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Research Article

Silica Adsorption from Boiler Effluent Using Activated Charcoal Derived from Palm Oil Fibre Waste with H_3PO_4 Activator

Adsorpsi Silika dari Limbah Boiler Menggunakan Arang Aktif yang Berasal Dari Limbah Serat Kelapa Sawit Dengan Aktivator H_3PO_4

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Abstract

Most waste from palm oil processing can be repurposed, such as using palm fibre waste to create activated charcoal. This study aimed to assess the effectiveness of activated charcoal, produced by activating palm fibre with H_3PO_4, in removing silica from boiler output water. The production process involved pyrolysis at 200ºC for 2.5 hours. A completely randomized design was employed to test the effects of different H_3PO_4 concentration (with 1 to 2 M) and reaction times (30, 60, and 90 min). Results revealed that the moisture content of the activated charcoal ranged from 1.96% to 2.42%, ash content from 9.82% to 21.63%, and iodine adsorption from 366.43 to 457.87 mg/g. The highest silica adsorption capacity (3.5 g/g) was achieved with 2 M H_3PO_4 for 90 min. This indicates that palm fibre-derived activated charcoal is effective for silica removal, highlighting it is potential for enhancing environmental sustainability in industrial sector.

Keywords*:* activated charcoal; adsorption; fibre waste; phosphoric acid; pyrolysis

Abstrak

Sebagian besar limbah dari pengolahan minyak kelapa sawit dapat dimanfaatkan, seperti menggunakan limbah serat kelapa sawit untuk membuat arang aktif. Penelitian ini bertujuan untuk menilai efektivitas arang aktif yang dihasilkan dari aktivasi serat kelapa dengan H_3PO_4 dalam menghilangkan silika dari air limbah boiler. Proses produksi melibatkan pirolisis pada suhu 200ºC selama 2,5 jam. Desain acak lengkap digunakan untuk menguji efek konsentrasi H_3PO_4 (1 hingga 2 M) dan waktu reaksi (30, 60, dan 90 menit). Hasilnya menunjukkan bahwa kadar air arang aktif berkisar antara 1,96% hingga 2,42%, kadar abu antara 9,82% hingga 21,63%, dan daya serap yodium antara 366,43 hingga 457,87 mg/g. Daya serap silika tertinggi (3,5 g/g) dicapai dengan 2 M H_3PO_4 selama 90 menit. Ini menunjukkan bahwa arang aktif dari serat kelapa sawit efektif dalam menghilangkan silika, menyoroti potensinya untuk meningkatkan keberlanjutan lingkungan di sektor industri.

Kata kunci: *adsorpsi; arang aktif; asam fosfat; limbah serat; pirolisis*

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1. Introduction

Along with the rapid development of the palm oil processing industry in Indonesia, the volume of waste produced is also increasing every year. During each processing stage, palm oil mills produce significant amounts of solid waste, including empty palm fruit bunches, kernel waste, sludge decanter, fibre, and liquid by-products, which make up 23%, 6.5%, 4%, 13%, and 50% of the total waste, respectively. Although these materials are commonly seen as waste, they are more accurately described as by-products due to their potential for use in various applications [1]. For example, palm fibre is obtained from the pulp of oil palm fruits after processes like kernel crushing and mechanical pressing in digesters and screw press machines [2]. This fibre is rich in nutrients such as phosphorus (P), calcium (Ca), magnesium (Mg), and carbon (C). Its composition mainly consists of lignocellulosic compounds, which are complexes of lignin, cellulose, and hemicellulose. Hemicellulose, with its hydrophilic properties, aids in water absorption, contributing to the fibre irregular structure [3]. In contrast, cellulose, when dry, shows hygroscopic tendencies, readily absorbing water while maintaining hardness and brittleness [4].

Given its nutrient-rich and fibrous composition, palm fibre can be transformed into activated charcoal, a solid substance characterized by its porous structure, which excels in adsorbing particles from liquids through surface adsorption. Adsorption, defined as the adhesion of molecules from a fluid onto a surface, occurs within these pores, enhancing the material's effectiveness in removing contaminants like colorants, odors, and dissolved metals from water [3, 5]. A recent study conducted by Herlambang et al. [6] has reported that palm kernel shell activated with 4.78% phosphoric acid (H_3PO_4) and 24.67 hours of reaction time can produce fixed carbon of 75.3008%. Although these studies primarily focus on enhancing carbon yield rather than metal adsorption, they underscore the potential of biomass sources for producing effective activated charcoals. In the context of palm fibre, activated charcoal production involves chemical activation with H_3PO_4, which enlarges carbon pores compared to base activators, thereby boosting its adsorption capacity [7-9]. This process typically includes dehydration, exposure to sunlight for preconditioning, carbonation at high temperatures ranging from 300 to 900°C, and a final chemical activation step to maximize pore accessibility [6, 10].

