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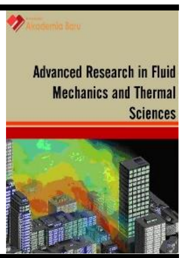

A Short Review on Developing Membrane Proficiency for Water Energy Sustainability

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ABSTRACT

Growing worldwide demand in energy usage offers various opportunities in green energy technologies innovation. Responding to the sustainable energy concern is very important for the communities in order to uphold secure as well as balanced future progress ecologically and economically. Lately, increasing interest can be seen in developing enhanced efficient technologies of sustainable energy with capability to reduce the worldwide environmental footprint. Increasing knowledge in hybrid methods results in environmental resources utilization decrement during energy production. Nevertheless, numerous aspects such as natural resources availability as well as diverse policies of economic limit sustainable energies enhancement. Energy is the primary aspect in the progress to a sustainable future. Lately, technologies based on membrane start to play a crucial role in environmental-friendly and sustainable energy development. Membrane technologies opportunities in energy sustainability are analysed in review article.

1. Introduction

The worldwide energy demands for the next two decades are expected to be doubled-up from the current demands. These increasing energy demands will be fulfilled using non-renewable and renewable energy sources. Non-renewable energy sources are fossil fuel which includes coal, natural gas, and crude oil while one of new renewable energy source is the hydrogen from the process of photocatalytic water splitting [1, 2]. Industries such as petrochemical and chemical have a significant role in energy structure, the world economy and environmental problems. The energy consumption needs to be controlled and the waste stream needs to be lowered by the application of engineering process technologies, specifically in the petrochemical and chemical industry [3, 4]. The catalysts

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development or coupled chemical process involving chemical reaction intensification and separation will improve the process. Sustainable energy is referred to as the significant way out in solving the main issues regarding the future for example economic and society growth balance, environmental protection and climate change. The previous two decades, various economic improvements can be witnessed in numerous countries [5-8]. Nevertheless, speedy growth of economic, industrial development, energy deficiency, environmental deterioration as well as rising demands due to increasing populations brought by enormous risk for future generations [9, 10]. Economic advancement is the key focus of various policy makers in sustainable development for many years until 1997 due to the commencement of Kyoto protocol agreement which emphasize environmental quality as the vital parameter in sustainable development [11, 12]. Expected increment of global electricity and energy consumption in the following twenty-five years opens various innovation opportunities especially on the production, storage, transmission and usage of energy. Particularly, sustainable energy technologies with capability in efficiency improvement and global carbon footprint reduction have gained various interests [13-15]. However, sustainable energy development is constrained by numerous aspects for example natural resources availability due to regional differences, differences in economic policy, rising water shortage as well as sensitivity to the environmental impacts of energy produced from fossil-fuel. Sustainable energy strategy development with aims to counter environmental issues, resource availability, cost, social impact as well as greenhouse gas release possess enormous obstacle [16-18].

The crucial focus in obtaining energy sustainability is to lessen and gradually substitute fossil fuels with renewable energy sources in power generation [19, 20]. Although certain factors of sustainable strategy are currently implemented, there are more have yet to be introduced commercially. As an example, primary concern on the release of carbon dioxide (CO_2) in power generation from fossil fuel results in a number of sustainable energy sources namely solar and wind as well as the technologies of carbon dioxide capture and sequestration [2, 21]. There is increasing acknowledgment for technologies such as cogeneration plants which refers to plants with a combination of techniques that offer reduction in water demand as energy is being generated leading to efficient water usage in meeting the demand. Both energy and water are crucial in future sustainable enhancement [9, 22, 23]. Desalination technologies transition from thermal to membrane as well as global market expansion is shown in Figure 1.

