sbspro.2015.06.237

Shirazi, M. M. A., Bazgir, S., & Meshkani, F. (2020). A novel dual-layer, gas-assisted electrospun, nanofibrous SAN4-HIPS membrane for industrial textile wastewater treatment by direct contact membrane distillation (DCMD). *Journal of Water Process Engineering*, *36*(April), 101315. https://doi.org/10.1016/j.jwpe.2020.101315

Singh, B., Kochkodan, V., Hashaikeh, R., & Hilal, N. (2013). A review on membrane fabrication : Structure , properties and performance relationship. *DES*, *326*, 77–95. https://doi.org/10.1016/j.desal.2013.06.016

Singh, D., & Sirkar, K. K. (2017). Performance of PVDF flat membranes and hollow fibers in desalination by direct contact membrane distillation at high temperatures. *Separation and Purification Technology*, *187*, 264–273. https://doi.org/10.1016/j.seppur.2017.06.012

Taha, K., & Suleiman, T. M. (2012). *Performance of Sudanese activated bentonite in bleaching cottonseed oil*. (April 2017). https://doi.org/10.3329/jbcs.v24i2.9708

Tan, Y. D., & Lim, J. S. (2019). Feasibility of palm oil mill effluent elimination towards sustainable Malaysian palm oil industry. *Renewable and Sustainable Energy Reviews*, *111*(May), 507–522. https://doi.org/10.1016/j.rser.2019.05.043

Tang, M., Hou, D., Ding, C., Wang, K., Wang, D., & Wang, J. (2019). Anti-oil-fouling hydrophobic-superoleophobic composite membranes for robust membrane distillation performance. *Science of the Total Environment*, *696*, 133883. https://doi.org/10.1016/j.scitotenv.2019.133883

Thi Tra My, N., Thi Yen Nhi, V., & Xuan Thanh, B. (2018). Factors Affecting Membrane Distillation Process for Seawater Desalination. *Journal of Applied Membrane Science & Technology*, *22*(1), 19–29. https://doi.org/10.11113/amst.v22n1.126

Tijing, L. D., Woo, Y. C., Choi, J. S., Lee, S., Kim, S. H., & Shon, H. K. (2015). Fouling and its control in membrane distillation-A review. *Journal of Membrane Science*, *475*, 215–244. https://doi.org/10.1016/j.memsci.2014.09.042

Ullah, R., Khraisheh, M., Esteves, R. J., Jr, J. T. M., Alghouti, M., Gad-el-hak, M., & Tafreshi, H. V. (2018). Energy e ffi ciency of direct contact membrane distillation. *Desalination*, *433*(January), 56–67. https://doi.org/10.1016/j.desal.2018.01.025

Wang, Z., & Lin, S. (2017). Membrane fouling and wetting in membrane distillation and their mitigation by novel membranes with special wettability. *Water Research*, *112*, 38–47. https://doi.org/10.1016/j.watres.2017.01.022

Winter, D., Koschikowski, J., Gross, F., Maucher, D., Düver, D., Jositz, M. & Hagedorn, A. (2017). Comparative analysis of full-scale membrane distillation contactors - methods and modules. *Journal of Membrane Science*, *524*(December 2016), 758–771. https://doi.org/10.1016/j.memsci.2016.11.080

Winter, D., Koschikowski, J., & Ripperger, S. (2012). Desalination using membrane distillation: Flux enhancement by feed water deaeration on spiral-wound modules. *Journal of Membrane Science*, *423–424*, 215–224. https://doi.org/10.1016/j.memsci.2012.08.018

Winter, D., Koschikowski, J., & Wieghaus, M. (2011). Desalination using membrane distillation: Experimental studies on full scale spiral wound modules. *Journal of Membrane Science*, *375*(1–2), 104–112. https://doi.org/10.1016/j.memsci.2011.03.030

Wu, T. Y., Mohammad, A. W., Md. Jahim, J., & Anuar, N. (2007). Palm oil mill effluent (POME) treatment and bioresources recovery using ultrafiltration membrane: Effect of pressure on membrane fouling. *Biochemical Engineering Journal*, *35*(3), 309–317. https://doi.org/10.1016/j.bej.2007.01.029

Wu, Y., Kang, Y., Zhang, L., Qu, D., Cheng, X., & Feng, L. (2018). Performance and fouling mechanism of direct contact membrane distillation (DCMD) treating fermentation wastewater with high organic concentrations. *Journal of Environmental Sciences (China)*, *65*, 253–261. https://doi.org/10.1016/j.jes.2017.01.015

Xie, Z., Duong, T., Hoang, M., Nguyen, C., & Bolto, B. (2009). Ammonia removal by sweep gas membrane distillation. *Water Research*, *43*(6), 1693–1699. https://doi.org/10.1016/j.watres.2008.12.052

Yao, M., Woo, Y. C., Tijing, L. D., Choi, J. S., & Shon, H. K. (2018). Effects of volatile organic compounds on water recovery from produced water via vacuum membrane distillation. *Desalination*, *440*(October 2017), 146–155. https://doi.org/10.1016/j.desal.2017.11.012

Zafar, S. (2019). *Properties and Uses of POME | BioEnergy Consult*. Retrieved from https://www.bioenergyconsult.com/introduction-to-pome/

Zainal, N. H., Jalani, N. F., Mamat, R., & Astimar, A. A. (2017). A review on the development of palm oil mill effluent (POME) final discharge polishing treatments. *Journal of Oil Palm Research*, *29*(4), 528–540. https://doi.org/10.21894/jopr.2017.00012

Zhang, B., Yang, C., Liu, S., Wu, Y., Wang, T., & Qiu, J. (2019). The positive/negative effects of bentonite on O2/N2 permeation of carbon molecular sieving membranes. *Microporous and Mesoporous Materials*, *285*(January), 142–149. https://doi.org/10.1016/j.micromeso.2019.04.070

Zhang, H., Li, B., Sun, D., Miao, X., & Gu, Y. (2018). SiO2-PDMS-PVDF hollow fiber membrane with high flux for vacuum membrane distillation. *Desalination*, *429*(November 2017), 33–43. https://doi.org/10.1016/j.desal.2017.12.004