One of the critical applications of activated charcoal in the palm oil industry is in the treatment of boiler water. Boilers play a crucial role in palm oil mills, functioning as pressurized vessels that transform water from H_3PO_4 plants into steam for various industrial processes, such as electricity generation and heating [11, 12]. After use, boiler water containing minerals like phosphate, sulfite, iron, alkali, and notably silica, is discharged. Silica, in particular, presents significant challenges as it tends to precipitate and create scale deposits on boiler surfaces when heated and then cooled. Its inherent stability and hydrophobic properties worsen these issues, requiring effective strategies to preserve boiler efficiency and lifespan [13, 14]. It is vital to reduce the silica content in boiler output water to prevent scale formation and deposition within the boiler system. Elevated silica levels can result in serious operational problems, including decreased

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heat transfer efficiency, higher energy consumption, and potential equipment damage, putting overall boiler performance and longevity at risk.

This research aims to explore the feasibility of using activated charcoal made from palm fibre waste to reduce silica levels in the water discharged from boilers in palm oil mills. By adsorbing silica, the study seeks to encourage water recycling efforts, which can help conserve important boiler feed water resources and improve overall operational sustainability. Utilizing palm fibre waste for activated charcoal not only helps address environmental issues related to waste disposal but also enhances resource efficiency in the palm oil processing sector. The study intends to establish a practical framework that combines waste utilization with water management strategies to support sustainable development objectives in industrial settings. By demonstrating the efficacy of palm fibre-derived activated charcoal in silica removal, this research aims to offer practical insights for enhancing water reuse efficiency and reducing the environmental impact of palm oil production.

2. Research Methods

2.1 Tools and Materials

The raw materials used in this research were palm fibre and boiler output water obtained from PT. Anaktuha Sawit Mandiri, located in Bumi Ratu Nuban Village, Bumi Ratu District, Central Lampung Regency. Materials for analysis included 0.1 N iodine solution, 1 M H_3PO_4 (Merck, Germany), 2 M 1% starch indicator, distilled water, and Na2SO3 (Merck, Germany). The tools used in this research include a silica meter (Hach, USA), a 100 mesh sieve (Retsch, Germany), a pyrolysis unit (Carbolite, UK), a pH meter (Hanna Instruments, USA), a thermometer (Fisherbrand, USA), an oven (Memmert, Germany).

2.2 Experimental Procedures

This research was carried out in two stages. The first stage involved the production of activated charcoal from palm fibre, followed by the second stage which tested the performance of activated charcoal on the adsorption capacity of silica content in boiler output water. The study focused on the impact of the activator H_3PO_4 and reaction time. The research design utilized the Completely Randomized Design method with two factors, as shown in Table 1.

Table 1. Experimental procedure to reduce silica content in the boiler water

H_3PO_4 concentration (M)	Boiler feed (min)	Repetitions	
		1	2
1	30	X1Y1	X1Y1
	60	X1Y2	X1Y2
	90	X1Y3	X1Y3
2	30	X2Y1	X2Y1
	60	X2Y2	X2Y2
	90	X2Y3	X2Y3

2.3 Activated Charcoal Production

Fibre waste was cleaned and removed from impurities such as remaining kernels and shells, then dried in the sun for 2 days. Next, the palm oil fibres are charred or carbonized using pyrolysis at an operating temperature of 200 ºC for 2.5 hours, and a proses slightly modified by Herlambang et al. [6] and Elisa et al. [15]. The resulting charcoal was reduced in size using a 60-mesh disk mill and sieved using a 100-mesh sieve.

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The weight of the resulting charcoal powder was measured to determine the yield of charcoal formed. The dried charcoal was then soaked at a temperature of 200 ºC using an activator in the form of a 1 M phosphoric acid solution for half of the sample and with 2 M phosphoric acid for the other half for 24 hours. The ratio of activated charcoal to phosphoric acid activator is 1:4, meaning that every 1 g of activated charcoal is activated with 4 mL of phosphoric acid. The soaked materials are filtered, and the residue is washed with distilled water until the pH is neutral. After washing, the activated carbon is dried in an oven at 105 ºC for 1 hour, then placed in a desiccator to cool.

