TESIS

PENGARUH MIL-101 (Cr)/Fe_3O_4 TERHADAP KARAKTERISTIK DAN KINERJA MEMBRANE NANOFILTRASI POLI ETERSULFON

Diajukan untuk memenuhi salah satu syarat memperoleh gelar Magister Sains

Program Studi Magister Kimia

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FAKULTAS PENDIDIKAN MATEMATIKA DAN ILMU PENGETAHUAN ALAM

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PENGARUH MIL-101 (Cr)/Fe_3O_4 TERHADAP KARAKTERISTIK DAN KINERJA MEMBRANE NANOFILTRASI POLI ETERSULFON

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Abstrak

Teknologi membran nanofiltrasi sebagai proses pretreatment desalinasi menjadi salah satu solusi pasokan air bersih alternatif karena hemat energi dan juga biaya. Penelitian ini bertujuan untuk Kondisi optimum sintesis, karakteristik dan kinerja membran nanofiltrasi berbasis MMM PES/MIL-101(Cr)/Fe_3O_4. Sintesis membran melalui metode inversi fasa dengan komposisi optimum PES 18%, MIL-101(Cr) 0,2% dan Fe_3O_4 sebanyak 0.004%. Hasil sintesis kemudian dikarakterisasi melalui FTIR, SEM, XRD, uji hidrofilisitas, uji porositas, *tensile strength* dan perhitungan *point of zero charge* (PZC). Membran diuji melalui uji permeabilitas, uji permselektivitas terhadap BSA, dan garam NaCl, $CaCl_2$, $FeCl_3$. Membran juga diuji melalui uji antifouling dan uji MWCO melalui retensi terhadap metil jingga, rhodamine B dan PEG 3000. hasil menunjukkan bahwa membran berhasil disintesis dengan interaksi khas pada spektrum FTIR 435 cm^{-1} untuk Fe-O dan 555 cm^{-1} untuk Cr-O, serta interaksi yang bergeser pada bilangan gelombang 1106 hingga 1111 untuk gugus O=S=O. penambahan filler MIL-101(Cr)/Fe_3O_4 juga meningkatkan hidrofilisitas dari 73^o hingga 54^o, meningkatkan persen porositas dari 48% hingga 72%, meningkatkan distribusi pori dan menurunkan ukuran pori dari 126,47 nm menjadi 61,87 nm serta meningkatkan ukuran kristal dari 0.83 nm ke 6.4 nm. penambahan filler MIL-101(Cr)/Fe_3O_4 juga menurukan nilai PZC dari 7,6 menjadi 7,1. Uji kinerja membran menunjukkan bahwa penambahan filler meningkatkan permeabilitas dari 7,04 L/m^2.h.bar menjadi 45,5 L/m^2.h.bar serta meningkatkan permselektivitas terhadap garam NaCl dari 40% menjadi 93% garam $CaCl_2$ dari 44% menjadi 93% dan garam $FeCl_3$ dari 50 menjadi 94%. Penambahan *filler* MIL-101(Cr)/Fe_3O_4juga meningkatkan *flux recovery ratio* (FRR) dari 55% menjadi 90% serta menurunkan rasio pengotoran total dari 46% menjadi 23%. Hasil uji MWCO menunjukkan bahwa membran PES/MIL-101(Cr)/Fe_3O_4 merupakan membran nanofiltrasi *"tight"* dengan nilai MWCO 327 Da.

Kata kunci: Membran nanofiltrasi, PES, *filler*, MIL-101(Cr)/Fe_3O_4, Karakterisasi, Uji kinerja

Abstract

Nanofiltration membrane technology has emerged as one of the alternative solutions for clean water supply due to its energy and cost efficiency in desalination pretreatment processes. This study aims to optimize the synthesis conditions, characterize, and evaluate the performance of nanofiltration membranes based on PES/MIL-101(Cr)/Fe_3O_4 MMM. The membranes were synthesized via phase inversion method with an optimum composition of PES 18%, MIL-101(Cr) 0.2%, and Fe_3O_4 0.004%. The synthesized membranes were characterized using FTIR, SEM, XRD, hydrophilicity test, porosity test, tensile strength measurement, and point of zero charge (PZC) calculation. Permeability test, BSA and salt selectivity test (NaCl, $CaCl_2$, $FeCl_3$), antifouling test, and MWCO test (retention of methyl orange, rhodamine B, and PEG 3000) were conducted to evaluate the membrane performance. The results indicated successful membrane synthesis with characteristic interactions observed in the FTIR spectrum at 435 cm-1 for Fe-O and 555 cm-1 for Cr-O, as well as shifted interactions at wave numbers 1106 to 1111 corresponding to the O=S=O group. The addition of MIL-101(Cr)/Fe_3O_4 filler improved hydrophilicity from 73° to 54°, increased porosity from 48% to 72%, increased pore distribution and decreased pore size from 126,47 nm to 61,87 nm and enlarged crystal size from 0.83 nm to 6.4 nm. Furthermore, the addition of MIL-101(Cr)/Fe_3O_4 filler reduced the PZC value from 7.6 to 7.1. Performance tests demonstrated that filler addition enhanced permeability from 7.04 L/m^2.h.bar to 45.5 L/m^2.h.bar and selectivity towards NaCl from 40% to 93%, $CaCl_2$ from 44% to 93%, and $FeCl_3$ from 50% to 94%. The inclusion of MIL-101(Cr)/Fe_3O_4 filler also improved flux recovery ratio (FRR) from 55% to 90% and reduced total fouling ratio from 46% to 23%. MWCO tests revealed that PES/MIL-101(Cr)/Fe_3O_4 membrane exhibited a "tight" nanofiltration membrane property with a MWCO value of 327 Da.

