The functionalization of pyrolyzed palm empty fruit bunches-based membranes adsorbent by fourier-transform infrared spectroscopy

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Abstract. Membranes adsorbent are successfully prepared derived from palm empty fruit bunches (PEFB) which pyrolyzed by furnace as physical activation. The PEFB membrane adsorbent was activated to develop porous structures and surface area which able to be applied for gas separation. The aims of this study are to fabricated the pyrolyzed PEFB-based membrane adsorbent with different loading of PEFB mass to identify the surface organic functional groups of the PEFB membrane adsorbent. Fabrication of this membrane adsorbent was conducted into three steps, i.e. (1) pre-treated PEFB materials; (2) pyrolyzed the PEFB adsorbent at 500°C; and (3) PEFB membrane adsorbent fabrication by mixed both of PVA and PEG polymers into PEFB adsorbent with varied mass (15-17.5 grams). The functionalization of this membrane adsorbents was analysed by Fourier Transform Infra-Red (FTIR) spectra. The result shows the three variations of the PEFB membrane adsorbents present the surface oxygen, functional group. The effect of PEFB mass loading to the carbon pores formation of PEFB membrane adsorbent was exhibited by the escalating of C-H and C-O groups. The membrane adsorbent by adding 17.5 grams of PEFB mass indicating the highest peak of hydroxyl C-O at wavenumber 1070 cm⁻¹. It demonstrates that membrane adsorbent with high PEFB mass loading and physic activation by pyrolyzing is great to tailoring the membrane adsorbent structure properties which capable to be applied for gas separation, especially for biogas upgrading.

1. Introduction
In the last decade, the clean and renewable energy has attracted among the industry and researcher. Biogas is one of the alternatives to alter fossil fuels thought as energy conservation. It is a mixture of gases mainly composed of methane (CH₄) and carbon dioxide (CO₂) of 60% and 30%, respectively [1]. The
methane fraction of biogas has a huge consideration for household utilization, generated electricity or vehicles. Thus, an effective method for upgrading biogas is needed. Nowadays, the upgrading biogas mainly made using adsorption process [2]. However, this method also has limitations, including high operating costs and problems with regeneration [3].

There has been a considerable growth in the research and development of organic and inorganic membrane materials [4-6] and for the separation of gas mixtures [7, 8]. Numerous novel membrane materials have been synthesized and evaluated. A recent study was reported by Iovane et al. that exhibited the polymer membrane has capable to remove CO$_2$ over 60% and successfully upgrading the methane concentration of > 80% [9]. However, polymer membranes have also a limitation due to the requirement of a multi-stage separation process to allow the membrane operate under low pressures, and need extra treatment to extend the membrane long term [10]. In order that such a concept has already been shown to improve the separation properties of polymers membrane by incorporated adsorbent into a polymeric matrix membrane. In the present study, the zeolite adsorbents have been incorporated into a polymeric matrix to form a heterogeneous membrane for separating CH$_4$ and CO$_2$ [11]. It founds presence of zeolite adsorbent was shown suitable pore size and able to improve the separation performance of polymer polydimethylsiloxane membrane. Unfortunately, zeolite is not economic materials. Affordable materials are needed to address this limitation.

Activated carbons from biomass waste such as Oil palm empty fruit bunches (PEFB) was continuing to attracted attention for biogas upgrading as they are reversible CO$_2$ adsorbents and present high adsorption capacity per mass unit. PEFB is rich by cellulose acetate, lignin and carbon content which favourable for membrane production [12]. The employing of PEFB has become attention to surmount the environmental issue and reused them as economical products. In the present study, Raja [12] has been reported the employing PEFB activated carbon as a membrane adsorbent derived from cellulose acetate modified by zeolite for water treatment. The previous study [13] has reported that activated carbon was fabricated from PEFB was carried out via physical carbonization by pyrolyzed. Regarding Sopiah, et al. [13] the carbonization process may improve the pore structure of absorbent with small density by opening the pores are closed with tar and amorphous carbon. Furthermore, the research conducted by Elma, et al. [14] also explaining incorporation of a high concentration carbon into membrane matrix may be affected to functional group content in its membrane. It is due to carbon loading was given to enhancing the condensation reaction effect [15]. In this work, we focused on fabricated the pyrolyzed PEFB-based membrane adsorbent with different loading of PEFB mass to identify the surface organic functional groups of the PEFB membrane adsorbent.