2.4 Analyzing the properties of activated charcoal

2.4.1 Moisture Content

Procedure for determining the amount of water refers to the Indonesian National Standard (SNI) 06–3730-1995, which outlines quality requirements and testing procedures for activated charcoal by Laresha et al. [16]. The moisture content was determined by weighing 1 g of activated charcoal and placing it in a porcelain cup that had been dried and weighed. The sample was then heated in an oven at 105°C for 1 hour, cooled in a desiccator for 15 min, and reweighed. Equation 1 can be utilized to calculate the moisture content. Where m_1 represents the mass of the cup plus sample before being placed in the oven, and m_2 represents the mass of the cup plus sample after being in the oven.

2.4.2 Ash content

A Pyrex porcelain cup with a known mass was used to weigh two grams of the substance [6]. The samples were placed in a furnace (B-One, China) and exposed to ash for three hours at a maximum temperature of 550°C. The sample was weighed until a consistent weight was reached after cooling it for 15 to 30 min in a desiccator. The amount of ash contained was determined using equation 2. Where W is the mass of the sample after the furnace, m_1 is the mass of the empty crucible, and m_2 is the mass of the sample itself. This calculation provides the ash content as a percentage of the sample mass.

$$\text{Moisture (\%)} = \frac{m_1 - m_2}{m_1} \times 100\% \quad \text{.....(1)}$$

$$\text{Ash (\%)} = \frac{m - m_1}{m_2} \times 100\% \quad \text{.....(2)}$$

$$A = \frac{B \times N_1}{N_2} \quad \text{.....(3)}$$

$$C = \frac{A \times 126.93 \times fp}{a} \quad \text{.....(4)}$$

2.4.3 Iodine Absorption Capacity

The iodine absorption test was conducted by weighing 0.5 g of activated carbon and mixing it with 5 mL of 0.1 N iodine solution. The mixture was then shaken with a shaker for 15 min and filtered. The filtered solution was adjusted back to its original volume by adding distilled water up to 25 mL. The filtrate solution was shaken, 5 mL was extracted, and titrated with 0.1 N sodium thiosulfate solution. If the yellow color of the solution starts to fade, 1% starch solution was added as an indicator [6, 15]. The dark blue color was titrated again until it became clear. Iodine absorption capacity was determined using equation 3 and 4. Where A is the volume of the iodine solution (mL), B is the volume of $Na_2S_2O_3$ used (mL), C is iodine absorption capacity, fp is the dilution factor, a is the weight of the activated carbon (g), N_1 is the

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concentration of iodine, N_2 is the concentration of iodine, and 126.93 is the amount of iodine corresponding to 1 mL of $Na_2S_2O_3$ solution.

2.4.4 Performance of activated charcoal for reducing silica in boiler water

Activated charcoal resulting from combustion at a temperature of 200 ºC, which had been activated with 1 M and 2 M H_3PO_4, was weighed at 2.5 grams each. The charcoal was then placed into a glass beaker containing a 100 mL sample of boiler output water. Subsequently, dissolution was conducted on a hot plate using a magnetic stirrer set at a stirring speed of 200 rpm. This process was repeated for 30 min, 60 min, and 90 min, each carried out twice, and then analyzed using a silica meter. This procedure was slightly modified from Fadilah et al. [17] for phosphorus removal. Silica removal was determined using equation 5. Where Co and Ce represent initial and final concentrations, respectively.

$$\text{Silica removal}(\%) = \frac{C_o - C_e}{C_o} \times 100\% \quad \textbf{....(5)}$$

3. Results and Discussion

3.1 Moisture content

Based on the test results in Figure 1, the moisture content of activated charcoal from palm fibre is relatively low and meets the quality requirements of SNI 06-3730-1995. The highest moisture content value was 2.42 ± 0.13% in the 2 M H_3PO_4 solution. Meanwhile, the lowest moisture content value was 1.96 ± 0.01% without activation. A study by Herlambang et al. [6] has reported that the moisture content of the adsorbent derived from palm kernel shells activated with H_3PO_4 was reported to be 1.0007%. This indicates that the moisture content increases with the acidity of phosphoric acid. High moisture content can negatively impact the absorption capacity of activated charcoal for liquids and gases. Low moisture content is desirable as it can lead to a higher absorption capacity due to the pores remaining unobstructed by moisture. A lower moisture content provides more available spaces in the activated charcoal pores for adsorbate molecules, optimizing the adsorption process. Moisture molecules in activated charcoal are absorbed by the activator, enlarging the pores in the carbon ash. Larger pores result in increased surface area of activated charcoal, enhancing its adsorption ability [18].