Keywords: Nanofiltration Membrane; PES; Filler; MIL-101(Cr)/Fe_3O_4; Characterization; Performance Test

DAFTAR ISI

DAFTAR GAMBAR

DAFTAR TABEL

5.2. Saran

1. Perlu dilakukan uji kekasaran dengan metode AFM untuk mengetahui morfologi dan topografi permukaan membran yang dapat mempengaruhi pengotoran membran.
2. Perlu dilakukan uji kinerja terhadap pemisahan Li_2SO_4, K_2SO_4 atau garam dengan ukuran yang lebih kecil.
3. Perlu dilakukan dilakukan pengambilan data PWF pada rentang waktu yang lebih lama untuk mengamati terjadinya fouling.

DAFTAR PUSTAKA

Al Lafi, A. G., Assfour, B., & Assaad, T. (2020). Metal Organic Framework MIL-101(Cr): Spectroscopic Investigations to Reveal Iodine Capture Mechanism. *Journal of Inorganic and Organometallic Polymers and Materials*, *30*(4), 1218–1230. https://doi.org/10.1007/s10904-019-01236-7

Amiri, S., Asghari, A., Vatanpour, V., & Rajabi, M. (2021). Fabrication of chitosan-aminopropylsilane graphene oxide nanocomposite hydrogel embedded PES membrane for improved filtration performance and lead separation. *Journal of Environmental Management*, *294*, 112918. https://doi.org/10.1016/j.jenvman.2021.112918

Ansari, M. S., Raees, K., Ali Khan, M., Rafiquee, M. Z. A., & Otero, M. (2020). Kinetic Studies on the Catalytic Degradation of Rhodamine B by Hydrogen Peroxide: Effect of Surfactant Coated and Non-Coated Iron (III) Oxide Nanoparticles. *Polymers*, *12*(10), 2246. https://doi.org/10.3390/polym12102246

Azmoon, P., Farhadian, M., Pendashteh, A., & Tangestaninejad, S. (2023). Adsorption and photocatalytic degradation of oilfield produced water by visible-light driven superhydrophobic composite of MIL-101(Cr)/Fe3O4-SiO2: Synthesis, characterization and optimization. *Applied Surface Science*, *613*, 155972. https://doi.org/10.1016/j.apsusc.2022.155972

Bagheripour, E., Moghadassi, A. R., Parvizian, F., Hosseini, S. M., & Van Der Bruggen, B. (2019). Tailoring the separation performance and fouling reduction of PES based nanofiltration membrane by using a PVA/Fe3O4 coating layer. *Chemical Engineering Research and Design*, *144*, 418–428. https://doi.org/10.1016/j.cherd.2019.02.028

Calatayud, M. P., Sanz, B., Raffa, V., Riggio, C., Ibarra, M. R., & Goya, G. F. (2014). The effect of surface charge of functionalized Fe3O4 nanoparticles on protein adsorption and cell uptake. *Biomaterials*, *35*(24), 6389–6399. https://doi.org/10.1016/j.biomaterials.2014.04.009

Chen, T., Zhu, H., Chen, X., Zheng, S., Liang, F., Yang, F., Yang, S., & Zhang, Y. (2023). Full-Coverage Spongy HEAA/PES Composite Ultrafiltration Membrane with High Selectivity and Antifouling Performances. *ACS Applied Polymer Materials*, *5*(4), 2727–2738. https://doi.org/10.1021/acsapm.3c00004

Ghiasi, S., Behboudi, A., Mohammadi, T., & Khanlari, S. (2019). Effect of surface charge and roughness on ultrafiltration membranes performance and polyelectrolyte nanofiltration layer assembly. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *580*, 123753. https://doi.org/10.1016/j.colsurfa.2019.123753

Gu, B., Renaud, D. L., Sanaei, P., Kondic, L., & Cummings, L. J. (2020). On the influence of pore connectivity on performance of membrane filters. *Journal of Fluid Mechanics*, *902*, A5. https://doi.org/10.1017/jfm.2020.520

Harrington, G. F., & Santiso, J. (2021). Back-to-Basics tutorial: X-ray diffraction of thin films. *Journal of Electroceramics*, *47*(4), 141–163. https://doi.org/10.1007/s10832-021-00263-6

He, H., Xin, X., Qiu, W., Li, D., Liu, Z., & Ma, J. (2022). Role of nano-Fe3O4 particle on improving membrane bioreactor (MBR) performance:

Alleviating membrane fouling and microbial mechanism. *Water Research*, *209*, 117897. https://doi.org/10.1016/j.watres.2021.117897

Holtrop, F., Visscher, K. W., Jupp, A. R., & Slootweg, J. C. (2020). Steric attraction: A force to be reckoned with. Dalam *Advances in Physical Organic Chemistry* (Vol. 54, hlm. 119–141). Elsevier. https://doi.org/10.1016/bs.apoc.2020.08.001