2. Methodology

2.1 Chemical and Materials
The chemicals and materials were employed to fabricate the membrane adsorbent are isopropyl alcohol (2-propanol, Merck), ammonium chloride (NH$_4$Cl, Merck), polyethylene glycol 400 (PEG 400), polyvinyl alcohol (PVA), filter paper, deionized water (DI water Merck), and palm empty fruit bunches (PEFB) collected from PT. Citra Hasnur Terpadu, Sungai Puting Village, South Kalimantan-Indoneisa.

2.2 Experimental Methods
2.2.1 Fabrication and Characterization of Membrane Adsorbent
The palm empty fruit bunches (PEFB) were collected from oil palm plantation that has been washed by freshwater and dried for 7 days under the sunlight. After a week, the PEFB were physically activated using pyrolysis apparatus at 500°C for 30 minutes. The activated PEFB subsequently was mashed and sieved with a size of 200-400 mesh to obtain the uniform size. Furthermore, the activated charcoal is
weighed as much as 12.5 grams, 15 grams, and 17.5 grams which are then mixed with 35 ml 2-propanol and the mixture is put in a 100 ml measuring cup, stirred at 600 rpm for 10 minutes [16]. Added 3.5 grams of NH₄Cl as a cationic surfactant which has been dissolved in 300 ml of distilled water. The mixture is then stirred with a magnetic stirrer for 1 hour to form nano-sized membrane pores [16]. Separate between solid and solution, then in variations of 12.5, 2.82 grams of PVA and 4.17 ml of PEG is added to the solid, and add 5 ml of remaining solution so that the membrane can adhere well. In the 15 grams variation, 3.4 grams of PVA and 5 ml of PEG were added, and 8 ml of the remaining solution gradually until the membrane mixture was solid and well adhered. Then added 5.09 grams of PVA, 7.52 ml of PEG and 8 ml of the remaining solution for a variation of 17.5 grams. The membrane is then stirred evenly until it is shaped like a paste and sticks together perfectly. The membrane mixture is then printed by stainless steels cast with a diameter of 7 cm, then the membrane is dried in the sun for about one day. After the upper surface of the membrane is slightly dry, the membrane is then pressed using a hydraulic jack with a pressure of 100 psi. The pressed membrane is then dried again for about 2 days and followed by drying using a furnace at 105°C for 30 minutes.

Characterization of the membrane adsorbent was carried out using the FTIR test to identify the content of functional groups of organic compounds based on the resulting spectra according to the peaks formed by a functional group. The spectra were recorded from 3000 to 500 cm⁻¹. Then, the results of the FTIR data were analysed by Fityk program to determines the quantity of peak area by gaussian models.

Where:

a. Palm empty fruit bunches (PEFB) are dried in the sun
b. Pyrolysis Apparatus
c. 200 & 400 mesh sieve size
d. Hot plate
e. Hydraulic jack
f. Adsorber membrane

Figure 1. The schematic fabrication of membrane adsorbent
3. Result and Discussion

3.1 Preparation of PEFB Membrane Adsorbent

Oil palm biomass has been great importance as various parts such as trunks, fronds, leaves, shells, and empty fruit bunches (EFB) for extensively studied as adsorbents. Palm empty fruit bunches (PEFB) is one of the largest amounts of solid wastes produced from an oil palm plantation is about 22-24% of the total fresh fruit bunch weight [17]. In the industrial sector, PEFB has an economic enough value, due to has millions of organic fibres that can be used in various fields, especially as raw material for producing such as activated charcoal, briquette raw materials, membranes adsorbent and many other benefits [18]. Due to high organic content in PEFB, makes it perfect for processing membrane adsorbent which can be applied for biogas upgrading. The complete chemical composition of the crude PEFB is shown in Table 1.