3.2 Ash content

Based on the test results in Figure 2, the ash content of palm fibre activated charcoal meets the quality requirements of SNI 06-3730-1995. The highest ash content value was 21.63 ± 0.17% without activation. Meanwhile, the lowest ash content was 9.82 ± 0.23% in the 2 M H_3PO_4. The high ash content is due to the activation process where the activator can react with the metals covering the surface of the activated charcoal to form salts that can dissolve in the activator solution. When heated at 900ºC, these salts also burn. The high and low levels of activated charcoal ash are influenced by minerals. Inorganic substances present in activated charcoal can be dissolved by the activator. Ash may develop due to the mineral elements like calcium, potassium, sodium, and magnesium found in activated charcoal. These elements disperse across the activated charcoal grid, clogging the pores. The residual minerals block the pores of the activated charcoal, hindering the adsorption process [19].

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3.3 Iodine absorption

Based on the quality requirements for activated charcoal, specifically SNI 06-3730-95, the minimum iodine absorption capacity should be 750 mg/g. However, the iodine absorption capacity of activated charcoal derived from palm fibre falls short of this standard due to impurities that obstruct the pores of the activated charcoal, resulting in insufficient micropores to adsorb the iodine solution. The highest iodine absorption value recorded was 457.87 ± 32.01 mg/g in the 1 M H_3PO_4, while the lowest iodine absorption capacity was 366.43 ± 3.52 mg/g without activation.

Figure 3 illustrates the iodine adsorption capacity of activated charcoal activated with 1 M and 2 M H_3PO_4. It is evident that as the molarity value of the activator increases, there is a decrease in iodine adsorption level, indicating a significant impact on the quality of activated charcoal in terms of pore formation and impurity absorption. The surface area of activated charcoal pores is a crucial parameter that influences its quality by affecting its adsorption capacity. The variance in iodine absorption capacity is attributed to the lack of mesopores and macropores in the activated charcoal for iodine absorption. The high iodine absorption capacity is linked to the formation of a micropore structure pattern, signifying the large pore diameter of activated charcoal that can only accommodate molecules with a diameter of less than 10 Angstroms [20].