Jiang, B.-L., Zhang, D.-X., Yuan, D.-D., Chen, Y.-G., Hao, T.-Z., & Song, H. (2023). Encapsulation of ionic liquid, phosphotungstic acid inside the nanocages of MIL-101(Cr): Effective and reusable catalyst for efficient solvent-free oxidative desulfurization from fuel oil. *Petroleum Science*, *20*(6), 3865–3874. https://doi.org/10.1016/j.petsci.2023.07.018

Joshi, U. S., Anuradha, & Jewrajka, S. K. (2023). Tight ultrafiltration and loose nanofiltration membranes by concentration polarization-driven fast layer-by-layer self-assembly for fractionation of dye/salt. *Journal of Membrane Science*, *669*, 121286. https://doi.org/10.1016/j.memsci.2022.121286

Kavitha, J., Rajalakshmi, M., Phani, A. R., & Padaki, M. (2019). Pretreatment processes for seawater reverse osmosis desalination systems—A review. *Journal of Water Process Engineering*, *32*, 100926. https://doi.org/10.1016/j.jwpe.2019.100926

Khoerunnisa, F., Amanda, P. C., Nurhayati, M., Hendrawan, H., Lestari, W. W., Sanjaya, E. H., Handayani, M., Oh, W.-D., & Lim, J. (2023). Promotional effect of ammonium chloride functionalization on the performance of polyethersulfone/chitosan composite-based ultrafiltration membrane.

Chemical Engineering Research and Design, *190*, 366–378. https://doi.org/10.1016/j.cherd.2022.12.040

Kim, J., Cho, Y., Kim, S., & Lee, J. (2017). 3D Cocontinuous Composites of Hydrophilic and Hydrophobic Soft Materials: High Modulus and Fast Actuation Time. *ACS Macro Letters*, *6*(10), 1119–1123. https://doi.org/10.1021/acsmacrolett.7b00642

Kusumocahyo, S. P., Ambani, S. K., & Marceline, S. (2021). Improved permeate flux and rejection of ultrafiltration membranes prepared from polyethylene terephthalate (PET) bottle waste. *Sustainable Environment Research*, *31*(1), 19. https://doi.org/10.1186/s42834-021-00091-x

Ma, X., Wang, C., Guo, H., Wang, Z., Sun, N., Huo, P., Gu, J., & Liu, Y. (2022). Novel dopamine-modified cellulose acetate ultrafiltration membranes with improved separation and antifouling performances. *Journal of Materials Science*, *57*(11), 6474–6486. https://doi.org/10.1007/s10853-022-07024-y

Mahlangu, O. T., & Mamba, B. B. (2021). Interdependence of Contributing Factors Governing Dead-End Fouling of Nanofiltration Membranes. *Membranes*, *11*(1), 47. https://doi.org/10.3390/membranes11010047

Manjula, N., Pulikkutty, S., & Chen, S.-M. (2023). Simple synthesis of MOF-derived Zn, Co electrocatalyst for sensitive detection of digoxin in urine sample. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *660*, 130830. https://doi.org/10.1016/j.colsurfa.2022.130830

Miao, A., Wei, M., Xu, F., & Wang, Y. (2020). Influence of membrane hydrophilicity on water permeability: An experimental study bridging simulations. *Journal of Membrane Science*, *604*, 118087. https://doi.org/10.1016/j.memsci.2020.118087

Ohanessian, K., Monnot, M., Moulin, P., Ferrasse, J.-H., Barca, C., Soric, A., & Boutin, O. (2020). Dead-end and crossflow ultrafiltration process modelling: Application on chemical mechanical polishing wastewaters. *Chemical Engineering Research and Design*, *158*, 164–176. https://doi.org/10.1016/j.cherd.2020.04.007

Park, M., & Snyder, S. A. (2020). Attenuation of contaminants of emerging concerns by nanofiltration membrane: Rejection mechanism and application in water reuse. Dalam *Contaminants of Emerging Concern in Water and Wastewater* (hlm. 177–206). Elsevier. https://doi.org/10.1016/B978-0-12-813561-7.00006-7

Ray, D., & Das, B. (2019). Micellization of Ionic Liquid Surfactants Induced by Sodium Polystyrenesulfonate in Aqueous Solutions. *Journal of Solution Chemistry*, *48*(11–12), 1576–1590. https://doi.org/10.1007/s10953-019-00929-4

Razi, F., Mulyati, S., & Arahman, N. (2019). The performance of bovine serum albumin filtration by using polyethersulfone-Tetronic 304 blend Ultrafiltration Membrane. *F1000Research*, *8*, 953. https://doi.org/10.12688/f1000research.18740.2

Rehmer, B., Bayram, F., Ávila Calderón, L. A., Mohr, G., & Skrotzki, B. (2023). Elastic modulus data for additively and conventionally manufactured variants of Ti-6Al-4V, IN718 and AISI 316 L. *Scientific Data*, *10*(1), 474. https://doi.org/10.1038/s41597-023-02387-6

