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Utilization of Ceramic Membrane Technology Based on Fluid Mechanics for Reducing COD, TDS, and TSS in Batik Wastewater

Arnesya Ramadhani[1], Frida Amriyati Azzizzah[1*], Happy Ayu Puspa Sari[1], Badril Azhar[2]

[1] Universitas Nahdlatul Ulama Al Ghazali Cilacap, Indonesia.
[2] Chemical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

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Corresponding Author:
Frida Amriyati Azzizzah
fridaamriyatiazzizzah@gmail.com

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Abstract: This study utilizes ceramic membrane technology with the best composition based on the principles of fluid mechanics to reduce pollutant levels, especially COD, TDS, and TSS in batik waste. Ceramic membranes were synthesized using activated fly ash and kaolin as the main ingredients with variations in the material composition ratio of 30:70, 50:50, 70:30 (fly ash: kaolin), sintering temperatures used were 750 °C and 950 °C. Membrane performance was evaluated based on its flux and efficiency in reducing COD, TDS, and TSS using a batch filtration system. The results showed that membranes with a 70:30 fly ash to kaolin composition ratio achieved optimal pollutant reduction, using both sintering temperatures of 750 °C and 950 °C. The 70:30 ratio (fly ash : kaolin) and sintering temperature of 750 °C (L_3) reduced COD by 57%, TDS by 13%, and TSS by 93%, while the 70:30 ratio (fly ash : kaolin) and sintering temperature of 950 °C (L_6) reduced COD by 52%, TDS by 12%, and TSS by 95%. This research also demonstrates the application of physics principles, especially in fluid mechanics and material properties, which can serve as contextual learning materials and strengthen the understanding of applied physics in industrial practice.

Keywords: Applied physics; Batik Waste; Ceramic Membrane; Fluid Mechanics; Fly Ash

Introduction

Waste is the byproduct of industrial production processes and human activities. In this era of modernization, many industries have emerged, both large and small, resulting in increasing waste production. Cilacap Regency is one of the main industrial areas in Central Java province (Dewi & Khotimah, 2019). One of the batik industries in Cilacap is in Kutawaru. However, batik liquid waste in Kutawaru is still processed simply because proper processing tends to be expensive, therefore processing efficiency is low, so that the Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), Total Suspended Solids (TSS) content is still far above the threshold. Batik waste that is disposed of directly into the environment has the potential to contain pollutant molecules, hazardous substances such as synthetic dyes and other organic compounds that can pollute the environment and cause health problems for the surrounding community (Ge et al., 2019; Guan et al., 2021; Liu et al., 2020; Liu et al., 2022; Peng et al., 2022). Based on this background, new technology is needed so that Kutawaru batik waste can be processed optimally, economically and without the potential to pollute the environment, one of which is ceramic membranes. Separation based on membrane technology is one efficient technology (Jaber et al., 2022)

Molecular separation based on membrane technology offers advantages in the field of process

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engineering that makes the process efficient for the separation and removal of pollutant molecules from mixtures (Dahlan et al., 2011; Haider et al., 2021; Luo et al., 2017; Yang et al., 2021). Ceramic membranes have better thermal, mechanical and stability resistance than polymer membranes, so many researchers develop ceramic membranes using economical materials (Abdullayev et al., 2019; Das et al., 2016; Hwa et al., 2018; Sarkar, 2014). The advantages of ceramic membrane technology compared to conventional processing include relatively low energy used for operation and maintenance, modular nature, does not require extreme conditions (temperature and pH), does not require chemicals and does not produce additional waste (Dahlan et al., 2016; Fitriana & Rahmayanti, 2020; I Gede Wenten et al., 2013).

Research conducted by Ahmad et al. (2022) shows that ceramic membranes made from fly ash with the addition of sodium hydroxide and sodium silicate as activators can remove more than 99% of TSS, 60-80% of COD and 60-80% of TDS in textile waste, however, the reduction in COD and TDS is still less than optimal. In research by Saidah, 2020, it shows that ceramic membranes made from clay and kaolin can remove dyes up to 99-100%, COD 80-93% and turbidity 98-100% in textile waste (Bousbih et al., 2021), the study shows that clay and kaolin have great potential to reduce dyes, COD and turbidity in textile waste. The research we have done, activated fly ash has great potential in maximally reducing batik waste (Manasikana & Ramadhani, 2025; Ramadhani et al., 2023). Therefore, this study offers an innovative approach using ceramic membranes made from activated fly ash and kaolin for batik waste processing. The novelty in this study is that the fly ash used has been activated using hydrochloric acid. Activation of fly ash can increase strength, porosity, weather resistance, and enhance adsorption capacity. Kaolin was chosen as the second base material because it has good mechanical strength, good chemical stability, compatibility with the membrane manufacturing process, tolerance to high temperatures, and has good separation capabilities for particles and dissolved substances in waste.