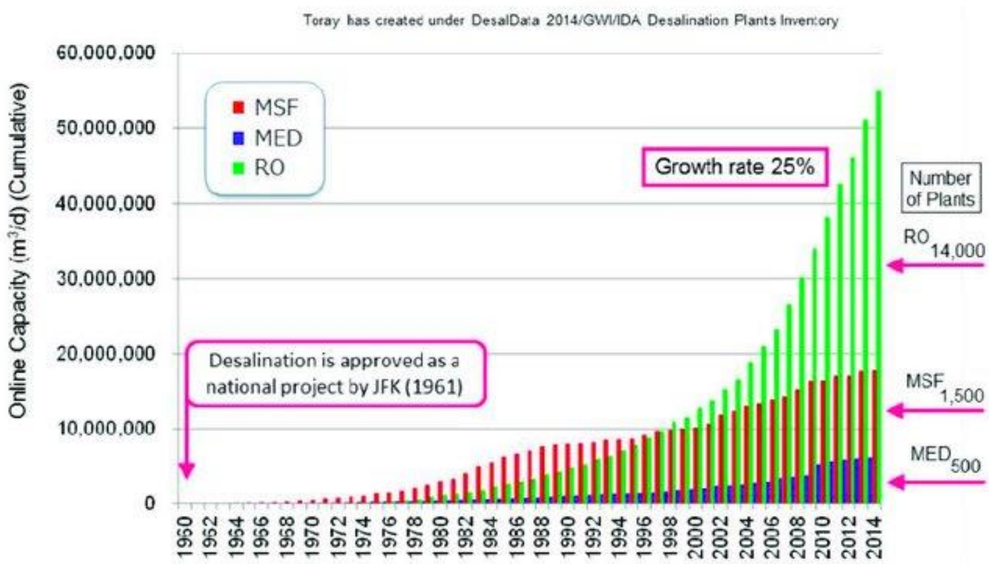

Fig. 1. Online capacity of various desalination technologies and the expansion of the global desalination market [24]

Some of the membrane technologies have been applied for industrial application and they are very important for water and energy sustainability. For example, wastewater treatment using membrane reactors (MBR), membrane-based fuel cells, lithium-ion batteries and desalination using reverse osmosis (RO). Besides, membrane technologies also have a significant role in sustainability criteria in the context of ease to use, adaptability, flexibility, usage of land and impacts on the environment [25, 26]. However, improvement in the context of cost-effectiveness, expertise, and consumption of energy is required through the advancement of membrane materials. Potential, advancement and revolution of membrane materials need a deeper study for water and energy sustainability to have better clarity for criteria targets of the membrane, supply end-users in the industry high-quality membrane technologies and strengthen the dependency between industrial and research sectors. Desalinated water is not commonly used in agriculture years ago because it is expensive compared to the cheap direct freshwater sources [3, 27]. Membrane technologies not only address issues related to water shortage and demand of energy but are also eligible as sustainability criteria in terms of adaptability, feasibility and flexibility. Nevertheless, affordability and costs improvement is needed which can be obtained by membrane-based technologies development. The aim of this short review article is to analyze the prospect of membrane technologies in tackling energy and water sustainability.

2. Role of Membrane Technology in Sustainable Water Generation

Potable water generation using membrane-based techniques relies primarily on the process of waste water treatment and desalination [2, 28]. Majority of the worldwide water reserves is consisting of saline with only 2.5% fresh water available. Besides, only 0.007% of fresh water can be used directly by human as a large ration of fresh water stock is either in remote location which is hard to access or frozen in polar areas [29]. Yet, the price of desalinated water starts to decrease make it competitive to groundwater in which its cost is increasing. This shows that the groundwater usage is not sustainable and it is expected that the usage of groundwater will be mitigated by new regulations. The costs to fully use the desalinated water for irrigation is too expensive but yet, it is still convenient to be used for intensive horticulture that produces high-value crops for example flowers and vegetables planted in coastal areas or greenhouse due to brines safe disposal is much easier compared to inland areas [30, 31]. Rising fresh water demand influenced the development of numerous methods in the past years for example multi-stage flash distillation (MSF), vacuum distillation, multiple-effect distillation (MED), as well as other technologies of membrane-based for instance membrane distillation (MD), reverse osmosis (RO), etc., for desalination of sea water. Amongst these technologies, membrane-based methods for example MD, RO, and forward osmosis are deemed to be attractive as replacements due to their low energy usage, less maintenance, low capital requirements and low operating costs. Desalination refers to fresh water production process from either brackish water or sea through salt content removal by thermal distillation process or membrane technologies. Desalination is important in water sustainability of numerous countries in the world, particularly in the Gulf Nations. For instance, desalination provides 100% of Kuwait and Qatar water supply for industrial and domestic usage [32]. According to Desaldata, production of 63.7% of total desalted water via membrane processes was reported, which proves the significance of membrane technologies [32]. Desalination water sources includes 19.9% from waste water and surface water, 21.2% from brackish ground water and 58.9% from seawater. Application of water produced through desalination process can be found in removing or recovering rare earth elements (REEs), mining, agriculture and drinking water [33]. Reverse osmosis (RO) has been utilized globally for many years indicated it as the most common desalination process used that is membrane-based