Table 1. Chemical Composition of Palm Empty Fruit Bunches Biomass

| Chemical composition | (%) of Raw PEFB | [17] | [19] | [20] |
|----------------------|----------------|------|------|------|
| Lignin               | 22.60          | 15.70| 17.84|
| Pentosan             | 25.90          | -    |      |
| A-Cellulose          | 45.80          | -    | 50.49|
| Holocellulose        | 71.88          | -    | 80.09|
| Ash                  | 1.6            | -    |      |
| Pectin               | 12.85          | -    |      |

Table 1 shows the summarized of the chemical composition of raw PEFB biomass. The highest chemical composition contains in PEFB are cellulose and holocellulose. In fundamental, lignocellulose substances contain three chief structural components: hemicellulose, cellulose and lignin. That three main parts have high molecular weights and contribute much mass, while the extractives are of small molecular size and are available in little quantity [20]. The hemicellulose chains have short branches and are amorphous. Amorphous morphology is partially soluble or swellable in water as shown in Table 2.

Table 2. Physical Properties of Palm Empty Fruit Bunches Biomass

| PEFB Physic Properties | (%) of PEFB | References |
|------------------------|-------------|------------|
| Solubility in aqueous  | 19.50-31.17 | [19]       |
| sodium hydroxide 1%    |             |            |
| Solubility in cold     | 13.89-14.79 | [17]       |
| water (30°C)           |             |            |
| Solubility in hot      | 2.50-14.79  | [17]       |
| water (100°C)          |             |            |
| Solubility in alcohol-benzene | 5.00 | [19]       |

Hemicellulose is mostly soluble in alkali and as such is more easily hydrolysed. Cellulose is formed by joining the anhydro-glucose units into glucose chains and act as a linear polymer chain. Cellulose is insoluble in largely solvents and has low accessibility to enzymatic hydrolysis and acid as shown in Table 2. Lignin is a natural polymer or aromatic compounds. It acts as a cementing agent matrix of cellulose fibres in the structures of plants along with hemicellulose. Their functions are to provide structural strength, provide sealing of water conducting system that links roots with leaves, and protect plants against degradation. This matrix comprises a variety of functional groups, such as hydroxyl, methoxyl,
and carbonyl, which impart a high polarity to the lignin macromolecule [20]. PEFB biomass is now considered to be one of the most promising non-wood lignocellulosic raw materials as adsorbents.

Generally, there was three main steps process to fabricates the PEFB membrane adsorbent in this work, i.e. (1) pre-treated PEFB materials by washed the raw PEFB using freshwater and dried it under sunlight for 7 days. Indirectly these compounds must be removed or first so that they do not directly affect the surface of the absorbent membrane and increase effectiveness activated carbon. (2) Activated PEFB adsorbent using pyrolyzed at 500 °C for 30 min in activated carbon reservation. (3) Finally, PEFB adsorbents were sieved at 200-400 mesh to obtain the uniform sizes of an adsorbent. The study has reported a physical activation process gives a similar morphological compared to adsorbent from chemical-physical activation [21]. Larger pore size has found than activated carbon resulting from chemical activation [22].

