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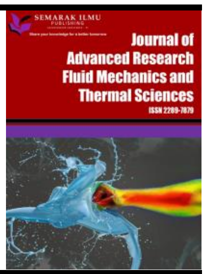

Novel Multi-Channel Coated Silica Based Membranes Applied for Peat Water Ultrafiltration

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ABSTRACT

South Kalimantan-Indonesia is in the Southern part of Borneo which almost half of the population lives in remote areas. Geographically, people are isolated and have poor access to electricity as well as a clean water supply. It is very essential to ensure the availability of clean water produced from peat water to overcome future water shortages. This work performs the fabrication of multi-channel silica-based membranes applied for peat water ultrafiltration which is demonstrated under various transmembrane pressure (TMP) and top layer types. The silica based top layer membranes were fabricated from three different sources (silica-pectin, organosilica, and pure silica) via dipcoating method onto macroporous multi-channel alumina support (4 bore). Peat water was treated by multi-channel membranes through ultrafiltration process through cross flow system. According to the results, all multiples top layer pore size were obtained with range from 2.1 to 6 nm classified as mesoporous membranes. This process exhibited a promising outcome for removal natural organic matter (NOM) about 89-71% (UV_{254} rejection) at TMP 1-3 bar, respectively. Besides that, normalized permeate fluxes of that membrane excellently stable over 180 min operation time. It is concluded that silica based multichannel membranes are either compatible to treat peat water that has high number of NOM as well as excellent to overcome membrane fouling.

1. Introduction

Half of the population in South Kalimantan, Indonesia lives in rural areas, which agriculture and fishery are the main source of income. They are often geographically isolated and lack access to clean water supply. Mostly rural homes may use water from river or peatland water. However, this is typical only done during a well or dry season is not available. Moreover, direct consumption of peat water is not advisable due to its characteristic rich by organic substances. There are multiple techniques to remove organic substances such as chemical process; chemical coagulation; biological

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process; such as activated sludge, and physical process; mainly filtration [1,2]. Therefore, a versatile water treatment technology like membrane separation is useful in this case [3-5].

Ultrafiltration is a membrane technology widely used as pretreatment or primer process in water purification plants [3,6-8]. This technology provides the attracting features of simple operation, less energy consumption, lower footprint, and lower cost [9-14]. Silica is an interesting material to applicates as ultrafiltration membrane, due to provide good molecular sieving, robust, resistant to high temperature and chemical, and more antifouling over polymer-based membrane [15]. Nevertheless, silica membrane also has a major drawback which has low stability when contacted with water [16].

Several strategies have been demonstrated to overcome the disadvantage of silica membrane by carbon template [17] and carbon hybrid silica membrane [18]. Carbon templated silica are considerably as an excellent strategy for membranes preparation applied for water treatment due to the hydrostability of the silica membrane is enhanced [10,13,15,19-29]. Furthermore, the hybrid carbon-silica membranes prepared from citric acid as catalyst is also produced carbon groups. This aims to strengthen the silica matrix [30,31]. The pure silica membrane applied for natural wetland water desalination is firstly reported by Elma and Assyaifi [32]. Then, other study was employed pectin from banana peels, citric acid and copolymer P123 as a carbon source which was incorporated into a silica matrix to enhance the hydrostability [24,29,33,34]. Other than that, banana peel is condsiderability for water clarification due to highly potential application as carbon carbon agent and bio-flocculant for water clarification [35]. Assyaifi *et al.,* [36] has been also reported, pectin could increase silica membrane performance for wetland saline water desalination via photocatalytic-pervaporation. The previous study have been succeed to fabricate silica-pectin membrane applied for wetland saline water desalination via pervaporation method [11,26,37-39]. Sumardi *et al.,* [10] has been successfully demonstrated organosilica membranes fabricated by addicted citric acid as acid catalyst applicated for water desalination. All of previous studies have shown carbon-silica based membranes fabricated with single channel tubular configuration, none of them have multichannel tubular configuration.

Commercially, tubular membrane support configuration has multiple type such as single and multichannel [21,31,34,38,40-50]. Multichannel tubular membrane offers high surface area than single one. Due to that, multi-channel membrane might potentially to developed and implemented for scaled up to provide potable water among rural communities. Multichannel membranes provide the bore more than one that effected the surface area of the membrane increase and produce higher flux than single channel membrane [51]. The objectives of this work are to investigate the characterization and morphology of pure silica membranes and excellent hydrostability membranes derived from pectin and organosilica fabricated employing multichannel tubular configuration. In addition, this work also demonstrates the performance of these membranes applied for peat water treatment via ultrafiltration process.

2. Methodology

2.1 Materials

The preparation of silica-based sols and membranes were conducted using primer of chemicals and materials such as: silica precursor from TEOS-tetraethyl orthosilicate (99% purchased from Sigma-Aldrich), organic solvent ethanol (96%, distribution from local company PT. Sumber Kita Indah, Bekasi-Indonesia), and demineralized water. Citric acid was purchased from Sigma-Aldrich and nitric acid obtained from Merck as acid catalyst, while base catalyst using ammonia purchased from Merck. Pectin as carbon template agent extracted from local banana peels waste [52]. Multichannel alumina membrane support (four bores, α-Al_2O_3 tubular substrate) was purchased from Ceramic Oxide Fabricators, Bendigo-Australia. Meanwhile, peat water as feed for ultrafiltration experiment was collected from Jalan Suka Maju, Banjarbaru, South Kalimantan-Indonesia at GPS coordinate of -3.405418, 114.719799.

2.2 Silica-Based Sols Preparation and Characterization

Preparation of silica-based sols were conducted via sol gel method. There are three types of thin film were used in this work, the composition and properties of all thin film are shown in Table 1, while the detail procedure of sols preparation can be seen in the previous work [11,15,49]. In order to characterize silica-based sols, the multiple sols were dried for overnight at 60 °C by oven, followed by grounded the dried sols to be powder. The dried silica-base sols then named as xerogel, afterward the varied silica-based xerogels were sintered under air condition at 600 °C for pure silica xerogel. In other hand, organosilica xerogels was sintered at 175 °C while silica-pectin at 300 °C under vacuum condition by furnace for an hour. These all xerogels sample were characterized by FTIR (Fourier Transform Infrared) – Bruker Alpha spectrometer at wavenumber range of 600–2000 cm^{-1} to functionalize the chemical properties of xerogels and the deconvolution of silanol/siloxane peaks derived from FTIR data. Then these data were curved fitting using Fityk software program by Gaussian approach to determine the quantitative of peak area ratio of functional group.