Therefore, the research problem formulation of this study is how the use of ceramic membranes in batik waste processing affects the quality of the permeate results, what is the optimal material composition and firing temperature for making ceramic membranes. This research is very important to conduct because batik waste can be a source of serious environmental pollution if not managed properly. The results of this study are expected to contribute to the development of environmentally friendly batik waste processing technology and can be a basis for the development of ceramic membrane applications. The successful application of this technology could not only enhance the efficiency of batik wastewater treatment but also contribute to the development of environmentally friendly and cost-effective solutions for industrial waste management.

This study also represents a direct application of fundamental physics concepts, particularly in fluid mechanics, heat transfer, and material structure, within an industrial context. The research findings can serve as contextual learning materials in physics education, linking the theoretical principles of pressure, flow rate, and porosity to their real-world applications in membrane systems. Thus, this study not only contributes to technological innovation but also supports research-based learning in the field of applied physics and science education.

Method

This study employed an experimental research design to develop and evaluate ceramic membrane technology for reducing COD, TDS, and TSS in batik wastewater. The research method consists of three main stages: membrane synthesis, performance evaluation, and wastewater treatment application.

Membrane Synthesis

Ceramic membranes were made using activated fly ash and kaolin as raw materials. The synthesis process used the slip casting method with variations in material composition ratios of 30:70, 50:50, and 70:30 (fly ash: kaolin) and sintering temperatures used were 750°C and 950°C. Fly ash was activated using 1N hydrochloric acid with a ratio of 1:5 for 180 minutes, then washed until neutral and dried in an oven until dry. Fly ash was activated to improve its adsorption properties, then mixed with kaolin and sodium silicate. The membrane was formed, dried, and sintered to achieve optimal porosity and structural integrity.

Performance Evaluation

The resulting membranes were tested for permeability by measuring their flux and efficiency in reducing COD, TDS, and TSS. These parameters were analyzed using standard testing methods shown in Figure 1 to determine the optimal composition and sintering conditions.

Wastewater Treatment Application

The batch filtration system shown in Figure 1 is designed to treat batik wastewater using ceramic membranes based on fluid mechanics. The system consists of a feed tank, a booster pump, and a pressure-controlled membrane housing. Wastewater samples are filtered under controlled conditions, and the permeate is analyzed for COD, TDS, and TSS reduction. Batik waste flows into the membrane pores and exits as a product called permeate. This process occurs due to a driving force. This methodology ensures a comprehensive evaluation of the performance and suitability of ceramic membranes for industrial wastewater treatment, particularly in the batik industry.

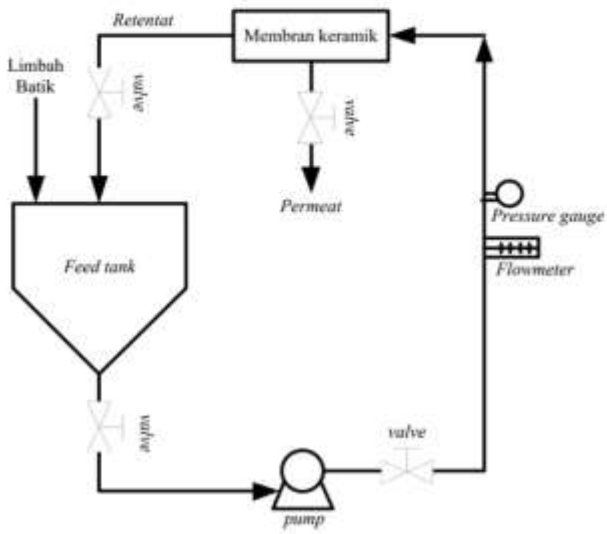


Figure 1. Batik waste processing test equipment.

Result and Discussion

The results demonstrate the effectiveness of ceramic membrane technology in reducing pollutant levels in batik wastewater. Membranes with varying compositions and firing temperatures exhibited varying performance, particularly in reducing COD, TDS, and TSS levels. The sample codes for this study are shown in Table 1.