The functional groups or carbon bonds can be seen based on the results of the FTIR analysis. In the Hidayu et al. (2013) work states that crude oil palm empty bunches have a complex and very clear spectrum, this is indicated by the adsorption peak at 3302 cm\(^{-1}\) which is associated with the O-H stretch functional group and this indicates the presence of bound hydroxide compounds in crude PEFB. The distribution of the peak point of the wave is also found at a wavelength of 1739 cm\(^{-1}\) which is indicated as the functional group C = O. The wavelength at 1216 cm\(^{-1}\) and 1032 cm\(^{-1}\) of PEFB membrane adsorbent also indicates the C-O stretch functional group [15]. Broadly speaking, crude oil palm empty bunches cannot be applied directly in the manufacture of adsorbent membranes, the presence of several compounds and functional groups contained in oil palm empty bunches will of course indirectly affect the surface area and effectiveness of the membrane. So that the compound or carbon content contained in it must be removed first using carbonization and physical activation, by the pyrolysis process at a temperature of 500°C as shown in Figure 2. The temperature of 500°C was chosen because most of the volatile material of PEFB evaporates at 410°C - 520°C. The small number of impurities are disappeared and become easier for further processing [23]. In addition, this physical activation is also required so that the pore structure of the membrane more stable and offers high absorption capacity [24].

![Figure 2. Membrane adsorbent derived from PEFB which pyrolyzed at 500 °C by loading of 17.5 grams biomass](image)

The PEFB membrane adsorbent has been cast using stainless steels mold, before the samples were analyzed using the Fourier Transform Infrared (FTIR) analysis to see the functional groups of all the sample. The conducted of PEFB membrane adsorbent after the cast has a diameter and thickness of 7 cm and 0.8 cm, respectively for biomass loading 17.5 grams (Figure 2). The multiple PEFB membrane adsorbent physic shape results are shorted in Table 3. The entire upper and lower surface of each membrane is smooth and flat and does not leave residual grains as can be seen in Figure 2.
Table 3. PEFB Membrane Adsorbent Physic Shape Result Measurement

| PEFB loading mass (grams) | Diameter (cm) | Thickness |
|---------------------------|---------------|-----------|
| 12.5                      | 7             | 0.4       |
| 15                        | 7             | 0.6       |
| 17.5                      | 7             | 0.8       |

3.2 Functionalization of PEFB Membrane Adsorbent

This study discusses the pyrolyzed PEFB-based membrane adsorbent with multiple biomass addiction is given in Figure 3. It shows FTIR spectra by adding 12.5, 15 and 17.5 grams of PEFB biomass at wavelength 3000-500 cm\(^{-1}\). The band found in the region of 1067-1076 cm\(^{-1}\) indicates to the C-O stretching vibration as a function of secondary alcohol groups (Figure 3). In line with the result reported by Nandiyanto, et al. [25]. The deconvolution of C-O group was presented in Table 4. Regarding the result, the highest PEFB loading mass of 17.5 grams also demonstrates the highest peak which almost 2-3 times broader than PEFB loading mass of 12.5 and 15 grams. Meanwhile, the band of 1236-1243 cm\(^{-1}\) were identified as aromatic ether groups with functional groups alkyl O–H stretch [25]. The broader of O-H group would imply increasing the water absorbing on the surface. This result same in line with a similar study by [26], has investigated coconut shell based activated carbon. Interestingly, the C-H mode only appears by PEFB loading mass of 12.5 and 17.5 grams at the wavelength region of 1440 and 1439 cm\(^{-1}\). The C-H stretching mode was indicating the function of cellulose groups [27]. Sharpening bands of C = C-C which a whole wave is associated with the aromatic ring stretch which observed at ~1580 cm\(^{-1}\).

Table 4. Deconvolution of PEFB Membrane Adsorbent Functionalize using Fityk Program

| PEFB loading mass (grams) | C-O groups (unit area) | C=C=C group (unit area) |
|---------------------------|------------------------|-------------------------|
| 12.5                      | 2.30                   | 0.25                    |
| 15                        | 1.89                   | 0.18                    |
| 17.5                      | 4.58                   | 0.71                    |