Tabel 1
The silica-based thin film composition and properties in this work

	Pure silica	Organosilica	Silica-pectin
Ref	Elma *et al.,* [49]	Elma *et al.,* [15]	Mustalifah *et al.,* [11]
Acid catalyst	Nitric acid (0.00078 N)	Citric acid (0.001 N)	Nitric acid (0.00078 N)
Base catalyst	NH_3 (0.0003 N)	NH_3 (0.0003 N)	NH_3 (0.0003 N)
Templated agent	-	-	Banana peel pectin
Calcination temp (°C)	600 (air)	175 (vacuum)	300 (vacuum)
Active surface area m^2	0.002		
Alumina substrate configuration	Multichannel (4 bores)	Multichannel (4 bores)	Multichannel (4 bores)

2.3 Multichannel Silica-Based Membranes Fabrication and Characterization

Fabrication of silica-based membranes were undertaken by coated the inner surface of multichannel support using silica-based thin film were have been prepared in 2.2 sub section. In this work, it has been prepared three types of membranes which coated by pure silica, organosilica and silica-pectin sols that every type membrane was producing 4 coating layers. Membrane was calcined under vacuum condition in every layer of coating by using furnace at different temperature 600, 175 and 300 °C for pure silica, organosilica and silica-pectin, respectively. The schematic of inner coating equipment of membrane fabrication displays in Figure 1. The morphology of multichannel silica-based membranes was determined by scanning electron microscopy (SEM, ZEISS).

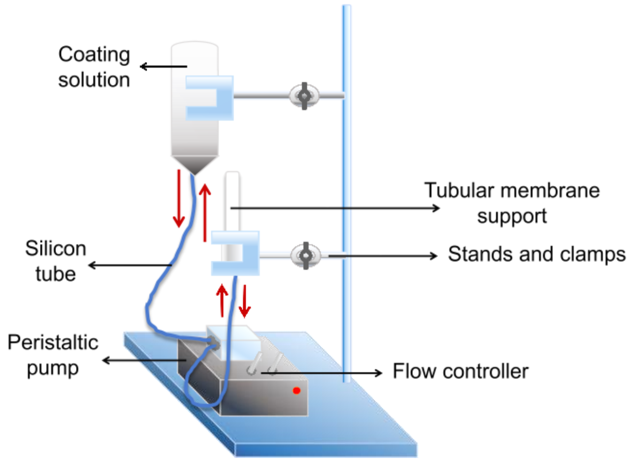

Fig. 1. Schematic for inner coating set up of multichannel silica-based membrane fabrication

2.4 Multichannel Silica-based Membranes Performance for Peat Water Ultrafiltration

Performance of multichannel silica-based membranes for peat water treatment processed by ultrafiltration. Schematic of laboratory-scale ultrafiltration set-up for testing peat water can be shown in Figure 2. A tubular module was placed as reactor for separation of natural organic matter that therein containing of multichannel silica-based membrane. Ultrafiltration of multichannel silica-based membranes were tested by cross flow system at different transmembrane pressure (TMP) 1-3 bar for an hour filtration time at room temperature (25 °C ± 2 °C). To supply the pressure for filtration, the system completed with booter pump, meanwhile the permeate volume was collected every 5 min.

The permeate flux (J, $Lm^{-2}h^{-1}bar^{-1}$) was calculated according the Eq. (1), where V is a permeate volume (L), A the membrane active surface area (m^2) and Δt is operation time (h). Whereas, the rejection of contaminant (R, %) was determined using Eq. (2), where Cf and Cp are the feed and permeate value of UV absorbance 254, respectively. The UV_{254} parameter was measured using Spectrophotometer Genesys 10S UV-Vis.

$$J= V/(A.\Delta t) \quad (1)$$

$$R= (Cf-Cp)/Cf \times 100\%, \quad (2)$$

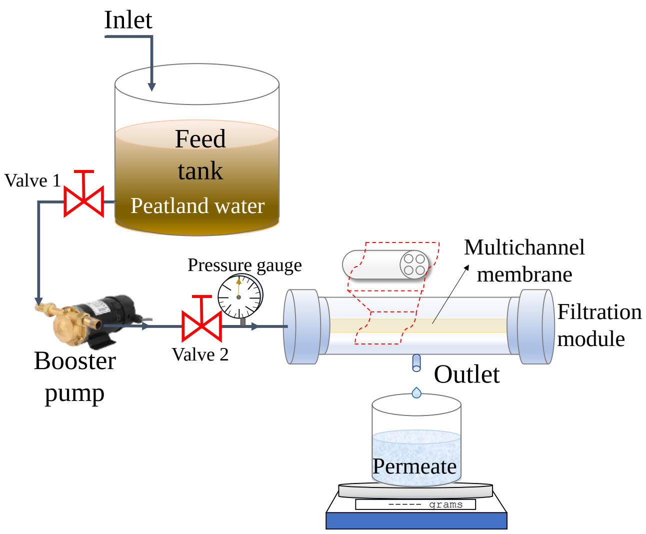

Fig. 2. Illustration of ultrafiltration equipment for peat water treatment using multichannel silica-based membranes

3. Results and Discussion

3.1 Silica-Based Membranes Functionalization and Deconvolution

In this work, three type of thin film (pure silica, organosilica, silica-pectin) were generated to compare the multiple xerogels characterization for fabrication of multichannel membranes. The all variation of thin film were chosen from the optimum sample in the previous work which applied for water desalination [11,15,49]. Pure silica xerogel was interpretated the silica membrane without the addition of template agent in order to enhance the hydrostability of silica matrix. Meanwhile, the organosilica and silica-pectin xerogels were represented the addition of carbon into silica matrix by hybrid (organosilica) and template (silica-pectin) strategies for each thin film type in order to improve the silica matrix stabilization in water.