Shahid, M. K., Mainali, B., Rout, P. R., Lim, J. W., Aslam, M., Al-Rawajfeh, A. E., & Choi, Y. (2023). A Review of Membrane-Based Desalination Systems Powered by Renewable Energy Sources. *Water*, *15*(3), 534. https://doi.org/10.3390/w15030534

Suhalim, N. S., Kasim, N., Mahmoudi, E., Shamsudin, I. J., Mohammad, A. W., Mohamed Zuki, F., & Jamari, N. L.-A. (2022). Rejection Mechanism of Ionic Solute Removal by Nanofiltration Membranes: An Overview. *Nanomaterials*, *12*(3), 437. https://doi.org/10.3390/nano12030437

Tamburini, A., Cipollina, A., Tedesco, M., Gurreri, L., Ciofalo, M., & Micale, G. (2019). The REAPower Project. Dalam *Current Trends and Future Developments on (Bio-) Membranes* (hlm. 407–448). Elsevier. https://doi.org/10.1016/B978-0-12-813551-8.00017-6

Wang, Y., Fu, X., Pan, T., Ma, X., Cao, H., & Jiang, W. (2022). Stable effect on MIL-101(Cr) with Cu2+ for the toluene adsorption. *Journal of Solid State Chemistry*, *316*, 123633. https://doi.org/10.1016/j.jssc.2022.123633

Wang, Z., Xiao, K., & Wang, X. (2018). Role of coexistence of negative and positive membrane surface charges in electrostatic effect for salt rejection by nanofiltration. *Desalination*, *444*, 75–83. https://doi.org/10.1016/j.desal.2018.07.010

Westworth, S., Ashwath, N., & Cozzolino, D. (2019). Application of FTIR-ATR spectroscopy to detect salinity response in Beauty Leaf Tree (Calophyllum inophyllum L). *Energy Procedia*, *160*, 761–768. https://doi.org/10.1016/j.egypro.2019.02.182

Xiong, Z., Huang, Y., Huang, Z., Shi, Y., Qu, F., Zhang, G., Yang, J., & Zhao, S. (2022). Confining Nano-Fe $_3$ O $_4$ in the Superhydrophilic Membrane Skin Layer to Minimize Internal Fouling. *ACS Applied Materials & Interfaces*, *14*(22), 26044–26056. https://doi.org/10.1021/acsami.2c04685

Xu, F., Wei, M., Zhang, X., Song, Y., Zhou, W., & Wang, Y. (2019). How Pore Hydrophilicity Influences Water Permeability? *Research*, *2019*, 2019/2581241. https://doi.org/10.34133/2019/2581241

Yin, J., Tang, H., Xu, Z., & Li, N. (2021). Enhanced mechanical strength and performance of sulfonated polysulfone/Tröger's base polymer blend ultrafiltration membrane. *Journal of Membrane Science*, *625*, 119138. https://doi.org/10.1016/j.memsci.2021.119138

Zare, A., Bordbar, A.-K., Razmjou, A., & Jafarian, F. (2019). The immobilization of Candida rugosa lipase on the modified polyethersulfone with MOF nanoparticles as an excellent performance bioreactor membrane. *Journal of Biotechnology*, *289*, 55–63. https://doi.org/10.1016/j.jbiotec.2018.11.011

Zhang, J., Huang, S., Guo, H., Fane, A. G., & Tang, C. Y. (2022). Effects of crossflow filtration cell configuration on membrane separation performance and fouling behaviour. *Desalination*, *525*, 115505. https://doi.org/10.1016/j.desal.2021.115505

Zhang, X., Wang, Y., Mi, J., Jin, J., & Meng, H. (2023). Dual hydrophobic modification on MIL-101(Cr) with outstanding toluene removal under high relative humidity. *Chemical Engineering Journal*, *451*, 139000. https://doi.org/10.1016/j.cej.2022.139000

Zhao, J., & Liu, X. (2022). Electron microscopic methods (TEM, SEM and energy dispersal spectroscopy). Dalam *Reference Module in Earth Systems and Environmental Sciences* (hlm. B9780128229743000136). Elsevier. https://doi.org/10.1016/B978-0-12-822974-3.00013-6

Zou, M., Dong, M., & Zhao, T. (2022). Advances in Metal-Organic Frameworks MIL-101(Cr). *International Journal of Molecular Sciences*, *23*(16), 9396. https://doi.org/10.3390/ijms23169396

Abdelkader, B. A., Antar, M. A., & Khan, Z. (2018). Nanofiltration as a Pretreatment Step in Seawater Desalination: A Review. *Arabian Journal for Science and Engineering*, *43*(9), 4413–4432. https://doi.org/10.1007/s13369-018-3096-3

Abdel-Karim, A., Ismail, S. H., Bayoumy, A. M., Ibrahim, M., & Mohamed, G. G. (2021). Antifouling PES/Cu@Fe3O4 mixed matrix membranes: Quantitative structure–activity relationship (QSAR) modeling and wastewater treatment potentiality. *Chemical Engineering Journal*, *407*, 126501. https://doi.org/10.1016/j.cej.2020.126501

Alammar, A., & Szekely, G. (2022). Polymer-based nanofiltration membranes. Dalam *Advancement in Polymer-Based Membranes for Water Remediation* (hlm. 159–196). Elsevier. https://doi.org/10.1016/B978-0-323-88514-0.00018-8