[34]. The mechanism of RO process is based on the concept of discarding dissolved salts and colloidal suspension from aqueous solution, hence producing pure water and concentrated brine that can permeates across a semi-permeable membrane caused by the pressure gradient existence across the membrane [3]. RO is broadly utilized in concentrating organic substances with its current usage also involve seawater desalination [35]. Through pressure application, water molecules in the feed solution involuntarily permeate across the membrane while at the same time retains the dissolved solid contents. Feed solution osmotic pressure can be overcome by applying 55-70 bar of high feed pressure for seawater desalination and 10–15 bar for brackish water.

About 22 percentage of water global consumption is consumed by industrial sectors and the largest consumption is used in generating power. The thermoelectric power plant requires 45,000 m3 of water per hour to generate 500 MW of electricity whereas 1.6 liters of water is required by a coal-fired power station to generate one kiloWatt energy per hour. Nowadays, a lot of efforts have been done in treating and reusing the released or produced wastewater [36, 37]. However, there is no available technology that has been commercialized to treat and recover a large quantity of water in the air originates from the evaporation of wastewater [38]. The regulations related to gas emissions to the atmosphere have been reinforced to limit the amount of discharged gas in the concern of the discharged gas will increase the greenhouse gas effect. The recovery and separation of waste gaseous streams containing water can become a new source of water and also in contrast, as a constraint. The results from Membrane Desalination (MD) technology for a few years ago show that there is a new membrane-assisted technology which is still in developing phase (membrane-assisted condensation) functions to recover water from the gaseous stream [27, 39]. The basic operating principle involves the recovery and condensation of water in the saturated gas. The hydrophobic membrane is used in membrane condenser to obstruct the water droplet from passing through in the saturated gas. The reduction of activation energy in the process of heterogeneous condensation leads to the process of condensing water vapor by the hydrophobic membrane. Generally, the water in the gases waste stream at a temperature in the range between 40 °C to 80 °C can be recovered (more than 65%) using the cooling process at a temperature lower than 20 °C which has been proven by a study [40]. Other than that, the composition of recovered liquid can be handled accurately depending on the parameters of the process such as humidity, flow rate, and temperature, also the membrane chemical-physical properties [32]. There are two different ways of controlling the composition of the recovered liquid suggested by condensation of contaminants which is by properly adjusting the operating conditions for water recovery.