Fundamentally, the silica matrix structure has high concentration of the surface hydrophilic silanol (Si-OH) species that contributes to decrease the hydrostable of silica structure during contacted with H_2O molecules [21]. FTIR spectra was examined to investigate the presence of silanol and other species were generated from multiple xerogels of silica-based sample. Functional groups of silica-based xerogels were prepared via sol gel method exhibits on Figure 3(a) to representative of FTIR spectra in range of 600-2000 cm^{-1}. The three of xerogels sample (pure silica, organosilica, and silica-pectin) xerogels presented several functional groups that are silanol (Si-HOH), siloxane (Si-O-Si), and silica-carbon (Si-C). The lower peak of Si-C was displayed on Figure 3(a) for pure silica xerogel, due to there is no carbon addition likes other two sample for organosilica from citric acid and silica-pectin xerogels from pectin loading. Organosilica and silica-pectin xerogels resulted to generate Si-C stretching vibration at wavelength 779 and 795 cm^{-1}, respectively. The functionalization peaks of silica-carbon bands are risen because the wagging mode of the carbon attached to Si which similar result also can be found to previous study [53].

The silanol and siloxane groups were formed via reaction of hydrolysis and water and alcohol condensation during the sol-gel process. The Si-O-Si stretching linear vibration also can be encountered at 1063-1077 cm^{-1} wavelength as either reported in previous results on silica membranes-based materials [16,17,54]. The silanol (Si-OH) peaks appear at shoulder of Si-O-Si peak near 946-966 cm^{-1} for all varied xerogels sample as displays on Figure 3(a). Siloxane is formed by water and alcohol condensation reaction when sol-gel process. Meanwhile, the silanol was obtained from the hydrolysis reaction at first-step process by addiction of acid catalyst (nitric acid and citric acid for preparation of (pure silica and silica-pectin) and organosilica, respectively. Addition of acid catalyst into the silica sol promoted the rate of the hydrolysis reaction [22]. The addiction of pectin and carbon derived from citric acid into silica matrices contributes to enhance the hydrostability of silica matrices that is proved by the presence of Si-O bond, where Figure 3(b) is the deconvolution peak ratio of silanol/siloxane. It is appropriated to the lates study that reported elsewhere [17]. This finding can also be explained as good indication to improve silica network and perform more stable material applied for water treatment.

Interestingly, Figure 3(b) shows the green scatter of plotting peak area ratio of Si-OH/Si-O-Si, while pink scatter appears the area of silanol or Si-C peak shown at wavelength of ~790 cm^{-1}. The lower peak area ratio of silanol over siloxane obtained for the silica-pectin xerogels, whereas the higher for pure silica xerogels sample. The lower area ratio of silanol over siloxane was indicated the presence of siloxane species dominated the silica structure compare to silanol. It can be concluded that the hydrostability of silica structure may led become excellent related to pure silica [10].

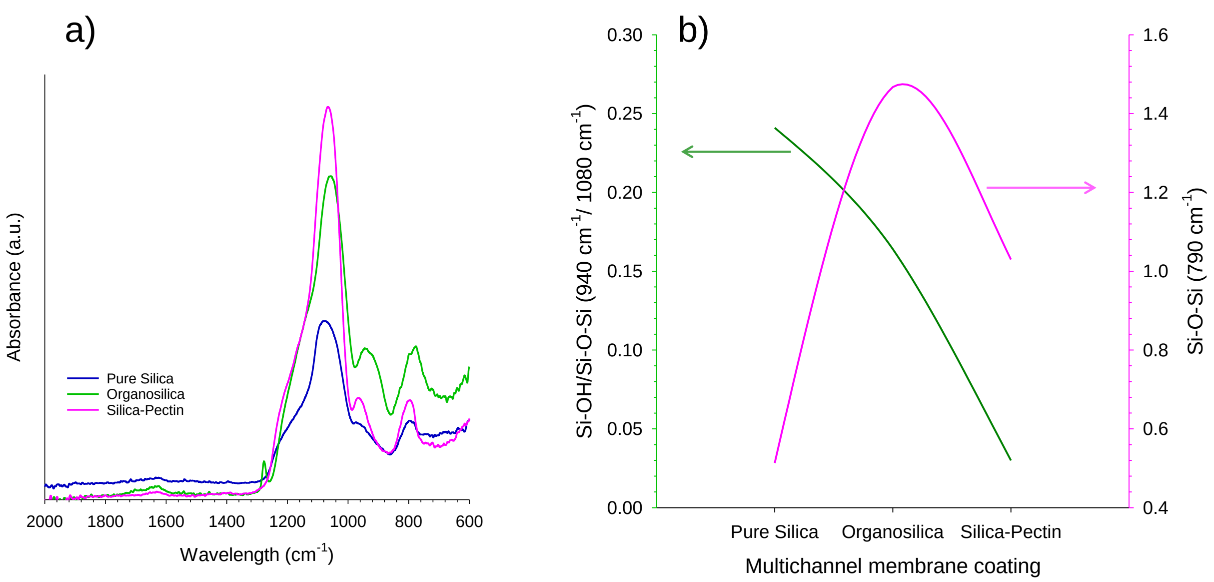

Fig. 3. (a) The Fourier-transform infrared spectroscopy spectra of silica based xerogels calcined in vacuum with their (b) area ratios between silanol (940 cm^{-1}) and siloxane (1080 cm^{-1}) in green and in pink for area of siloxane at 790 cm^{-1}

3.2 Multichannel Silica-Based Membranes Morphology Structure, BET Properties and Pure Water Permeability

Figure 4 performs the SEM images of all multichannel silica-based membranes surface area that indicates the morphology structure. The surface morphology of pure silica membrane looks smoothers than organosilica and silica-pectin membranes (Figure a, b, and c). It is due to the SEM image on Figure 4(b) and (c) containing carbon, so the surface of top layer become rougher than Figure 4(a). This result also similar to other work which employed pectin from apple as carbon template to fabricate silica-pectin membranes [55].

The outlook image of the membranes is presented in high resolution to display the effect of the coating on inner surface of the multichannel substrate. In all of Figure 4 the coated membrane of multichannel silica-based membranes can be seen the top layer have the roughness and boulders of the alumina particles substrate protruding on multiples membrane surface. Moreover, the top layer of all membranes looks not delicate due to its membranes were coated without interlayer, or called as interlayer-free as first time reported by Elma *et al.,* [22].