Table 1. Sample Code

Sample Code	Information
L_1	Material composition ratio 30/70, firing temperature 750 ^{0}C
L_2	Material composition ratio 50/50, firing temperature 750 ^{0}C.
L_3	Material composition ratio 70/30, firing temperature 750 ^{0}C
L_4	Material composition ratio 30/70, firing temperature 950 ^{0}C
L_5	Material composition ratio 50/50, firing temperature 950 ^{0}C.
L_6	Material composition ratio 70/30, firing temperature 950 ^{0}C

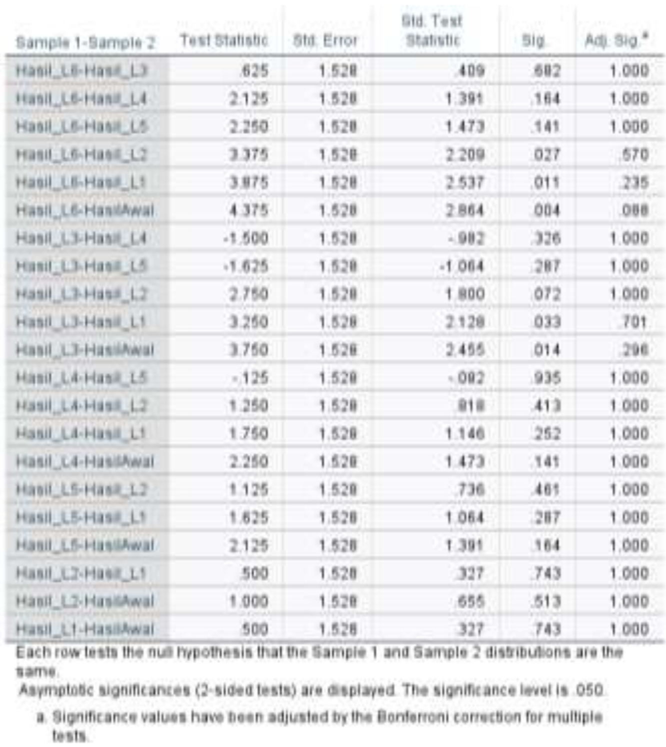
Statistical Test Results on Initial Values for Variables L_1-L_6

The output results in this section are used to determine whether there is an effect of filtering using a membrane with variables L_1-L_6 on changes in the test parameter values, namely COD, TDS and TSS. The hypotheses to be tested are as follows.

H_0 : There is no significant influence between filtering using membranes with variables L_1-L_6 on changes in test parameter values.

H_1 : There is an influence between filtration using a membrane with variables L_1-L_6 on changes in test parameter values.

The testing criteria are if the sig value > 0.05 then H_0 is accepted. The test was conducted using SPSS 27.0. Because the purpose of the study was to determine which variables have a more significant influence on the test parameter value or initial value, the output results that are considered are the output between the variables and the initial value or result.



Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.ª
Hasil_L6-Hasil_L3	.625	1.528	.409	.682	1.000
Hasil_L6-Hasil_L4	2.125	1.528	1.391	.164	1.000
Hasil_L6-Hasil_L5	2.250	1.528	1.473	.141	1.000
Hasil_L6-Hasil_L2	3.375	1.528	2.209	.027	.570
Hasil_L6-Hasil_L1	3.875	1.528	2.537	.011	.235
Hasil_L6-HasilAwal	4.375	1.528	2.864	.004	.088
Hasil_L3-Hasil_L4	-1.500	1.528	-.982	.326	1.000
Hasil_L3-Hasil_L5	-1.625	1.528	-1.064	.287	1.000
Hasil_L3-Hasil_L2	2.750	1.528	1.800	.072	1.000
Hasil_L3-Hasil_L1	3.250	1.528	2.128	.033	.701
Hasil_L3-HasilAwal	3.750	1.528	2.455	.014	.296
Hasil_L4-Hasil_L5	-.125	1.528	-.082	.935	1.000
Hasil_L4-Hasil_L2	1.250	1.528	.818	.413	1.000
Hasil_L4-Hasil_L1	1.750	1.528	1.146	.252	1.000
Hasil_L4-HasilAwal	2.250	1.528	1.473	.141	1.000
Hasil_L5-Hasil_L2	1.125	1.528	.736	.461	1.000
Hasil_L5-Hasil_L1	1.625	1.528	1.064	.287	1.000
Hasil_L5-HasilAwal	2.125	1.528	1.391	.164	1.000
Hasil_L2-Hasil_L1	.500	1.528	.327	.743	1.000
Hasil_L2-HasilAwal	1.000	1.528	.655	.513	1.000
Hasil_L1-HasilAwal	.500	1.528	.327	.743	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .050.
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Figure 2. Output Results of the Effect of Membrane Filtration with the variables L_1-L_6 on changes in test parameter values