Currently, membrane technology is the main element in the process of producing water, treating and recovering the wastewater. However, there are some technical challenges in this technology due to its improved performance such as fouling control and permeate quality while the socio-economic challenges are the MDGs and response towards climate change. There is potential to enhance membranes and modules for desalination by implementing techniques such as FO, advances EDR and MD in the future. The performance of the water treatment process can be improved using tighter cutoff and higher permeability [41]. The common membrane used is ceramic membranes. A study reported that water treatment and desalination process can be carried out with low energy and low greenhouse gas emission, however, it is at a capital cost penalty. Improvement in biofouling control strategies which is still under development is expected to enhance the RO process in water reclamation. There is a potential to obtain reclaimed water with a low amount of greenhouse gas emissions by implementing a low-pressure process using the combination of a bioreactor with either FO or MD [42]. The development of MBRs is increasing includes the moving biofilm MBR. Moving biofilm MBR has higher sustainable fluxes due to the biomass supported on a floating media. The net greenhouse gas emissions can be reduced in the process of wastewater by the implementation of anaerobic MBRs. MFC is another form of MBR. Lastly, membranes are very suitable to improve the process of wastewater and water, also capable to meet the requirements of MDGs. Enhancement in terms of integrity monitoring and affordability is needed. Similarly, as in the other thermal processes, Membrane Distillation (MD) process entails a significant thermal energy amount for water vapor generation from its liquid phase. Solar energy or industrial waste offers high potential as significant alternative energy source for this process. MD process receives a lot of attention due to low energy necessity, high quality water production, assumed to be the potential substitute to thermal desalination and SWRO process as well as promising to be used in combination with old desalination methods for energy requirements and operating costs reduction [27]. Numerous membrane distillation types are already utilized for a few years for example vacuum MD (VMD), direct contact MD (DCMD), air gap MD (AGMD) and sweep gas MD (SGMD) according to the permeate side condensation process type, having feed to be directly connected to the membrane in all of the process. In MD process, the membrane is recognized as the vital feature as it rules the process's selectivity and total flux. Nevertheless, the latest throughput for MD process is fairly low compared to RO process due to insufficient membrane features causing unfavourable economics and higher flux to the process. Although the MD process has the benefits of operation under low atmospheric pressure and temperature, able to endure high brine concentration as well as solar heat or waste heat utilization for operations, MD process suffers from the shortcoming of low membrane yield [43]. It is vital for membranes produced for MD process to possess appropriate structural chemistry in order to obtain high performance. In order to solve these concerns, numerous research groups contributed on novel membrane enhancement using exceptional techniques of fabrication as well as adapting appropriate nanomaterials, which offers membrane structural chemistry control, all of which are the significant in MD performance enhancement [32]. Solar heating-assisted MD desalination system schematic is shown in Figure 2.

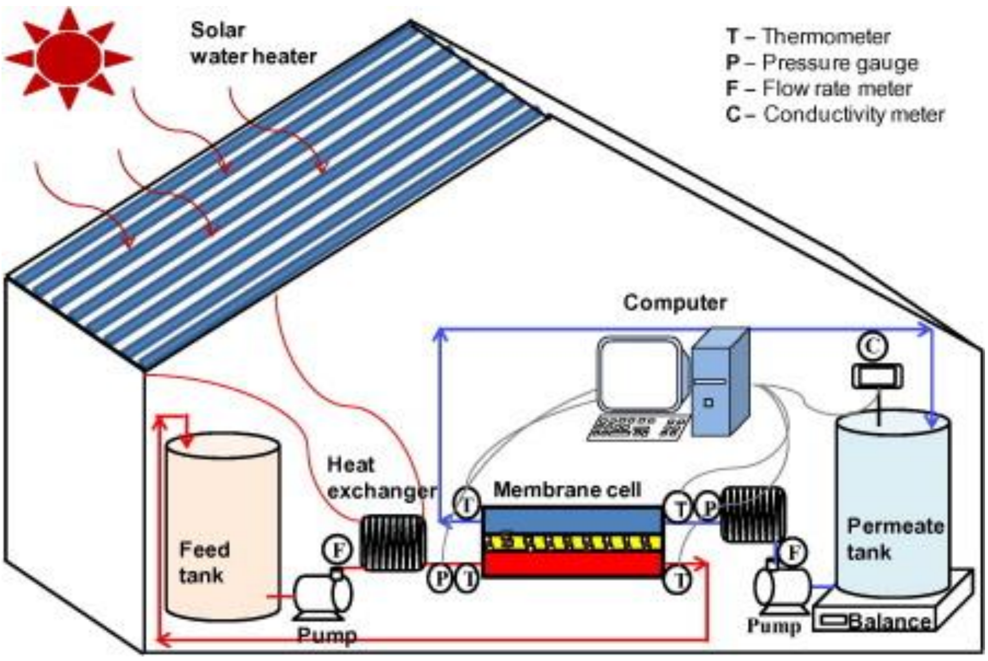

Fig. 2. A schematic of a solar heating-assisted MD desalination system [44]