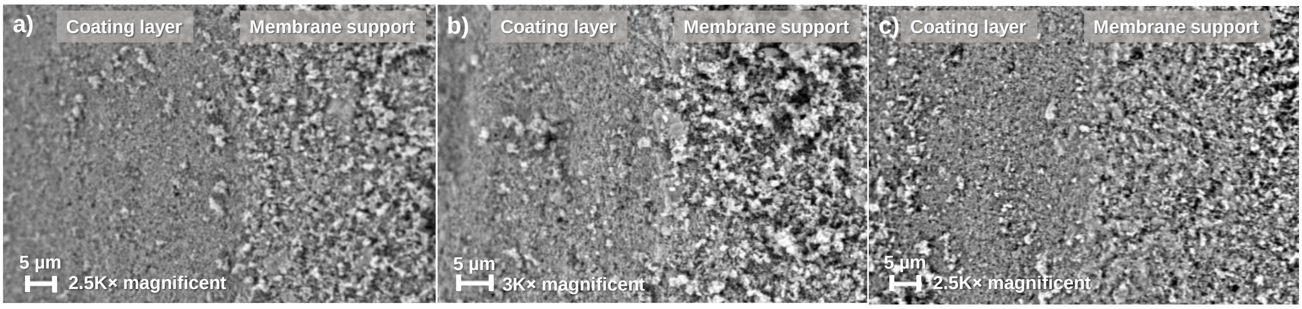

Fig. 4. The scanning electron microscope images of (a) pure silica; (b) organosilica; and (c) silica-pectin multi-channel membrane calcined in vacuum

The surface properties of the xerogels were observed by BET N_2 physisorption. The list of BET surface areas, average pore size, and pore volumes of silica-based bulk xerogels is writen in Table 2. The highest BET surface area obatained from silica-pectin xerogels (2.5 to 4 time higher than organosilica and pure silica xerogels), respectively. The BET surface areas of pure silica and organosiica in this work are slightly lower than pure silica and organosilica xerogels prepared by Elma *et al.,* [50] and Elma *et al.,* [47], respectively. It is due to the pure silica xerogels synthesized by previous study was prepared under vacuum using conventional thermal processing (CTP) technique. In other hand, the organosilica by Elma *et al.,* [47] fabricated at different calcination temperature of 250 °C. Beside that, the pore volume of silica-pectin xerogels also shows higher than other samples of 0.71392 cm^3/g (Table 2). These results caused by the addiction of pectin template into silica sols and brings the xerogel tend to form mesoporous. That is proved by the average pore size of silica-pectin also wider than pure silica and organosilica pore size about 3 fold times bigger. The bigger average pore size of silica-pectin will be collided with the membrane performance.

Table 2
Surface properties of bulk silica-based xerogels in varied type sols

Samples	BET surface area (m^2/g)	Pore volume (cm^3/g)	Pore size (nm)
Pure Silica	101.1553	0.054508	2.1554
Organosilica	221.9961	0.119156	2.147
Silica-Pectin	470.2607	0.71392	6.07254

From the results shown in Figure 5, it was apparent that TMP influenced the pure water permeability, and the performance of this membrane for treating peat water was investigated on Figure 6, using multiple TMPs (1-3 bar). The membrane permeability is an important factor to be considered during the ultrafiltration process. It is performed that the pure water permeate flux is increased by the raising of TMP. The gradient of the dash line represented pure water permeability of the silica-based membranes, which the results shown sufficient fit with Darcy's law, with R^2 of 0.976, 0.9737 and 0.9868, for varied multichannel membrane that coated by pure silica, organosilica and silica-pectin sols, respectively. These results indicated that transmembrane pressures ranging from 1 to 3 bar was very suitable for further ultrafiltration experiments.

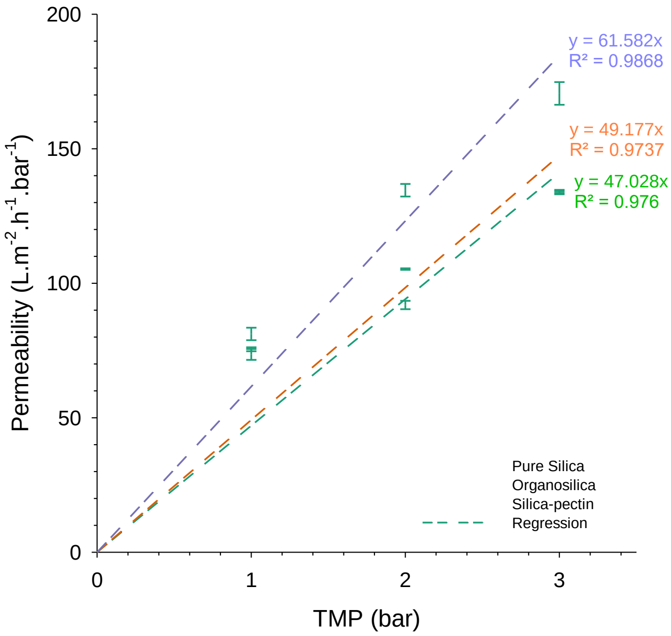

Fig. 5. The effect of the transmembrane pressure (TMP) on the pure water permeability of various multichannel membranes thin film coating

3.3 Multichannel Silica-Based Membranes Performance for Peat Water Ultrafiltration

From the results shown in Figure 6, it was apparent that TMP influenced the permeate flux, and the performance of all multichannel silica-based membranes for treating peat water at different TMP. It is observed that the permeate fluxes gradually arise by increasing TMP. It is due to the driving force from TMP contributes to improve the hydraulic efficiency on ultrafiltration membrane and led the fluxes to increase [56]. The highest permeate flux was obtained from multichannel silica-pectin membrane at TMP 3 bar (96 $Lm^{-2}.h^{-1}.bar^{-1}$).

Furthermore, all UV_{254} rejection of multichannel silica-based membranes obtained high as shown in Figure 6 at variation of TMP from 1 to 3 bar. The highest UV_{254} rejection obtained for multichannel organosilica and pure silica membranes over silica-pectin membrane at all TMP minimum 88%. Meanwhile, the multichannel silica-pectin membrane performs the lower UV_{254} rejection of 71% (Figure 6). It could be explained the average pore size of multichannel silica-pectin membrane was bigger than other membrane 3 times. Therefore, the rejection of UV_{254} of multichannel silica-pectin membrane become lower than other membranes rejection.