Based on the output results of Figure 2, it was obtained that the results on L_6 and the initial value after testing had a sig value = 0.004, sig < 0.05 then H_0 was rejected. So, there is a significant influence between filtration using a membrane with the variable L_6 on changes in the value of the test parameters. Furthermore, it was obtained that the results on L_3 and the initial value after testing had a sig value = 0.014, sig < 0.05 then H_0 was rejected. So, there is a significant influence between filtration using a membrane with the variable L_3 on changes in the value of the test parameters. However, for variables L_1, L_2, L_4 and L_5 statistically did not have a significant influence. After it was known that the influence of filtration using a membrane with variables L_1-L_6 on changes in the value of the test parameters had a significant effect, especially for membrane variables L_6 and L_3.

COD, TDS and TSS Analysis Results

The batik waste processing in this study is based on fluid mechanics, using the tool in Figure 1. The batik waste is collected in a feed tank and then flowed using a pump, the pressure is read at 3 bar, the batik waste flows into the membrane pores and comes out as a product called permeate. This process occurs due to the driving force, where there is a difference in pressure between the feed and permeate sides.

From a physics perspective, the flow of wastewater through the membrane pores can be explained using fluid mechanics principles, where the membrane flux is directly proportional to the pressure difference (ΔP) and inversely proportional to the membrane resistance. This relationship follows Darcy's law and the Hagen–Poiseuille equation, which are fundamental in fluid flow analysis. Therefore, the filtration process in this study exemplifies the practical implementation of physics concepts related to pressure, viscosity, and flow dynamics in porous materials.

Table 2. Results of COD, TDS and TSS analysis on membrane variables L_1, L_2 and L_3

Parameter	Unit	Initial Waste	Results		
			L_1	L_2	L_3
COD	mg/L	9375	4775	4725	4000
TDS	mg/L	1658	1692	1611	1447
TSS	mg/L	4500	542	356	334

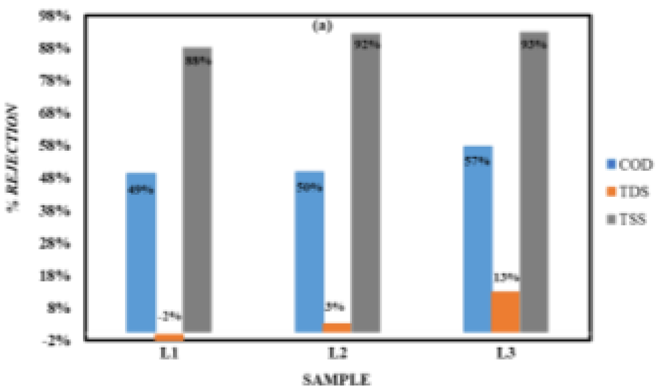


Figure 3. Graph of percentage reduction in COD, TDS and TSS on variable membranes L_1, L_2 and L_3

The initial batik waste and the batik waste resulting from ceramic membrane processing were tested at the Yogyakarta health center laboratory. The results of testing the COD, TDS and TSS parameters on batik waste with variables L_1, L_2, L_4 and L_5 showed less significant changes, especially in variables L_1 and L_2 showed less good results. However, in contrast to variables L_3 and L_6, both showed quite good results. This is in accordance with the results of statistical tests on the initial value of variables L_1-L_6, where the results show the effect of filtering using a membrane with variables L_1-L_6 on changes in the test parameter values, having a significant effect on the membrane variables L_6 and L_3. COD testing results on batik waste showed significant changes. The best COD reduction percentage was achieved using the L_3 variable membrane at 57%, followed by the L_6 variable membrane at 52%.