Membrane process utilization in numerous technologies of desalination play an important role especially RO which has the most market share worldwide (60–90%). MSF and MED technology are the leading desalination Gulf countries compared to other processes of thermal evaporative. Nevertheless, restrictions of the RO as well as the other thermal evaporative processes offers various opportunity for other upcoming membrane-based desalination processes for instance forward osmosis (FO), pressure-retarded RO (PRO), membrane capacitive deionization (MCDI), nanofiltration (NF), electrodialysis (ED), pervaporation, etc. [32]. Lately, forward osmosis (FO) gained rising attention as a developing technique of purification with thorough investigation on desalination were conducted in by academicians as well as in the industrial sectors [9]. Initially, the technology was proposed as a breakthrough technology in terms of low consumption of power with high recovery of water, nevertheless, tests related to membrane back salt diffusion, regeneration of membrane and recovery of draw solution restrict its energy feasibility and efficiency for desalination. Compared to the old RO process which needs high hydraulic pressure, FO spontaneously occurs as it runs under osmotic pressure, therefore decreasing scaling of fouling as well as brine discharge [3]. FO process possess similarity to RO in terms of process necessities. FO entails separation of two fluids via selectively permeable membrane with various osmotic pressure with two-step purification process, i.e., draw solution dilution and fresh water generation via draw solution purification. Although operation cost and FO desalination plant construction is lower than the old RO plants, requirements of energy in recovering water causes a huge concern [44-46].

3. Future Prospects

Water and energy interrelationship significantly intensify due to its economical, regional as well as ecological implications. The advantages of high-quality desalinated water over brackish water (direct use) are the negative impacts on crops and soils can be reduced, salty soils can be recovered and less water consumption is required Other than that, desalinated water is independent of the weather which makes it a sustainable water resource specifically for drought countries. Besides, the quality and productivity of crops can be enhanced using desalinated water. The agriculture sector does not require water with drinking water quality and for most cases, partial desalination water is enough especially for salt-resistant crops. Primary concerns in the development of sustainable desalination technology are: lowering energy usage, minimizing the impact to the environment as well as minimizing the costs for water production. Membrane as well as membrane-based technologies are broadly implemented in numerous applications of waste treatment and water purification, either as individual process or combined with other processes. Nowadays, membrane processes for example MD, RO, NF, UF and FO are adapted in the application of waste water treatment and seawater desalination. Effective membrane technologies utilization as sustainable answer for various applications entails novel membrane materials as well as customized separation characteristics. Even though, significant enhancement in desalination area is observed based on salt rejection and high rate of permeation, membranes having distinct and controlled pores, custom-made functionalities as well as clear passage channels for specific constituents could results in purification, separation enhancement, and important product recovery from numerous resources. Latest enhancements in polymeric materials as well as the rise of nanomaterials offer various applications for membrane-based processes with promising industrial usage. Nevertheless, new membrane materials fabrication having upgraded thermal and chemical stability for industrial effluents treatment requires future exploration. According to specific applications requirements, water quality is able be monitored and another water treatment should be applied, which indicates an open challenge. Although it has its benefits, enormous efforts are still needed for mitigation purposes of certain crucial concerns for example selectivity, fouling, polarization in membrane desalination process cases as well as high recovery according to the treated feed amount. Membrane processes is crucial in both generations of sustainable energy and purification of water either used individually or combined with other techniques of membrane-based or through low-cost heat sources utilization for the purpose of making the process more economical and viable for industrial implementations. Membranes begin to be significant energy sectors from the production of biofuel until the application of fuel cell. In these sectors, their performance is based on the availability and the quality of the membrane components, therefore it is crucial to obtain the synthesis of highly chemical, oxidative resistant materials and thermal. As a summary, membrane-based techniques proposed avenues for sustainable environment development with respect to energy generation and water treatment offering continuous challenges for membrane technologist and material scientists to construct new and robust materials with economical hybrid processes.