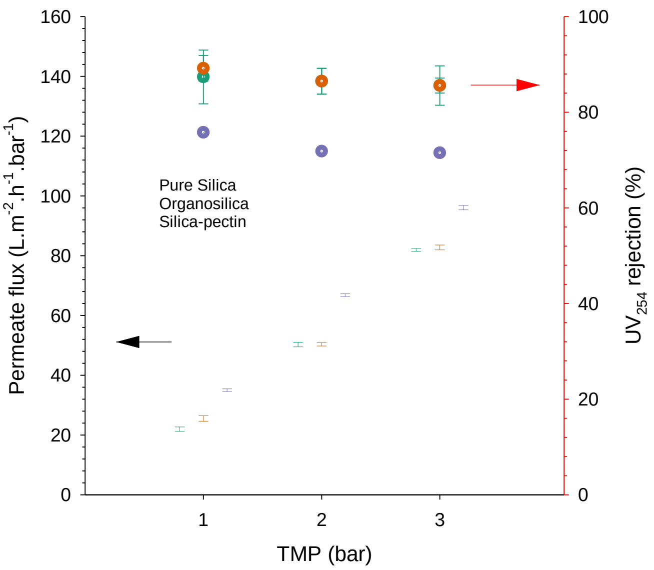

Fig. 6. Membrane performance of multi-channel silica-based membranes in varied thin film coating at different transmembrane pressure (TMP) 0.1, 0.2, and 0.3 bar

Figure 7 demonstrated the normalized permeate fluxes (J_α) of multiple type silica-based membrane as function of filtration time at TMP 3 bar operation condition of peat water as feed. From all of normalized permeate fluxes multichannel silica-based membrane that consists of pure silica, organosilica and silica-pectin exhibit excellent stability for 180 min filtration time of peat water. As shown in Figure 7, the multichannel organosilica membrane performs fluctuated maybe due to the noise of the data, even though the trends of normalize permeate flux still ecellent condition for over 3 hours operation. It proves that all of multichannel silica-based membranes have excellent performance for treating peat water via ultrafiltration process.

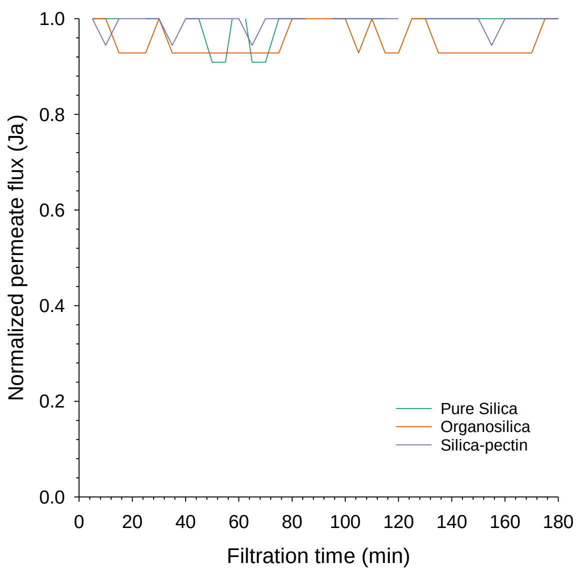

Fig. 7. Performance of silica based membranes on normalized permeate flux variation over time, for various multi-channel thin film coating, at TMP 3 bar

Henceforth, Figure 7 shows excellent performance using all of multichannel silica-based membranes applied for peat water ultrafiltration for over 3 hours. This result indicates that there is no fouling occurred during time operation. Previous work was reported the multichannel ceramic membrane at TMP 1 bar for cattle wastewater ultrafiltration under feed temperature 30 °C shows sharply declining data on normalized permeate flux in the initial 10 min operation time [57]. If comparing to this result, the finding of silica-based membranes performance is much more stable and showing that there is no fouling found during ftreating of peat water for 3 hours of filtration process.

4. Conclusions

Silica based xerogels and multichannel membranes were prepared from the sol-gel method and inner coating technique. The silica based xerogels in this work consisted of pure silica, organosilica and silica-pectin thin film which coated onto multi-channel alumina substrate (four bores) that is calcined under vacuum condition. The application of various multi-channel silica based membranes coating were investigated for treating peatland water via ultrafiltration at multiple transmembrane pressure (TMP) from 1 to 3 bar. The functionalization of all silica-based xerogels were found that there are silanol, siloxane and silica-carbon. While deconvolution of peak area ratio of silanol over siloxane is obtained lower at silica-pectin xerogel. That means that the silica-pectin has lower hydrophilic silanol species than other materials. Also, it brings out the silica structures become more stable attaching in the water. The highest BET surface area, pore volumes and average pore size also obtained from silica-pectin xerogels. It is about 2-4 folds time than pure silica and organosilica. The performance all of multichannel silica-based membrane performs stable for operation test over 180 h at peat water ultrafiltration at TMP 3 bar. Overall, all off membranes shows high natural organic matter rejection by UV_{254} parameter (above 70%) for high TMP. Due to this, the performance of multichannel silica-based membranes are very good for treating peat water treatment via ultrafiltration process at TMP from 1 to 3 bar.

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References

[1] Isa, Eleen Dayana Mohamed, Kamyar Shameli, Roshafima Rasheid Ali, and Vekes Balasundram. "Advances in Nanocellulose Based Materials as Adsorbent for Wastewater Treatment." *Journal of Research in Nanoscience and Nanotechnology* 5, no. 1 (2022): 43-64. https://doi.org/10.37934/jrnn.5.1.4364

[2] Sethu, Vasanthi, Peck Loo Kiew, Swee Pin Yeap, and Lian See Tan. "Time to Get Serious about Sustainable Water Management." *Progress in Energy and Environment* 14, no. 1 (2020): 13-15.

[3] Elma, Muthia, Amalia Enggar Pratiwi, Aulia Rahma, Erdina Lulu Atika Rampun, Mahmud Mahmud, Chairul Abdi, Raissa Rosadi, Dede Heri Yuli Yanto, and Muhammad Roil Bilad. "Combination of coagulation, adsorption, and ultrafiltration processes for organic matter removal from peat water." *Sustainability* 14, no. 1 (2021): 370. https://doi.org/10.3390/su14010370

[4] Mat Nawi, Normi Izati, Afiq Mohd Lazis, Aulia Rahma, Muthia Elma, Muhammad Roil Bilad, Nik Abdul Hadi Md Nordin, Mohd Dzul Hakim Wirzal, Norazanita Shamsuddin, Hazwani Suhaimi, and Norhaniza Yusof. "A Rotary Spacer System for Energy-Efficient Membrane Fouling Control in Oil/Water Emulsion Filtration." *Membranes* 12, no. 6 (2022): 554. https://doi.org/10.3390/membranes12060554