Alenazi, N. A., Hussein, M. A., Alamry, K. A., & Asiri, A. M. (2017). Modified polyether-sulfone membrane: A mini review. *Designed Monomers and Polymers*, *20*(1), 532–546. https://doi.org/10.1080/15685551.2017.1398208

Aliyu, U. M., Rathilal, S., & Isa, Y. M. (2018). Membrane desalination technologies in water treatment: A review. *Water Practice and Technology*, *13*(4), 738–752. https://doi.org/10.2166/wpt.2018.084

Alsamhary, K. I. (2020). Eco-friendly synthesis of silver nanoparticles by Bacillus subtilis and their antibacterial activity. *Saudi Journal of Biological Sciences*, *27*(8), 2185–2191. https://doi.org/10.1016/j.sjbs.2020.04.026

Alsayed, A. F. M., & Ashraf, M. A. (2021). Modified nanofiltration membrane treatment of saline water. Dalam *Water Engineering Modeling and Mathematic Tools* (hlm. 25–44). Elsevier. https://doi.org/10.1016/B978-0-12-820644-7.00005-0

Ang, M. B. M. Y., Tang, C.-L., De Guzman, M. R., Maganto, H. L. C., Caparanga, A. R., Huang, S.-H., Tsai, H.-A., Hu, C.-C., Lee, K.-R., & Lai, J.-Y. (2020). Improved performance of thin-film nanofiltration membranes fabricated with the intervention of surfactants having different structures for water treatment. *Desalination*, *481*, 114352. https://doi.org/10.1016/j.desal.2020.114352

Asad, A., Sameoto, D., & Sadrzadeh, M. (2020). Overview of membrane technology. Dalam *Nanocomposite Membranes for Water and Gas Separation* (hlm. 1–28). Elsevier. https://doi.org/10.1016/B978-0-12-816710-6.00001-8

Ashfaq, M. Y., Da'na, D. A., Wahib, S. A., & Al-Ghouti, M. A. (2021). The integrated/hybrid membrane systems for membrane desalination. Dalam *Integrated and Hybrid Process Technology for Water and Wastewater Treatment* (hlm. 145–170). Elsevier. https://doi.org/10.1016/B978-0-12-823031-2.00013-6

Bagheripour, E., Moghadassi, A. R., Parvizian, F., Hosseini, S. M., & Van Der Bruggen, B. (2019). Tailoring the separation performance and fouling reduction of PES based nanofiltration membrane by using a PVA/Fe3O4 coating layer. *Chemical Engineering Research and Design*, *144*, 418–428. https://doi.org/10.1016/j.cherd.2019.02.028

Bardhan, A., Akhtar, A., & Subbiah, S. (2022). Microfiltration and ultrafiltration membrane technologies. Dalam *Advancement in Polymer-Based Membranes for Water Remediation* (hlm. 3–42). Elsevier. https://doi.org/10.1016/B978-0-323-88514-0.00001-2

Bargeman, G. (2023). Maximum allowable retention for low-salt-rejection reverse osmosis membranes and its effect on concentrating undersaturated NaCl solutions to saturation. *Separation and Purification Technology*, *317*, 123854. https://doi.org/10.1016/j.seppur.2023.123854

Berber, M. R. (2020). Current Advances of Polymer Composites for Water Treatment and Desalination. *Journal of Chemistry*, *2020*, 1–19. https://doi.org/10.1155/2020/7608423

Biniaz, P., Rahimpour, E., Basile, A., & Rahimpour, M. R. (2022). Fundamentals of membrane technology. Dalam *Current Trends and Future Developments on (Bio-) Membranes* (hlm. 1–23). Elsevier. https://doi.org/10.1016/B978-0-12-822257-7.00011-X

Boo, C., Wang, Y., Zucker, I., Choo, Y., Osuji, C. O., & Elimelech, M. (2018). High Performance Nanofiltration Membrane for Effective Removal of Perfluoroalkyl Substances at High Water Recovery. *Environmental Science & Technology*, *52*(13), 7279–7288. https://doi.org/10.1021/acs.est.8b01040

Buonomenna, M. G. (2022). Mixed matrix membranes for gas separation. Dalam *Nano-Enhanced and Nanostructured Polymer-Based Membranes for Energy Applications* (hlm. 203–254). Elsevier. https://doi.org/10.1016/B978-0-08-101985-6.00007-0

Cai, X., Lei, T., Sun, D., & Lin, L. (2017). A critical analysis of the α, β and γ phases in poly(vinylidene fluoride) using FTIR. *RSC Advances*, *7*(25), 15382–15389. https://doi.org/10.1039/C7RA01267E

Chai, P. V., Law, J. Y., Mahmoudi, E., & Mohammad, A. W. (2020). Development of iron oxide decorated graphene oxide (Fe3O4/GO) PSf mixed-matrix membrane for enhanced antifouling behavior. *Journal of Water Process Engineering*, *38*, 101673. https://doi.org/10.1016/j.jwpe.2020.101673

Chakraverty, R., Samanta, K., Mandal, P., Karmakar, S., & Karmakar, S. (2023). Mechanisms of action of antibacterial agents (AMA). Dalam *How Synthetic Drugs Work* (hlm. 421–429). Elsevier. https://doi.org/10.1016/B978-0-323-99855-0.00018-X