Table 3. Results of COD, TDS and TSS analysis on membrane variables L_4, L_5 and L_6

Parameter	Unit	Initial Waste	Results		
			L_4	L_5	L_6
COD	mg/L	9375	5150	5000	4500
TDS	mg/L	1658	1479	1454	1454
TSS	mg/L	4500	313	290	242

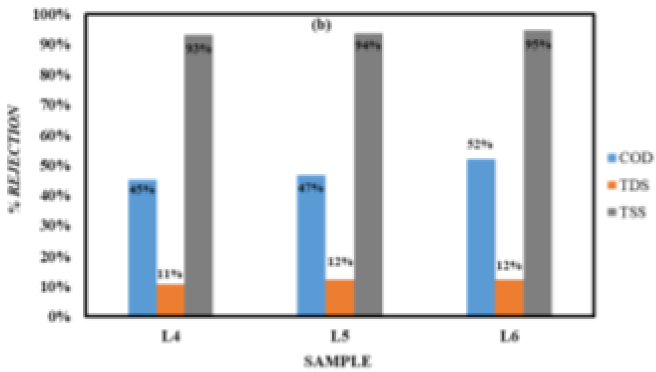


Figure 4. Graph of percentage reduction in COD, TDS, TSS on variable membranes L_4, L_5 and L_6

The results of the TDS test on batik waste showed less significant changes. Variables L_1 and L_2 showed poor results, with a very small percentage reduction in TDS. This is likely due to the sintering temperature used, which is 750^{0}C. At this temperature, the bond between particles is not yet perfect, so the strength of the membrane is still low and there is a possibility that some particles dissolve in the permeate (Nahar et al., 2022). Another influence that causes low membrane strength at 750^{0}C is the composition ratio of 30:70, 50:50 (fly ash: kaolin). Meanwhile, using a sintering temperature of 950^{0}C, the bond between particles is quite good, resulting in a strong membrane. The best percentage reduction in TDS was using the L_3 variable membrane at 13%, followed by the L_6 and L_5 variable membranes at 12%. The results of TSS testing on batik waste showed very significant changes, the best TSS reduction percentage was using the L_6 variable membrane at 95%, followed by the L_5, L_4 and L_3 variable membranes at 94%, 93% and 93%. The best compounds contained in the ceramic membrane were SiO_2 and Al_2O_3. The SiO_2 compound helps in the absorption of small molecules and impurities in batik waste, while Al_2O_3 can increase the hardness and durability of the ceramic membrane (Jamalludin et al., 2018; Liu et al., 2022). This study shows that the ceramic membrane from HCl and kaolin activated fly ash has great potential in batik waste processing. The results of COD, TDS and TSS analysis on the L_1, L_2 and L_3 variable membranes are shown in Table 2, and the results of COD, TDS and TSS analysis on the L_4, L_5 and L_6 variable membranes are shown in Table 3. The percentage reduction of COD, TDS, TSS on variable membranes L_1, L_2 and L_3 is shown in Figure 3, and the percentage reduction of COD, TDS, TSS on variable membranes L_4, L_5 and L_6 is shown in Figure 4.

Conclusion

This study shows that ceramic membrane technology based on fluid mechanics is an effective solution for processing batik liquid waste. Batik waste can be filtered through the ceramic membrane due to the driving force, the feed pressure is read at 3 bar. The results showed that the membrane with a composition ratio of fly ash and kaolin of 70:30 achieved optimal pollutant reduction, using sintering temperatures of 750 ^{0}C and 950 °C. The ratio of 70:30 (fly ash: kaolin) and sintering temperature of 750 ^{0}C (L3) was able to reduce COD by 57%, TDS by 13%, and TSS by 93%, while the ratio of 70:30 (fly ash: kaolin) and sintering temperature of 950 ^{0}C (L6) was able to reduce COD by 52%, TDS by 12%, and TSS by 95%. This is in accordance with the results of statistical tests on the initial values of variables L_1-L_6, which show the effect of filtration using membranes with variables L_1-L_6 on changes in test parameter values, which significantly affect membrane variables L_6 and L_3. This study also shows that at a sintering temperature of 950 °C, the bond between particles is good enough to produce a strong membrane compared to a temperature of 750 °C. This technology offers an economical and sustainable alternative for industrial wastewater treatment. Future studies should focus on optimizing membrane design and integrating system operation under various conditions to maximize the technology's potential. In addition to providing a technological solution for wastewater treatment, this study also strengthens the understanding and application of fundamental physics concepts, such as fluid pressure, porosity, and mass transfer, in real-world industrial contexts. The findings can be used as an example of contextual and project-based learning in physics education, bridging theory with practice to enhance students' scientific literacy and understanding of applied physics phenomena.