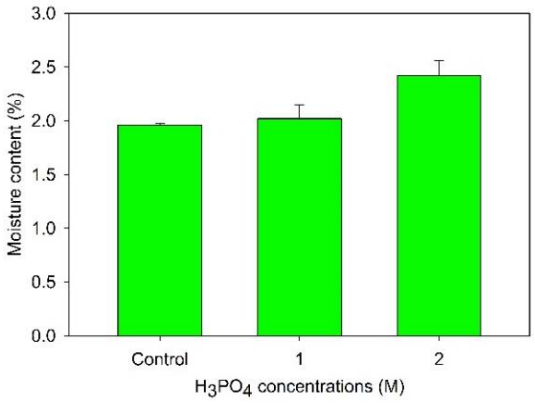

Figure 1. Moisture content results with various concentrations of H_3PO_4

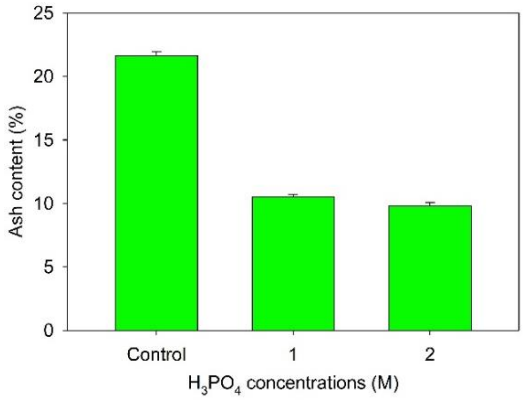

Figure 2. Ash content result with different H_3PO_4 concentrations

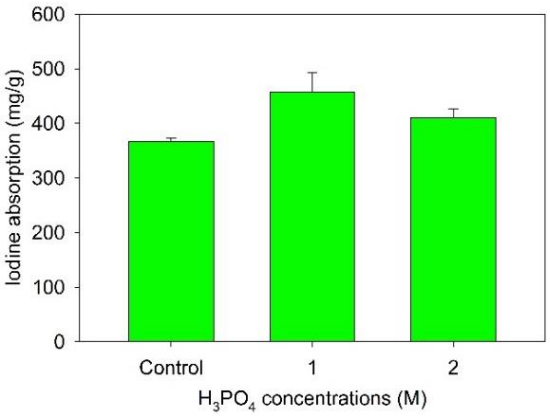

Figure 3. Iodine absorption content result with different H_3PO_4 concentrations

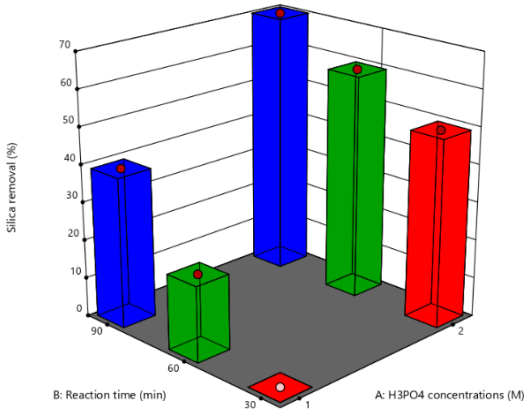

Figure 4. Silica removal result with different H_3PO_4 concentrations and reaction time

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3.4 Activated charcoal performance

Figure 4 illustrates the effect of H_3PO_4 concentrations (1 M and 2 M) and reaction times (30, 60, and 90 min) on silica removal percentages. At the shortest reaction time of 30 min, silica removal was minimal with 1 M H_3PO_4 (0%), moderate with 1.5 M (20%), and highest with 2 M (30%). As the reaction time increased to 60 min, silica removal improved significantly across all concentrations: 1 M reached about 40%, 1.5 M achieved around 50%, and 2 M approached 60%. At the longest reaction time of 90 min, silica removal continued to increase, with 1 M reaching approximately 50%, 1.5 M achieving about 60%, and 2 M peaking around 70%. This trend indicates that both higher concentrations of H_3PO_4 and longer reaction times contribute positively to the efficiency of silica removal. In addition, a higher activator concentration causes the driving force of the adsorbate molecules to be higher so that the number of silica molecules absorbed becomes greater [21].

Adsorption of silica from boiler water using activated charcoal derived from palm fibre waste involves a detailed understanding of the physicochemical interactions between silica and the activated charcoal surface. Silica, a common impurity in boiler water, can precipitate and form scale under high-temperature conditions, reducing boiler efficiency. The adsorption process relies on the ability of activated charcoal to attract and retain silica molecules on its surface and within its pores, mitigating scale formation and improving boiler performance. Factors influencing adsorption efficiency include surface area, pore size distribution, pH of the water, temperature, and the presence of competing ions [12]. The application of activated charcoal from palm fibre waste offers a sustainable solution by utilizing agricultural residues, contributing to waste valorization and environmental sustainability in boiler water H_3PO_4 applications.

3.5 Future prospect and challenges

Looking ahead, the future prospects for utilizing activated charcoal derived from palm fibre waste for silica removal in boiler water H_3PO_4 are promising yet face several challenges. Firstly, the sustainability aspect of using agricultural residues aligns with global initiatives towards circular economy practices and sustainable development goals. This approach not only reduces environmental impact by repurposing waste materials but also supports cost-effective and environmentally friendly solutions in industrial water H_3PO_4. Advances in activation techniques and material science can further optimize the surface area and pore structure of activated charcoal, enhancing its adsorption capacity and efficiency in removing silica and other contaminants from boiler water.

However, several challenges must be addressed to fully realize the potential of this technology. The variability in feedstock quality and composition of palm fibre waste can impact the consistency and performance of activated charcoal. This necessitates rigorous quality control measures and standardization in production processes to ensure reliable and effective adsorption properties. Moreover, while activated charcoal offers sustainable advantages, the cost-effectiveness and scalability of production remain critical considerations. Balancing production costs with performance requirements and market competitiveness is essential for widespread adoption in diverse industrial applications.