Chauke, N. M., Moutloali, R. M., & Ramontja, J. (2020). Development of ZSM-22/Polyethersulfone Membrane for Effective Salt Rejection. *Polymers*, *12*(7), 1446. https://doi.org/10.3390/polym12071446

Chen, W., Gu, Z., Ran, G., & Li, Q. (2021). Application of membrane separation technology in the treatment of leachate in China: A review. *Waste Management*, *121*, 127–140. https://doi.org/10.1016/j.wasman.2020.12.002

Cunliffe, A. J., Askew, P. D., Stephan, I., Iredale, G., Cosemans, P., Simmons, L. M., Verran, J., & Redfern, J. (2021). How Do We Determine the Efficacy of an Antibacterial Surface? A Review of Standardised Antibacterial Material Testing Methods. *Antibiotics*, *10*(9), 1069. https://doi.org/10.3390/antibiotics10091069

Fadel, M., Wyart, Y., & Moulin, P. (2020). An Efficient Method to Determine Membrane Molecular Weight Cut-Off Using Fluorescent Silica Nanoparticles. *Membranes*, *10*(10), 271. https://doi.org/10.3390/membranes10100271

Folens, K., Leus, K., Nicomel, N. R., Meledina, M., Turner, S., Van Tendeloo, G., Laing, G. D., & Van Der Voort, P. (2016). Fe_3O_4 @MIL-101 – A Selective and Regenerable Adsorbent for the Removal of As Species from Water. *European Journal of Inorganic Chemistry*, *2016*(27), 4395–4401. https://doi.org/10.1002/ejic.201600160

Fouad, D., Bachra, Y., Ayoub, G., Ouaket, A., Bennamara, A., Knouzi, N., & Berrada, M. (2020). A Novel Drug Delivery System Based on Nanoparticles of Magnetite Fe_3O_4 Embedded in an Auto Cross-Linked Chitosan. Dalam *Chitin and Chitosan—Physicochemical Properties and Industrial Applications [Working Title]*. IntechOpen. https://doi.org/10.5772/intechopen.94873

Gabrielyan, L., Badalyan, H., Gevorgyan, V., & Trchounian, A. (2020). Comparable antibacterial effects and action mechanisms of silver and iron oxide nanoparticles on Escherichia coli and Salmonella typhimurium. *Scientific Reports*, *10*(1), 13145. https://doi.org/10.1038/s41598-020-70211-x

Giridhar, G., Manepalli, R. K. N. R., & Apparao, G. (2017). Contact Angle Measurement Techniques for Nanomaterials. Dalam *Thermal and Rheological Measurement Techniques for Nanomaterials Characterization* (hlm. 173–195). Elsevier. https://doi.org/10.1016/B978-0-323-46139-9.00008-6

Gorjian, S., Ghobadian, B., Ebadi, H., Ketabchi, F., & Khanmohammadi, S. (2020). Applications of solar PV systems in desalination technologies. Dalam

Photovoltaic Solar Energy Conversion (hlm. 237–274). Elsevier. https://doi.org/10.1016/B978-0-12-819610-6.00008-9

Goudarzi, S., Azizi, N., Eslami, R., & Zarrin, H. (2022). Polymer-based nanoenhanced nanofiltration membranes. Dalam *Advancement in Polymer-Based Membranes for Water Remediation* (hlm. 197–235). Elsevier. https://doi.org/10.1016/B978-0-323-88514-0.00003-6

Gozali Balkanloo, P., Mahmoudian, M., & Hosseinzadeh, M. T. (2020). A comparative study between MMT-Fe3O4/PES, MMT-HBE/PES, and MMT-acid activated/PES mixed matrix membranes. *Chemical Engineering Journal*, *396*, 125188. https://doi.org/10.1016/j.cej.2020.125188

Harrington, G. F., & Santiso, J. (2021). Back-to-Basics tutorial: X-ray diffraction of thin films. *Journal of Electroceramics*, *47*(4), 141–163. https://doi.org/10.1007/s10832-021-00263-6

Hosseini, S. M., Afshari, M., Fazlali, A. R., Koudzari Farahani, S., Bandehali, S., Van Der Bruggen, B., & Bagheripour, E. (2019). Mixed matrix PES-based nanofiltration membrane decorated by (Fe3O4–polyvinylpyrrolidone) composite nanoparticles with intensified antifouling and separation characteristics. *Chemical Engineering Research and Design*, *147*, 390–398. https://doi.org/10.1016/j.cherd.2019.05.025

Hussain, C. M., Rawtani, D., Pandey, G., & Tharmavaram, M. (2021). Energy dispersive X-ray (EDX) coupled microscopy in forensic science. Dalam *Handbook of Analytical Techniques for Forensic Samples* (hlm. 281–300). Elsevier. https://doi.org/10.1016/B978-0-12-822300-0.00015-X

Jee, H., Jang, J., Kang, Y., Eisa, T., Chae, K.-J., Kim, I. S., & Yang, E. (2022). Enhancing the Dye-Rejection Efficiencies and Stability of Graphene Oxide-Based Nanofiltration Membranes via Divalent Cation Intercalation and Mild Reduction. *Membranes*, *12*(4), 402. https://doi.org/10.3390/membranes12040402