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References
[1] Abdalla, Abdalla M., Shahzad Hossain, Ozzan B. Nisfindy, Atia T. Azad, Mohamed Dawood, and Abul K. Azad. "Hydrogen production, storage, transportation and key challenges with applications: a review." *Energy Conversion and Management* 165 (2018): 602-627.
[2] Lu, G. Q., JC Diniz Da Costa, Mikel Duke, S. Giessler, R. Socolow, R. H. Williams, and T. Kreutz. "Inorganic membranes for hydrogen production and purification: a critical review and perspective." *Journal of Colloid and Interface Science* 314, no. 2 (2007): 589-603.
[3] Ravanchi, Maryam Takht, Tahereh Kaghazchi, and Ali Kargari. "Application of membrane separation processes in petrochemical industry: a review." *Desalination* 235, no. 1-3 (2009): 199-244.
[4] Achilias, D. S., Ch Roupakias, P. Megalokonomos, A. A. Lappas, and E. V. Antonakou. "Chemical recycling of plastic wastes made from polyethylene (LDPE and HDPE) and polypropylene (PP)." *Journal of Hazardous Materials* 149, no. 3 (2007): 536-542.
[5] Ajanovic, Amela, and Reinhard Haas. "Economic prospects and policy framework for hydrogen as fuel in the transport sector." *Energy Policy* 123 (2018): 280-288.
[6] He, Xuezhong. "Techno-economic feasibility analysis on carbon membranes for hydrogen purification." *Separation and Purification Technology* 186 (2017): 117-124.
[7] Burra, Kiran Raj G., Ghada Bassioni, and Ashwani K. Gupta. "Catalytic transformation of H2S for H2 production." *International Journal of Hydrogen Energy* 43, no. 51 (2018): 22852-22860.
[8] Haider, Shamim, Arne Lindbråthen, and May-Britt Hägg. "Techno-economical evaluation of membrane based biogas upgrading system: A comparison between polymeric membrane and carbon membrane technology." *Green Energy & Environment* 1, no. 3 (2016): 222-234.
[9] Roy, Sagar, and Smruti Ragunath. "Emerging membrane technologies for water and energy sustainability: future prospects, constrains and challenges." *Energies* 11, no. 11 (2018): 1-32.
[10] Grewe, Tobias, Mariem Meggouh, and Harun Tueysuez. "Nanocatalysts for solar water splitting and a perspective on hydrogen economy." *Chemistry–An Asian Journal* 11, no. 1 (2016): 22-42.
[11] Hong, Miao, and Eugene Y-X. Chen. "Chemically recyclable polymers: a circular economy approach to sustainability." *Green Chemistry* 19, no. 16 (2017): 3692-3706.
[12] Hottle, Troy A., Melissa M. Bilec, and Amy E. Landis. "Sustainability assessments of bio-based polymers." *Polymer Degradation and Stability* 98, no. 9 (2013): 1898-1907.
[13] Sołowski, Gaweł, Marwa S. Shalaby, Heba Abdallah, Ahmed M. Shaban, and Adam Cenian. "Production of hydrogen from biomass and its separation using membrane technology." *Renewable and Sustainable Energy Reviews* 82 (2018): 3152-3167.
[14] Acar, Canan, and Ibrahim Dincer. "The potential role of hydrogen as a sustainable transportation fuel to combat global warming." *International Journal of Hydrogen Energy* (2018).
[15] Dunn, Seth. "Hydrogen futures: toward a sustainable energy system." *International Journal of Hydrogen Energy* 27, no. 3 (2002): 235-264.
[16] Sazali, N., W. N. W. Salleh, A. F. Ismail, K. Kadirgama, F. E. C. Othman, and N. H. Ismail. "Impact of stabilization environment and heating rates on P84 co-polyimide/nanocrystaline cellulose carbon membrane for hydrogen enrichment." *International Journal of Hydrogen Energy* 44, no. 37 (2019): 20924-20932.