[5] Nabilah, NN Ain, Ratri Rahmawati, M. R. Bilad, A. E. Pratiwi, Muthia Elma, and Norwahyu Jusoh. "Finned spacer panel system for fouling control in Chlorella vulgaris harvesting." In *IOP Conference Series: Materials Science and Engineering* 736, no. 6 (2020): 062009.
[6] Elma, Muthia, Erdina Lulu Atika Rampun, Aulia Rahma, Amalia Enggar Pratiwi, Chairul Abdi, and Raisa Rossadi. "Effect of two stages adsorption as pre-treatment of natural organic matter removal in ultrafiltration process for peat water treatment." In *Materials Science Forum* 988, (2020): 114-121. https://doi.org/10.4028/www.scientific.net/MSF.988.114
[7] Sun, Yangyang, Yan Wang, Nan Xue, Cong Yu, Yingjie Meng, Baoyu Gao, and Qilin Li. "The effect of DOM on floc formation and membrane fouling in coagulation/ultrafiltration process for treating TiO2 nanoparticles in various aquatic media." *Chemical Engineering Journal* 316 (2017): 429-437. https://doi.org/10.1016/j.cej.2017.01.126
[8] Jafari, Ali, Amir Hossein Mahvi, Simin Nasseri, Alimorad Rashidi, Ramin Nabizadeh, and Reza Rezaee. "Ultrafiltration of natural organic matter from water by vertically aligned carbon nanotube membrane." *Journal of Environmental Health Science and Engineering* 13, no. 1 (2015): 1-9. https://doi.org/10.1186/s40201-015-0207-x
[9] Elma, Muthia, Norlian Ledyana Sari, and Dhimas Ari Pratomo. "TEKNOLOGI MEMBRAN ORGANO-SILICA UNTUK DESALINASI AIR ASAM TAMBANG." *Konversi* 8, no. 1. https://doi.org/10.20527/k.v8i1.6508
[10] Sumardi, Anna, Muthia Elma, Erdina Lulu Atika Rampun, Aptar Eka Lestari, Zaini Lambri Assyaifi, Adi Darmawan, Dede Heri Yuli Yanto, Isna Syauqiah, Yanti Mawaddah, and Linda Suci Wati. "Designing a mesoporous hybrid organo-silica thin film prepared from an organic catalyst." *Membrane Technology* 2021, no. 2 (2021): 5-8. https://doi.org/10.1016/S0958-2118(21)00029-X
[11] Mustalifah, F. R., A. Rahma, and M. Elma. "Chemical cleaning to evaluate the performance of silica-pectin membrane on acid mine drainage desalination." In *IOP Conference Series: Materials Science and Engineering* 1195, no. 1 (2021): 012057. https://doi.org/10.1088/1757-899X/1195/1/012057
[12] Huda, N., E. Lulu Atika Rampun, R. Ayu Lestari, Y. Raharjo, D. Heri Yuli Yanto, and M. Elma. "Membrane pervaporation performance applied for brackish water prepared by vacuum impregnation method." In *IOP Conference Series: Materials Science and Engineering* 1195, no. 1 (2021): 012056. https://doi.org/10.1088/1757-899X/1195/1/012056
[13] Razak, Nik Nurul Ain Nabilah, Ratri Rahmawati, Muhammad Roil Bilad, Amalia Enggar Pratiwi, Muthia Elma, Normi Izati Mat Nawi, Juhana Jaafar, and Man Kee Lam. "Finned spacer for enhancing the impact of air bubbles for membrane fouling control in Chlorella vulgaris filtration." *Bioresource Technology Reports* 11 (2020): 100429. https://doi.org/10.1016/j.biteb.2020.100429
[14] Wang, David K., Muthia Elma, Julius Motuzas, Wen-Che Hou, Diego Ruben Schmeda-Lopez, Tianlong Zhang, and Xiwang Zhang. "Physicochemical and photocatalytic properties of carbonaceous char and titania composite hollow fibers for wastewater treatment." *Carbon* 109 (2016): 182-191. https://doi.org/10.1016/j.carbon.2016.08.001
[15] Elma, Muthia, Anna Sumardi, Adhe Paramita, Aulia Rahma, Aptar Eka Lestari, Dede Heri Yuli Yanto, Sutarto Hadi, Zaini Lambri Assyaifi, and Yanuardi Raharjo. "Physicochemical properties of mesoporous organo-silica xerogels fabricated through organo catalyst." *Membranes* 11, no. 8 (2021): 607. https://doi.org/10.3390/membranes11080607
[16] Wijaya, S., M. C. Duke, and JC Diniz da Costa. "Carbonised template silica membranes for desalination." *Desalination* 236, no. 1-3 (2009): 291-298. https://doi.org/10.1016/j.desal.2007.10.079
[17] Elma, Muthia. "Interlayer-free hybrid carbon-silica membranes for processing brackish to brine salt solutions by pervaporation." *Journal of Membrane Science* (2020). https://doi.org/10.1016/j.memsci.2014.10.026
[18] Elma, Muthia, David K. Wang, Christelle Yacou, and João C. Costa. "Interlayer-Free Hybrid organo-silica membranes based teos and tevs for water desalination." *International Conference on Oleo and Petrochemical engineering* (2015).
[19] Duke, Mikel C., JC Diniz Da Costa, Duong D. Do, Peter G. Gray, and Gao Q. Lu. "Hydrothermally robust molecular sieve silica for wet gas separation." *Advanced Functional Materials* 16, no. 9 (2006): 1215-1220. https://doi.org/10.1002/adfm.200500456
[20] Wijaya, S., M. C. Duke, and JC Diniz da Costa. "Carbonised template silica membranes for desalination." *Desalination* 236, no. 1-3 (2009): 291-298. https://doi.org/10.1016/j.desal.2007.10.079
[21] Elma, Muthia, Erdina LA Rampun, Aulia Rahma, Zaini L. Assyaifi, Anna Sumardi, Aptar E. Lestari, Gesit S. Saputro, Muhammad Roil Bilad, and Adi Darmawan. "Carbon templated strategies of mesoporous silica applied for water desalination: A review." *Journal of Water Process Engineering* 38 (2020): 101520. https://doi.org/10.1016/j.jwpe.2020.101520
[22] Elma, Muthia, Muhammad Roil Bilad, Amalia Enggar Pratiwi, Aulia Rahma, Zaini Lambri Asyyaifi, Hairullah Hairullah, Isna Syauqiah, Yulian Firmana Arifin, and Riani Ayu Lestari. "Long-Term Performance and Stability of Interlayer-Free Mesoporous Silica Membranes for Wetland Saline Water Pervaporation." *Polymers* 14, no. 5 (2022): 895. https://doi.org/10.3390/polym14050895