Kamari, S., & Shahbazi, A. (2020). Biocompatible Fe3O4@SiO2-NH2 nanocomposite as a green nanofiller embedded in PES–nanofiltration membrane matrix for salts, heavy metal ion and dye removal: Long–term operation and reusability tests. *Chemosphere*, *243*, 125282. https://doi.org/10.1016/j.chemosphere.2019.125282

Kanwal, A., Yaqoob, A. A., Siddique, A., Ibrahim, M. N. M., & Ahmad, A. (2023). Polyethersulfone (PES) nanofiltration membrane for treatment of toxic metal contaminated water. Dalam *Emerging Techniques for Treatment of Toxic Metals from Wastewater* (hlm. 319–341). Elsevier. https://doi.org/10.1016/B978-0-12-822880-7.00004-2

Kavun, V., Van Der Veen, M. A., & Repo, E. (2021). Selective recovery and separation of rare earth elements by organophosphorus modified MIL-101(Cr). *Microporous and Mesoporous Materials*, *312*, 110747. https://doi.org/10.1016/j.micromeso.2020.110747

Kayvani Fard, A., McKay, G., Buekenhoudt, A., Al Sulaiti, H., Motmans, F., Khraisheh, M., & Atieh, M. (2018). Inorganic Membranes: Preparation and Application for Water Treatment and Desalination. *Materials*, *11*(1), 74. https://doi.org/10.3390/ma11010074

Khan, F. S. A., Ahmed, S., Karri, R. R., Mubarak, N. M., Jatoi, A. S., Khalid, M., Tan, Y. H., Khan, N. A., & Koduru, J. R. (2023). Nanofiltration membranes for wastewater treatment and biotechnological applications. Dalam *Hybrid Nanomaterials for Sustainable Applications* (hlm. 321–337). Elsevier. https://doi.org/10.1016/B978-0-323-98371-6.00001-X

Kong, N., Chen, C., Zeng, Q., Li, B., Shen, L., & Lin, H. (2022). Enriching Fe3O4@MoS2 composites in surface layer to fabricate polyethersulfone (PES) composite membrane: The improved performance and mechanisms. *Separation and Purification Technology*, *302*, 122178. https://doi.org/10.1016/j.seppur.2022.122178

Li, G., He, X., Yin, F., Chen, B., & Yin, H. (2019). Co-Fe/MIL-101(Cr) hybrid catalysts: Preparation and their electrocatalysis in oxygen reduction reaction. *International Journal of Hydrogen Energy*, *44*(23), 11754–11764. https://doi.org/10.1016/j.ijhydene.2019.03.095

Liu, J., Bahadoran, A., Emami, N., Al-Musawi, T. J., Dawood, F. A., Nasajpour-Esfahani, N., Najafipour, I., Mousavi, S. E., Ghazuan, T., Mosallanezhad, M., & Toghraie, D. (2023). Removal of diclofenac sodium and cefixime from wastewater by polymeric PES mixed-matrix-membranes embedded with MIL101-OH/Chitosan. *Process Safety and Environmental Protection*, *172*, 588–593. https://doi.org/10.1016/j.psep.2023.02.060

Mahmodi, G., Bafti, R. R., Boroujeni, N. I., Pradhan, S., Dangwal, S., Sengupta, B., Vatanpour, V., Sorci, M., Fathizadeh, M., Bikkina, P., Belfort, G., Yu, M., & Kim, S.-J. (2023). Improving cellulose acetate mixed matrix membranes by incorporating hydrophilic MIL-101(Cr)-NH2 nanoparticles for treating dye/salt solution. *Chemical Engineering Journal*, *477*, 146736. https://doi.org/10.1016/j.cej.2023.146736

Manawi, Y., Kochkodan, V., Mahmoudi, E., Johnson, D. J., Mohammad, A. W., & Atieh, M. A. (2017). Characterization and Separation Performance of a Novel Polyethersulfone Membrane Blended with Acacia Gum. *Scientific Reports*, *7*(1), 15831. https://doi.org/10.1038/s41598-017-14735-9

Moradihamedani, P. (2022). Recent advances in dye removal from wastewater by membrane technology: A review. *Polymer Bulletin*, *79*(4), 2603–2631. https://doi.org/10.1007/s00289-021-03603-2

Munir, N., Hanif, M., Dias, D. A., & Abideen, Z. (2021). The role of halophytic nanoparticles towards the remediation of degraded and saline agricultural lands. *Environmental Science and Pollution Research*, *28*(43), 60383–60405. https://doi.org/10.1007/s11356-021-16139-9

Nagy, E. (2019). *Basic equations of the mass transport through a membrane layer* (Second edition). Elsevier.