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Author Contributions

Conceptualization, A.R. and F.A.A.; methodology, A.R.; software, A.R.; validation, A.R., F.A.A. and B.A.; formal analysis, A.R. and F.A.A.; investigation, A.R., H.A.P.S. and B.A.; resources, A.R.; data curation, A.R., H.A.P.S. and B.A.; writing—original draft preparation, F.A.A.; writing—review and editing, F.A.A. and A.R.; visualization, A.R. and F.A.A.; supervision, A.R.; project administration, A.R.; funding acquisition, A.R. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest. The funders, the Ministry of Research and Technology/Higher Education (Kemenristek Dikti), provided funding for this research and were involved in monitoring the progress through regular report submissions and final report evaluations. The funders also conducted activity monitoring through two reviewers. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

Abdullayev, A., Bekheet, M. F., Hanaor, D. A. H., & Gurlo, A. (2019). Materials and applications for low-cost ceramic membranes. *Membranes*, *9*(9). https://doi.org/10.3390/membranes9090105

Ahmad, B., Dilshad, M. R., Haider, B., Anwar, M. M., Ali, H., Gilani, S. M. A., Ahmad, H. B., & Farooq, M. (2022). Synthesis of novel fly ash based geo-polymeric membranes for the treatment of textile waste water. *International Journal of Environmental Science and Technology*, *19*(7), 6117–6126. https://doi.org/10.3390/ijms13067186

Bousbih, S., Errais, E., Darragi, F., Duplay, J., Trabelsi-Ayadi, M., Daramola, M. O., & Ben Amar, R. (2021). Treatment of textile wastewater using monolayered ultrafiltation ceramic membrane fabricated from natural kaolin clay. *Environmental Technology (United Kingdom)*, *42*(21), 3348–3359. https://doi.org/10.1080/09593330.2020.1729242

Dahlan, M. H., Pratama, E. J., & Odina, M. (2016). Pengaruh Penggunaan Membran Keramik Berbasis Zeolit Dan Gypsum Terhadap Emisi Gas Co, Nox Kendaraan Bermotor. *Jurnal Teknik Kimia*, *22*(2), 10–18. Retrieved from https://shorturl.asia/lRyuU

Dahlan, M. H., Teguh, D., & Utama, F. (2011). Kinerja Membran Keramik Dalam Pengolahan Air Sumur Menjadi Air Bersih. *Jurnal Teknik Kimia*, *17*(5), 38–49. Retrieved from https://shorturl.asia/L2BXd

Das, B., Chakrabarty, B., & Barkakati, P. (2016). Preparation and characterization of novel ceramic membranes for micro-filtration applications. *Ceramics International*, *42*(13), 14326–14333. https://doi.org/10.1016/j.ceramint.2016.06.125

Dewi, R. S., & Khotimah, K. (2019). Aspergillus sp. 3 pada Pengolahan Limbah Cair Batik Kutawaru Cilacap dan Pengaruhnya terhadap Zea mays dan Vigna radiata. *Life Science, 8(2), 150-1598*. Retrieved from https://shorturl.asia/4IvCo

Fitriana, N., & Rahmayanti, M. (2020). Aplikasi Membran Filter Keramik Untuk Menurunkan Konsentrasi Zat Warna Remazol Red dan Nilai COD Limbah Cair Batik. *Al-Kimia*, *8*, 159–167. https://doi.org/10.24252/al-kimiav8i2.15932

Ge, D., Yuan, H., Xiao, J., & Zhu, N. (2019). Insight into the enhanced sludge dewaterability by tannic acid conditioning and pH regulation. *Science of the Total Environment*, *679*, 298–306. https://doi.org/10.1016/j.scitotenv.2019.05.060

Guan, Q., Zeng, G., Song, J., Liu, C., Wang, Z., & Wu, S. (2021). Ultrasonic power combined with seed materials for recovery of phosphorus from swine wastewater via struvite crystallization process. *Journal of Environmental Management*, *293*(June), 112961. https://doi.org/10.1016/j.jenvman.2021.112961

Haider, S. A., Sajid, M., & Iqbal, S. (2021). Forecasting hydrogen production potential in islamabad from solar energy using water electrolysis. *International Journal of Hydrogen Energy*, *46*(2), 1671–1681. https://doi.org/10.1016/j.ijhydene.2020.10.059