[23] Syauqiah, I., M. Elma, D. P. Mailani, and N. Pratiwi. "Activated carbon from Nypa (Nypa fruticans) leaves applied for the Fe and Mn removal." In *IOP Conference Series: Materials Science and Engineering* 980, no. 1, (2020): 012073. https://doi.org/10.1088/1757-899X/980/1/012073

[24] Rahman, Sazila Karina, Aulia Rahma, Isna Syauqiah, and Muthia Elma. "Functionalization of hybrid organosilica based membranes for water desalination–Preparation using Ethyl Silicate 40 and P123." *Materials Today: Proceedings* 31 (2020): 60-64. https://doi.org/10.1016/j.matpr.2020.01.187

[25] Rahma, Aulia, Muthia Elma, Erdina Lulu Atika Rampun, Amalia Enggar Pratiwi, Arief Rakhman, and Fitriani Fitriani. "Rapid thermal processing and long term stability of interlayer-free silica-P123 membranes for wetland saline water desalination." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 71, no. 2 (2020): 1-9. https://doi.org/10.37934/arfmts.71.2.19

[26] Rahma, Aulia, Muthia Elma, Amalia E. Pratiwi, and Erdina LA Rampun. "Performance of interlayer-free pectin template silica membranes for brackish water desalination." *Membrane Technology* 2020, no. 6 (2020): 7-11. https://doi.org/10.1016/S0958-2118(20)30108-7

[27] Rahman, Sazila Karina, Erdina Lulu Atika Rampun, Aulia Rahma, and Muthia Elma. "Deconvolution of carbon silica templated thin film using ES40 and P123 via rapid thermal processing method." *Materials Today: Proceedings* 31 (2020): 75-78. https://doi.org/10.1016/j.matpr.2020.01.195

[28] Elma, Muthia, Erdina Lulu Atika Rampun, Aulia Rahma, Amalia Enggar Pratiwi, Chairul Abdi, and Raisa Rossadi. "Effect of two stages adsorption as pre-treatment of natural organic matter removal in ultrafiltration process for peat water treatment." In *Materials Science Forum* 988, (2020): 114-121. https://doi.org/10.4028/www.scientific.net/MSF.988.114

[29] Ayu Lestari, Riani, Muthia Elma, Aulia Rahma, Dewi Suparsih, Syarifah Anadhliyah, Norlian Ledyana Sari, Dhimas Ari Pratomo et al. "Organo silica membranes for wetland saline water desalination: effect of membranes calcination temperatures." In *E3S Web of Conferences* 148, (2020): 07006. https://doi.org/10.1051/e3sconf/202014807006

[30] Elma, Muthia, Aptar Eka Lestari, and Sadidan Rabiah. "Fabrication of Silica Thin Film Using Organic Catalyst as Inorganic Membrane Coatings." *Konversi* 7, no. 2 (2018): 62-66. https://doi.org/10.20527/k.v7i2.6499

[31] Elma, Muthia, and Heru Setyawan. "Synthesis of silica xerogels obtained in organic catalyst via sol gel route." In *IOP Conference Series: Earth and Environmental Science* 175, no. 1 (2018): 012008. https://doi.org/10.1088/1755-1315/175/1/012008

[32] Elma, Muthia, and Zaini Lambri Assyaifi. "Desalination process via pervaporation of wetland saline water." In *IOP Conference Series: Earth and Environmental Science* 175, no. 1 (2018): 012009. https://doi.org/10.1088/1755-1315/175/1/012009

[33] Elma, Muthia, Amalia E. Pratiwi, Erdina LA Rampun, and Aulia Rahmah. "Aplikasi membran interlayer-free silika-pektin pada pengolahan air payau dan air rawa asin." In *Prosiding Seminar Nasional Lingkungan Lahan Basah* 4, no. 2 (2019): 268-273. 2019.

[34] Elma, Muthia, Arief Rakhman, and Rahmi Hidayati. "Silica P123 Membranes for desalination of wetland saline water in South Kalimantan." In *IOP Conference Series: Earth and Environmental Science* 175, no. 1, (2018): 012007. https://doi.org/10.1088/1755-1315/175/1/012007

[35] Chong, Kian Hen, and Peck Loo Kiew. "Potential of banana peels as bio-flocculant for water clarification." *Progress in Energy and Environment* 1 (2017): 47-56.

[36] Assyaifi, Zaini L., Muthia Elma, Isna Syauqiah, Erdina LA Rampun, Aulia Rahma, Anna Sumardi, Aptar E. Lestari et al. "Photocatalytic–pervaporation using membranes based on organo-silica for wetland saline water desalination." *Membrane Technology* 2021, no. 7 (2021): 7-11. https://doi.org/10.1016/S0958-2118(21)00109-9

[37] Rahma, Aulia, Muthia Elma, Erdina LA Rampun, Sintong Leonardo Sintungkir, and Muhammad Farid Hidayat. "Effect of backwashing process on the performance of an interlayer-free silica–pectin membrane applied to wetland saline water pervaporation." *Membrane Technology* 2022, no. 2 (2022). https://doi.org/10.12968/S0958-2118(22)70019-5

[38] Elma, Muthia, Amalia Enggar Pratiwi, Aulia Rahma, Erdina Lulu Atika Rampun, and Noni Handayani. "The performance of membranes interlayer-free silica-pectin templated for seawater desalination via pervaporation operated at high temperature of feed solution." In *Materials Science Forum* 981, (2020): 349-355. https://doi.org/10.4028/www.scientific.net/MSF.981.349

[39] Elma, Muthia, Fitri Ria Mustalifah, Lilis Suryani, Erdina Lulu Atika Rampun, and Aulia Rahma. "Wetland saline water and acid mine drainage desalination by interlayefree silica pectin membrane from banan peels." *Nusantara Science and Technology Proceedings* (2020): 271-279. https://doi.org/10.11594/nstp.2020.0543