Nguyen, M. D., Tran, H.-V., Xu, S., & Lee, T. R. (2021). Fe3O4 Nanoparticles: Structures, Synthesis, Magnetic Properties, Surface Functionalization, and Emerging Applications. *Applied Sciences*, *11*(23), 11301. https://doi.org/10.3390/app112311301

Obotey Ezugbe, E., & Rathilal, S. (2020a). Membrane Technologies in Wastewater Treatment: A Review. *Membranes*, *10*(5), 89. https://doi.org/10.3390/membranes10050089

Obotey Ezugbe, E., & Rathilal, S. (2020b). Membrane Technologies in Wastewater Treatment: A Review. *Membranes*, *10*(5), 89. https://doi.org/10.3390/membranes10050089

Perez-Gavilan, A., De Castro, J. V., Arana, A., Merino, S., Retolaza, A., Alves, S. A., Francone, A., Kehagias, N., Sotomayor-Torres, C. M., Cocina, D., Mortera, R., Crapanzano, S., Pelegrín, C. J., Garrigos, M. C., Jiménez, A., Galindo, B., Araque, M. C., Dykeman, D., Neves, N. M., & Marimón, J. M. (2021). Antibacterial activity testing methods for hydrophobic patterned surfaces. *Scientific Reports*, *11*(1), 6675. https://doi.org/10.1038/s41598-021-85995-9

Qadir, D., Idris, A., Nasir, R., Abdul Mannan, H., Sharif, R., & Mukhtar, H. (2023). Prediction of single salt rejection in PES/CMS based membranes. *Chemosphere*, *311*, 136987. https://doi.org/10.1016/j.chemosphere.2022.136987

Qiu, S., Wang, Y., Wan, J., Han, J., Ma, Y., & Wang, S. (2020). Enhancing water stability of MIL-101(Cr) by doping Ni(II). *Applied Surface Science*, *525*, 146511. https://doi.org/10.1016/j.apsusc.2020.146511

Rajati, H., Navarchian, A. H., Rodrigue, D., & Tangestaninejad, S. (2021). Effect of immobilizing ionic liquid on amine-functionalized MIL-101(Cr) incorporated in Matrimid membranes for CO2/CH4 separation. *Chemical Engineering and Processing - Process Intensification*, *168*, 108590. https://doi.org/10.1016/j.cep.2021.108590

Selatile, M. K., Ray, S. S., Ojijo, V., & Sadiku, R. (2018). Recent developments in polymeric electrospun nanofibrous membranes for seawater desalination. *RSC Advances*, *8*(66), 37915–37938. https://doi.org/10.1039/C8RA07489E

Sharma, P., & Shahi, V. K. (2020). Assembly of MIL-101(Cr)-sulphonated poly(ether sulfone) membrane matrix for selective electrodialytic separation of Pb2+ from mono-/bi-valent ions. *Chemical Engineering Journal*, *382*, 122688. https://doi.org/10.1016/j.cej.2019.122688

Song, N., Sun, Y., Xie, X., Wang, D., Shao, F., Yu, L., & Dong, L. (2020). Doping MIL-101(Cr)@GO in polyamide nanocomposite membranes with improved water flux. *Desalination*, *492*, 114601. https://doi.org/10.1016/j.desal.2020.114601

Su, Q.-W., Lu, H., Zhang, J.-Y., & Zhang, L.-Z. (2019). Fabrication and analysis of a highly hydrophobic and permeable block GO-PVP/PVDF membrane for membrane humidification-dehumidification desalination. *Journal of Membrane Science*, *582*, 367–380. https://doi.org/10.1016/j.memsci.2019.04.023

Subasi, Y., & Cicek, B. (2017). Recent advances in hydrophilic modification of PVDF ultrafiltration membranes – a review: Part I. *Membrane Technology*, *2017*(10), 7–12. https://doi.org/10.1016/S0958-2118(17)30191-X

Suwaileh, W. A., Johnson, D. J., Sarp, S., & Hilal, N. (2018). Advances in forward osmosis membranes: Altering the sub-layer structure via recent fabrication and chemical modification approaches. *Desalination*, *436*, 176–201. https://doi.org/10.1016/j.desal.2018.01.035

Tang, Y., Yin, X., Mu, M., Jiang, Y., Li, X., Zhang, H., & Ouyang, T. (2020). Anatase TiO2@MIL-101(Cr) nanocomposite for photocatalytic degradation of bisphenol A. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *596*, 124745. https://doi.org/10.1016/j.colsurfa.2020.124745

Undavalli, V. K., Ling, C., & Khandelwal, B. (2021). Impact of alternative fuels and properties on elastomer compatibility. Dalam *Aviation Fuels* (hlm. 113–132). Elsevier. https://doi.org/10.1016/B978-0-12-818314-4.00001-7

Wang, H., Yang, J., Zhang, H., Zhao, J., Liu, H., Wang, J., Li, G., & Liang, H. (2024). Membrane-based technology in water and resources recovery from the perspective of water social circulation: A review. *Science of The Total Environment*, *908*, 168277. https://doi.org/10.1016/j.scitotenv.2023.168277

Wang, Y.-N., Goh, K., Li, X., Setiawan, L., & Wang, R. (2018). Membranes and processes for forward osmosis-based desalination: Recent advances and future prospects. *Desalination*, *434*, 81–99. https://doi.org/10.1016/j.desal.2017.10.028

Yadav, S., Ibrar, I., Samal, A. K., Altaee, A., Déon, S., Zhou, J., & Ghaffour, N. (2022). Preparation of fouling resistant and highly perm-selective novel PSf/GO-vanillin nanofiltration membrane for efficient water purification. *Journal of Hazardous Materials*, *421*, 126744. https://doi.org/10.1016/j.jhazmat.2021.126744