[17] Sazali, N., W. N. W. Salleh, A. F. Ismail, K. C. Wong, and Y. Iwamoto. "Exploiting pyrolysis protocols on BTDA-TDI/MDI (P84) polyimide/nanocrystalline cellulose carbon membrane for gas separations." *Journal of Applied Polymer Science* 136, no. 1 (2019): 46901.
[18] Ismail, N. H., W. N. W. Salleh, N. Sazali, A. F. Ismail, N. Yusof, and F. Aziz. "Disk supported carbon membrane via spray coating method: Effect of carbonization temperature and atmosphere." *Separation and Purification Technology* 195 (2018): 295-304.
[19] Muradov, N. "Emission-free fuel reformers for mobile and portable fuel cell applications." *Journal of Power Sources* 118, no. 1-2 (2003): 320-324.
[20] Baysan, Serdar, Ozgur Kabadurmus, Emre Cevikcan, Sule Itir Satoglu, and Mehmet Bulent Durmusoglu. "A simulation-based methodology for the analysis of the effect of lean tools on energy efficiency: An application in power distribution industry." *Journal of Cleaner Production* 211 (2019): 895-908.
[21] Saeidi, Samrand, Nor Aishah Saidina Amin, and Mohammad Reza Rahimpour. "Hydrogenation of CO2 to value-added products—A review and potential future developments." *Journal of CO2 Utilization* 5 (2014): 66-81.
[22] Musioł, Marta, Wanda Sikorska, Henryk Janeczek, Wojciech Wałach, Anna Hercog, Brian Johnston, and Joanna Rydz. "(Bio) degradable polymeric materials for a sustainable future–part 1. Organic recycling of PLA/PBAT blends in the form of prototype packages with long shelf-life." *Waste Management* 77 (2018): 447-454.
[23] Yazdanifard, Farideh, Mehran Ameri, and Ehsan Ebrahimnia-Bajestan. "Performance of nanofluid-based photovoltaic/thermal systems: A review." *Renewable and Sustainable Energy Reviews* 76 (2017): 323-352.
[24] Roy, Sagar, and Smruti Ragunath. "Emerging membrane technologies for water and energy sustainability: Future prospects, constraints and challenges." *Energies* 11, no. 11 (2018): 2997.
[25] Haider, Shamim, Arne Lindbråthen, Jon Arvid Lie, Ingerid Caroline Tvenning Andersen, and May-Britt Hägg. "CO2 separation with carbon membranes in high pressure and elevated temperature applications." *Separation and Purification Technology* 190 (2018): 177-189.
[26] Sazali, N., W. N. W. Salleh, M. Nur Izwanne, Z. Harun, and K. Kadirgama. "Precursor selection for carbon membrane fabrication: a review." *Journal of Applied Membrane Science & Technology* 22, no. 2 (2018).
[27] Padaki, Mahesh, R. Surya Murali, Ms S. Abdullah, Nurasyikin Misdan, A. Moslehyani, M. A. Kassim, Nidal Hilal, and A. F. Ismail. "Membrane technology enhancement in oil–water separation. A review." *Desalination* 357 (2015): 197-207.
[28] Ilbeygi, Hamid, Mostafa Ghasemi, D. Emadzadeh, Ahmad Fauzi Ismail, S. M. J. Zaidi, Saad A. Aljlil, Juhana Jaafar, Darren Martin, and Samaneh Keshani. "Power generation and wastewater treatment using a novel SPEEK nanocomposite membrane in a dual chamber microbial fuel cell." *International Journal of Hydrogen Energy* 40, no. 1 (2015): 477-487.
[29] Said, Z., R. Saidur, A. Hepbasli, and N. A. Rahim. "New thermophysical properties of water based TiO2 nanofluid—The hysteresis phenomenon revisited." *International Communications in Heat and Mass Transfer* 58 (2014): 85-95.
[30] Powell, Clem E., and Greg G. Qiao. "Polymeric CO2/N2 gas separation membranes for the capture of carbon dioxide from power plant flue gases." *Journal of Membrane Science* 279, no. 1-2 (2006): 1-49.
[31] Shao, Lei, Jon Samseth, and May-Britt Hägg. "Crosslinking and stabilization of high fractional free volume polymers for gas separation." *International Journal of Greenhouse Gas Control* 2, no. 4 (2008): 492-501.
[32] Yang, Zhe, Xiao-Hua Ma, and Chuyang Y. Tang. "Recent development of novel membranes for desalination." *Desalination* 434 (2018): 37-59.
[33] Al-Shamrani, A. A., A. James, and H. Xiao. "Destabilisation of oil–water emulsions and separation by dissolved air flotation." *Water Research* 36, no. 6 (2002): 1503-1512.
[34] Loeb, Sidney, Leonid Titelman, Emmanuel Korngold, and Joseph Freiman. "Effect of porous support fabric on osmosis through a Loeb-Sourirajan type asymmetric membrane." *Journal of Membrane Science* 129, no. 2 (1997): 243-249.
[35] Khulbe, Kailash Chan, and Takeshi Matsuura. "Recent progress in polymeric hollow-fibre membrane preparation and applications." *Membrane Technology* 2016, no. 7 (2016): 7-13.
[36] Song, Chengwen, Tonghua Wang, Yanqiu Pan, and Jieshan Qiu. "Preparation of coal-based microfiltration carbon membrane and application in oily wastewater treatment." *Separation and Purification Technology* 51, no. 1 (2006): 80-84.
[37] Yang, Wenbo, Nazim Cicek, and John Ilg. "State-of-the-art of membrane bioreactors: Worldwide research and commercial applications in North America." *Journal of Membrane Science* 270, no. 1-2 (2006): 201-211.
[38] Hua, F. L., Yiu Fai Tsang, Y. J. Wang, S. Y. Chan, H. Chua, and S. N. Sin. "Performance study of ceramic microfiltration membrane for oily wastewater treatment." *Chemical Engineering Journal* 128, no. 2-3 (2007): 169-175.
[39] Wu, Yonghong, Xiaoyu Zhang, Shanshan Liu, Bing Zhang, Yunhua Lu, and Tonghua Wang. "Preparation and applications of microfiltration carbon membranes for the purification of oily wastewater." *Separation Science and Technology* 51, no. 11 (2016): 1872-1880.