[40] Elma, Muthia, N. L. Sari, D. A. Pratomo, S. Annadliyah, E. L. A. Rampun, A. Rahma, and A. E. Pratiwi. "Organo-silica membrane for brine water pervaporation." In *IOP Conference Series: Earth and Environmental Science* 473, no. 1 (2020): 012129. https://doi.org/10.1088/1755-1315/473/1/012129

[41] Elma, Muthia, and Gesit Satriaji Saputro. "Performance of cobalt-silica membranes through pervaporation process with different feed solution concentrations." In *Materials Science Forum* 981, (2020): 342-348. https://doi.org/10.4028/www.scientific.net/MSF.981.342

[42] Elma, Muthia, Aulia Rahma, Amalia E. Pratiwi, and Erdina LA Rampun. "Coagulation as pretreatment for membrane-based wetland saline water desalination." *Asia-Pacific Journal of Chemical Engineering* 15, no. 4 (2020): e2461. https://doi.org/10.1002/apj.2461

[43] Elma, Muthia, Dwi Rasy Mujiyanti, Noor Maizura Ismail, Muhammad Roil Bilad, Aulia Rahma, Sazila Karina Rahman, Fitriani Fitriani, Arief Rakhman, and Erdina Lulu Atika Rampun. "Development of hybrid and templated silica-P123 membranes for brackish water desalination." *Polymers* 12, no. 11 (2020): 2644. https://doi.org/10.3390/polym12112644

[44] Lestari, Riani Ayu, Muthia Elma, Erdina Lulu Atika Rampun, Anna Sumardi, Adhe Paramitha, Aptar Eka Lestari, Sadidan Rabiah, Zaini Lambri Assyaifi, and Gesit Satriaji. "Functionalization of Si-C using TEOS (tetra ethyl ortho silica) as precursor and organic catalyst." In *E3S Web of Conferences* 148, (2020): 07008. https://doi.org/10.1051/e3sconf/202014807008

[45] Pratiwi, Amalia Enggar, Muthia Elma, Aulia Rahma, Erdina LA Rampun, and Gesit Satriaji Saputro. "Deconvolution of pectin carbonised template silica thin-film: synthesis and characterisation." *Membrane Technology* 2019, no. 9 (2019): 5-8. https://doi.org/10.1016/S0958-2118(19)30167-3

[46] Elma, Muthia, Heru Setyawan, Aulia Rahma, A. E. Pratiwi, and Erdina Lulu A. Rampun. "Fabrication of Interlayer-free P123 Caronised Template Silica Membranes for Water Desalination: Conventional Versus Rapid Thermal Processing (CTP vs RTP) Techniques." In *IOP Conference Series: Materials Science and Engineering* 543, no. 1 (2019): 012076. https://doi.org/10.1088/1757-899X/543/1/012076

[47] Elma, Muthia, Riani Ayu, Erdina LA Rampun, Syarifah Annahdliyah, Dewi R. Suparsih, Norlian Ledyana Sari, and Dhimas Ari Pratomo. "Fabrication of interlayer-free silica-based membranes–effect of low calcination temperature using an organo-catalyst." *Membrane Technology* 2019, no. 2 (2019): 6-10. https://doi.org/10.1016/S0958-2118(19)30037-0

[48] Elma, Muthia, and Nur Riskawati. "Silica membranes for wetland saline water desalination: performance and long term stability." In *IOP Conference Series: Earth and Environmental Science* 175, no. 1 (2018): 012006. https://doi.org/10.1088/1755-1315/175/1/012006

[49] Elma, Muthia, and Zaini Lambri Assyaifi. "Desalination process via pervaporation of wetland saline water." In *IOP Conference Series: Earth and Environmental Science* 175, no. 1 (2018): 012009. https://doi.org/10.1088/1755-1315/175/1/012009

[50] Elma, Muthia, Christelle Yacou, João C. Diniz da Costa, and David K. Wang. "Performance and long term stability of mesoporous silica membranes for desalination." *Membranes* 3, no. 3 (2013): 136-150. https://doi.org/10.3390/membranes3030136

[51] Yue, Maowen, Shuaifei Zhao, Paul HM Feron, and Hong Qi. "Multichannel tubular ceramic membrane for water and heat recovery from waste gas streams." *Industrial & Engineering Chemistry Research* 55, no. 9 (2016): 2615-2622. https://doi.org/10.1021/acs.iecr.6b00242

[52] Isdayanti, Mirna, Muhammad Irham Rasidi, and Muthia Elma. "Pektin dari kulit pisang kepok (Musa Paradisiaca Linn) sebagai edible film and coating." *PEKTIN DARI KULIT PISANG KEPOK (Musa paradisiaca linn) SEBAGAI EDIBLE FILM AND COATING (SNIKSDA 2016)* (2016).

[53] Wieder, H., M. Cardona, and C. R. Guarnieri. "Vibrational spectrum of hydrogenated amorphous Si C films." *physica status solidi (b)* 92, no. 1 (1979): 99-112. https://doi.org/10.1002/pssb.2220920112

[54] Bertoluzza, Alessandro, Concezio Fagnano, Maria Antonietta Morelli, Vittorio Gottardi, and Massimo Guglielmi. "Raman and infrared spectra on silica gel evolving toward glass." *Journal of Non-Crystalline Solids* 48, no. 1 (1982): 117-128. https://doi.org/10.1016/0022-3093(82)90250-2

[55] Pratiwi, Amalia Enggar, Muthia Elma, Meilana Dharma Putra, Agus Mirwan, Aulia Rahma, and Erdina Lulu Atika Rampun. "Innovation of carbon from pectin templated in fabrication of interlayer-free silica-pectin membrane." *Jurnal Kimia Sains dan Aplikasi* 22, no. 3 (2019): 93-98. https://doi.org/10.14710/jksa.22.3.93-98

[56] Kabsch-Korbutowicz, M., A. Biłyk, and M. Mołczan. "The Effect of Feed Water Pretreatment on Ultrafiltration Membrane Performance." *Polish Journal of Environmental Studies* 15, no. 5 (2006).

[57] Ren, Qiuhui, Xiaomiao Chen, Yuki Yumminaga, Na Wang, Weizhi Yan, Yonghong Li, Li Liu, and Jiping Shi. "Effect of operating conditions on the performance of multichannel ceramic ultrafiltration membranes for cattle wastewater treatment." *Journal of Water Process Engineering* 41 (2021): 102102. https://doi.org/10.1016/j.jwpe.2021.102102