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In addition to technological challenges, regulatory compliance, and competition from alternative water H_3PO_4 technologies pose significant hurdles. Meeting stringent regulatory standards for water quality and discharge limits requires continuous innovation and adaptation of H_3PO_4 technologies. Furthermore, competing technologies such as chemical precipitation and membrane filtration offer alternative approaches to silica removal, prompting comparative studies and technological advancements to demonstrate the unique advantages of activated charcoal-based adsorption systems. Overcoming these challenges will require collaborative efforts across academia, industry, and regulatory bodies to drive innovation, optimize operational efficiencies, and promote sustainable practices in boiler water H_3PO_4 using activated charcoal from palm fibre waste.

4. Conclusion

Activated charcoal produced from palm fibre waste via pyrolysis and H_3PO_4 activation exhibits promising characteristics for water treatment applications, particularly in silica removal from boiler water. The results demonstrated that moisture content, ash content, and iodine absorption capacity were significantly influenced by the concentration of H_3PO_4 used during the activation process. The study found that higher concentrations of H_3PO_4 led to increased moisture content and lower ash content, which positively influenced the adsorption capacity of the activated charcoal. Specifically, the activated charcoal produced using a 2 M concentration of H_3PO_4 was most effective, achieving up to 70% silica removal after 90 min of reaction time. This concentration not only optimized the pore structure of the charcoal, leading to better adsorption efficiency but also minimized ash content, enhancing the overall quality of the activated charcoal. This finding highlights the potential of utilizing agricultural waste products like palm fibre in creating sustainable solutions for industrial water treatment, contributing to both resource efficiency and environmental sustainability.

References

[1] Haryanti, A., Norsamsi, N., Fanny Sholiha, P. S., & Putri, N. P. (2014). Studi Pemanfaatan Limbah Padat Kelapa Sawit. *Konversi*, 3 (2), 20-20. http://dx.doi.org/10.20527/k.v3i2.161

[2] Shivashankar, S., Suresh, K., Anitha, P., & Sathish, A. (2024). Chapter-6 Processing of Oil Palm Bunches and Valorization of Oil Palm Biomass. *Practices Research*, 97. https://doi.org/10.22271/ed.book.2607

[3] Chen, Y., Su, N., Zhang, K., Zhu, S., Zhu, Z., Qin, W., Yang, Y., Shi, Y., Fan, S., & Wang, Z. (2018). Effect of fibre surface treatment on structure, moisture absorption and mechanical properties of luffa sponge fibre bundles. *Industrial Crops and Products*, 123 341-352. https://doi.org/10.1016/j.indcrop.2018.06.079

[4] Fine, F. S., Charloq, & Ferry, E. T. S. (2016). Penambahan Sabut Kelapa pada Media Tanam dan Frekuensi Penyiraman terhadap Pertumbuhan Kecambah Kelapa Sawit (Elaeis quineensis Jacq.) diPre Nursery. *Jurnal Agroteknologi FP USU*, 6 (3), 1-23. https://doi.org/10.32734/joa.v6i3.2403

[5] Widodo, L. U., Najah, S., & Istiqomah, C. (2020). Pembuatan Adsorben Berbahan Baku Tanah Liat Dari Limbah Industri Pencucian Pasir Silika Dengan Perbedaan Konsentrasi Hcl Dan Waktu Aktivasi. *Journal of Research and Technology*, 6 (1), 10-15. https://doi.org/10.55732/jrt.v6i1.134

[6] Herlambang, M. J., Ramandani, A. A., Cendekia, D., Rhea, L., & Efendi, M. N. (2023). Optimization and Characterization of Adsorbent from Palm Kernel Shell Waste Using H3PO4

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Activator. *CHEESA: Chemical Engineering Research Articles*, 6 (2), 118-125. http://dx.doi.org/10.25273/cheesa.v6i2.15906.118-125

[7] Sholikhah, H. I., Putri, H. R., & Inayati, I. (2021). Pengaruh Konsentrasi Aktivator Asam Fosfat (H3PO4) pada Pembuatan Karbon Aktif dari Sabut Kelapa terhadap Adsorpsi Logam Kromium. *Equilibrium Journal of Chemical Engineering*, 5 (1), 45-45. https://doi.org/10.20961/equilibrium.v5i1.53572

[8] Gao, Y., Yue, Q., Gao, B., & Li, A. (2020). Insight into activated carbon from different kinds of chemical activating agents: A review. *Sci. Total Environ.*, 746 141094. https://doi.org/10.1016/j.scitotenv.2020.141094