[40] Salahi, Abdolhamid, Mohsen Abbasi, and Toraj Mohammadi. "Permeate flux decline during UF of oily wastewater: Experimental and modeling." *Desalination* 251, no. 1-3 (2010): 153-160.
[41] Abadi, Sareh Rezaei Hosein, Mohammad Reza Sebzari, Mahmood Hemati, Fatemeh Rekabdar, and Toraj Mohammadi. "Ceramic membrane performance in microfiltration of oily wastewater." *Desalination* 265, no. 1-3 (2011): 222-228.
[42] Ba, Chaoyi, James Langer, and James Economy. "Chemical modification of P84 copolyimide membranes by polyethylenimine for nanofiltration." *Journal of Membrane Science* 327, no. 1-2 (2009): 49-58.
[43] Fu, Ywu-Jang, Sheng-Wen Hsiao, Chien-Chieh Hu, Kueir-Rarn Lee, and Juin-Yih Lai. "Prediction of long-term physical aging of poly (methyl methacrylate) membranes for gas separation." *Desalination* 234, no. 1-3 (2008): 51-57.
[44] Shim, Wang Geun, Ke He, Stephen Gray, and Il Shik Moon. "Solar energy assisted direct contact membrane distillation (DCMD) process for seawater desalination." *Separation and Purification Technology* 143 (2015): 94-104.
[45] Nurul Ain Mazlan, Khairul Faezah Md Yunos, Mohd Nazli Mohd Naim, Azhari Samsu Baharuddin. "Performances of Sandwich Membrane in Reclamation of Water from Final Discharged POME." *Journal of Advanced Research in Materials Science* 47, no. 1 (2018): 1-8.
[46] A. M. Alamaria, M. G. Mohd Nawawi, Z. Zamrud. "Chemical Cross-linking of Sago/PVA Blend Membrane for Pervaporation Separation of Water from Ethyl Acetate Mixture." *Journal of Advanced Research in Materials Science* 1, no.1 (2014): 14-21.