Hwa, L. C., Uday, M. B., Ahmad, N., Noor, A. M., Rajoo, S., & Zakaria, K. Bin. (2018). Integration and fabrication of the cheap ceramic membrane through 3D printing technology. *Materials Today Communications*, *15*, 134–142. https://doi.org/10.1016/j.mtcomm.2018.02.029

I Gede Wenten, Khoiruddi, K., A.N. Hakim, A. P. T. . (2013). Polarisasi Konsentrasi dan Fouling pada Membran. January 2016. *Jurnal Teknologi Kimia Institut Teknologi Bandung* Retrieved from https://shorturl.asia/NFy0P

Jaber, L., Elgamouz, A., & Kawde, A. N. (2022). An insight to the filtration mechanism of Pb(II) at the surface of a clay ceramic membrane through its preconcentration at the surface of a graphite/clay composite working electrode. *Arabian Journal of Chemistry*, *15*(12), 104303. https://doi.org/10.1016/j.arabjc.2022.104303

Jamalludin, M. R., Harun, Z., Othman, M. H. D., Hubadillah, S. K., Yunos, M. Z., & Ismail, A. F. (2018). Morphology and property study of green ceramic hollow fiber membrane derived from waste sugarcane bagasse ash (WSBA). *Ceramics International*, *44*(15), 18450–18461. https://doi.org/10.1016/j.ceramint.2018.07.063

Liu, W., Li, J., Zheng, J., Song, Y., Shi, Z., Lin, Z., & Chai, L. (2020). Different Pathways for Cr(III) Oxidation: Implications for Cr(VI) Reoccurrence in Reduced Chromite Ore Processing Residue. *Environmental Science and Technology*, *54*(19), 11971–11979. https://doi.org/10.1021/acs.est.0c01855

Liu, Y., Li, B., Lei, X., Liu, S., Zhu, H., Ding, E., & Ning, P. (2022). Novel method for high-performance simultaneous removal of NOx and SO2 by coupling yellow phosphorus emulsion with red mud. *Chemical Engineering Journal*, *428*(x), 131991. https://doi.org/10.1016/j.cej.2021.131991

Luo, Y., Ma, S., Liu, C., Zhao, Z., Zheng, S., & Wang, X. (2017). Effect of particle size and alkali activation on coal fly ash and their role in sintered ceramic tiles. *Journal of the European Ceramic Society*, *37*(4), 1847–1856. https://doi.org/10.1016/j.jeurceramsoc.2016.11.032

Manasikana, A., & Ramadhani, A. (2025). Filtration of Kutawaru Cilacap batik waste using fly ash activated by sulfuric acid. *Jurnal Rekayasa Proses,* 203–208. https://doi.org/10.22146/jrekpros.11219

Nahar, Sariadi, Nanang R.W., Novi Q.R., & Diana, S. (2022). Sintesis Membran Keramik Berbasis Nano Partikel Zeolit, Kaolin, dan Karbon Aktif Tempurung Kelapa Sawit dengan Metode Sintering. *Proceeding Seminar Nasional Politeknik Negeri Lhokseumawe*, *6*(1), A187–A190. Retrieved from https://e-jurnal.pnl.ac.id/semnaspnl/article/view/3509

Peng, F., Yang, W., & Liu, Y. (2022). Hybrid mechanistic approach in the estimation of flow properties in cylindrical membrane modules. *Arabian Journal of Chemistry*, *15*(12), 104306. https://doi.org/10.1016/j.arabjc.2022.104306

Ramadhani, A., Raharjo, S. H., & Nyamiati, R. D. (2023). Utilization of Fly Ash and Zeolite to Reduce Chemical Oxygen Demand (COD) in Domestic Waste at the Al Ihya Ulumaddin Islamic Boarding School Cilacap. *Formosa Journal of Applied Sciences*, *2*(3), 303–312. https://doi.org/10.55927/fjas.v2i3.3347

Sarkar, S. (2014). Process for Preparation of Low Cost Clay-Alumina Multichannel Ceramic Membrane for Liquid Filtration Application. *Transactions of the Indian Ceramic Society*, *73*(3), 239–244. https://doi.org/10.1080/0371750X.2014.888319

Yang, Y., Zhu, H., Xu, X., Bao, L., Wang, Y., Lin, H., & Zheng, C. (2021). Construction of a novel lanthanum carbonate-grafted ZSM-5 zeolite for effective highly selective phosphate removal from wastewater. *Microporous and Mesoporous Materials*, *324*(May), 111289. https://doi.org/10.1016/j.micromeso.2021.111289