[9] Ateş, A. (2023). The effect of microwave and ultrasound activation on the characteristics of biochar produced from tea waste in the presence of H3PO4 and KOH. *Biomass Conversion and Biorefinery*, 13 (10), 9075-9094. https://doi.org/10.1007/s13399-021-01838-7

[10] Dwityaningsih, R., Evila, T., Sri, P., Handayani, M., & Nurhilal, M. (2023). Pengaruh Variasi Konsentrasi H 3 PO 4 Sebagai Zat Aktivator Terhadap Karakteristik Karbon Aktif dari Sekam Padi. 14 (01), 98-104. https://doi.org/10.35970/infotekmesin.v14i1.1641

[11] Sabiani, N. H. M., Alkarimiah, R., Ayub, K. R., Makhtar, M. M. Z., Aziz, H. A., Hung, Y.-T., Wang, L. K., & Wang, M.-H. S., "Treatment of palm oil mill effluent," in *Waste Treatment in the Biotechnology, Agricultural and Food Industries: Volume 2*: Springer, 2023, pp. 227-284.

[12] Ong, E. S., Rabbani, A. H., Habashy, M. M., Abdeldayem, O. M., Al-Sakkari, E. G., & Rene, E. R. (2021). Palm oil industrial wastes as a promising feedstock for biohydrogen production: A comprehensive review. *Environ. Pollut.*, 291 118-160. https://doi.org/10.1016/j.envpol.2021.118160

[13] Safentry, A., Husnah, & Habib, F. (2019). Studi Teknologi Membran Mikro Untuk Air Dipusat Pengumpul Produksi (PPP) Pertamina Ep Asset 2 Field Prabumulih. *Jurnal Redoks*, 4 (1), 16-26. https://doi.org/10.31851/redoks.v4i1.3071

[14] Rochmat, A., Pramudita, M., Fathiayasa, F., & Buchari, A. (2016). Karakteristik SiO2 - Getah Flamboyan (Delonix regia) sebagai Material Coating Pencegah Korosi. *Teknika: Jurnal Sains dan Teknologi*, 12 (1), 83-83. https://doi.org/10.36055/tjst.v12i1.6618

[15] Elisa, E., Shintawati, S., Afifah, D. A., & Ramandani, A. A. (2024). Characteristics candlenut shell-based Activated Carbon for reduction Iron (Fe) in surface water from Bratasena Tulang Bawang, Lampung. *Journal of Natural Sciences and Mathematics Research*, 10 (1), 35-45. https://doi.org/10.21580/jnsmr.v10i1.20320

[16] Laresha, M. H. A., Cendekia, D., Ermaya, D., Shintawati, S., & Ramandani, A. A. (2024). Adhesive formulation and particle size in making bio-briquettes from bamboo pyrolysis waste charcoal. *Jurnal Litbang Industri*, 14 (1), 35-42. https://doi.org/10.24960/jli.v14i1.8522.35-42

[17] Fadilah, R., Hanifah, W., Cendekia, D., & Ramandani, A. A. (2023). Formation of Phosphate Crystals from Cow Urine Using Aeration System Batch Reactor. *CHEMICA : Jurnal Teknik Kimia*, 10 (2), 66-75. http://dx.doi.org/10.26555/chemica.v10i2.26595

[18] Verayana, Paputungan, M., & Iyabu, H. (2018). Effect of HCl and H3PO4 activators on the characteristics (pore morphology) of activated coconut shell charcoal and adsorption tests on lead (Pb) metal. *Jurnal Entropi*, 13 (1), 67-75.

[19] Jamilatun, S., Setyawan, M., Salamah, S., Purnama, D. A. A., & Putri, R. U. M. (2015). Pembuatan Arang Aktif dari Tempurung Kelapa dengan Aktivasi Sebelum dan Sesudah Pirolisis. *Seminar Nasional Sains dan Teknologi*, (0258), 1-8.

[20] Rahman, A., Murad, S. W., Mohsin, A., & Wang, X. (2024). Does renewable energy proactively contribute to mitigating carbon emissions in major fossil fuels consuming countries? *Journal of Cleaner Production*, 452 142113. https://doi.org/10.1016/j.jclepro.2024.142113

[21] Rezk, A., Ilis, G. G., & Demir, H. (2022). Experimental study on silica gel/ethanol adsorption characteristics for low-grade thermal driven adsorption refrigeration systems. *Thermal Science and Engineering Progress*, 34 101429. https://doi.org/10.1016/j.tsep.2022.101429

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