Based on this work the difference biomass weight loading has a significant effect on the functional groups produced, especially C-O and aromatic groups (C=C=C) [28]. Moreover, the pyrolyzed process greatly affects the deoxygenation process with lignocellulosic material to reduce the aliphatic structure in the C-O aromatic structure [29]. The pyrolyzed excellently affected based on Figure 3. The activation temperature is an important factor on the formation quality of activated carbon, so it has been impacted by the absorption capacity of carbon in ionic levels [30]. The physical activations carried out on each of the adsorbent membrane variations still leave compounds that are dominated by carbon elements which are covalently bonded, and of course, this is very helpful in expanding the membrane surface so that the pores are open and with thus has a great absorption of other substances, especially in the gas phase [13]. On the outer surface OH increase rapidly, this results in line with previous research [31, 32].
Figure 3. FTIR spectra of membrane adsorbent derived from PEFB which pyrolyzed at 500 °C by loading of varied PEFB mass

4. Conclusion
Membranes adsorbent are successfully fabrication by employing palm empty fruit bunches (PEFB) biomass waste. The PEFB membranes adsorbent were activated by physical activation to the developed porous structure and high surface area. The functionalization of all biomass weight variation on the membrane adsorbent identifying the C-O stretch functional groups dominates in all sample. Most of the O-H (water) content in the membrane perfectly evaporates during the activation process. So that what remains is only other carbon elements that are needed in the process of forming membrane pores. Furthermore, physical activation leads the membrane adsorbent to carbonization and enlarging the surface area of the membrane to apply for gas purification.

References
[1] M. A. Lourenço, C. Nunes, J. R. Gomes, J. Pires, M. L. Pinto, and P. Ferreira, "Pyrolyzed chitosan-based materials for CO2/CH4 separation," *Chemical Engineering Journal*, vol. 362, pp. 364-374, 2019.
[2] C. A. Grande, D. Morence, A. M. Bouzga, and K. A. Andreassen, "Silica gel as a selective adsorbent for biogas drying and upgrading," *Industrial & Engineering Chemistry Research*, 2020.
[3] C. G. Joseph, M. Wan, K. S. Quek, and S. Kogularama, "Parametric and adsorption kinetic studies of reactive black 5 removal from textile simulated wastewater using oil palm (Elais guineensis) empty fruit bunch," *Journal of Applied Sciences*, vol. 15, no. 8, pp. 1103-1111, 2015.
[4] A. Rahma, M. Elma, E. L. A. Rampun, A. E. Pratiwi, A. Rakhman, and Fitriani, "Rapid Thermal Processing and Long Term Stability of Interlayer-free Silica-P123 Membranes for Wetland Saline Water Desalination," *Advanced Research in Fluid Mechanics and Thermal Sciences*, vol. 71, no. 2, pp. 1-9, July 2020 2020, Art no. 1.
[5] A. Rahma, M. Elma, A. E. Pratiwi, and E. L. Rampun, "Performance of interlayer-free pectin template silica membranes for brackish water desalination," Membrane Technology, vol. 2020, no. 6, pp. 7-11, 2020.

[6] M. Elma et al., "Carbon templated strategies of mesoporous silica applied for water desalination: A review," Journal of Water Process Engineering, vol. 38, p. 101520, 2020/12/01/ 2020.

[7] F. M. Baena-Moreno, E. le Saché, L. Pastor-Pérez, and T. Reina, "Membrane-based technologies for biogas upgrading: a review," Environmental Chemistry Letters, pp. 1-10, 2020.

[8] C. Liang, G. Sha, and S. Guo, "Carbon membrane for gas separation derived from coal tar pitch," Carbon, vol. 37, no. 9, pp. 1391-1397, 1999.

[9] P. Iovane, F. Nanna, Y. Ding, B. Bikson, and A. Molino, "Experimental test with polymeric membrane for the biogas purification from CO2 and H2S," Fuel, vol. 135, pp. 352-358, 2014/11/01/ 2014.

[10] K. Khulbe and T. Matsuura, "Removal of heavy metals and pollutants by membrane adsorption techniques," Applied water science, vol. 8, no. 1, p. 19, 2018.

[11] J. M. Duval, B. Folkers, M. H. V. Mulder, G. Desgrandchamps, and C. A. Smolders, "Adsorbent filled membranes for gas separation. Part 1. Improvement of the gas separation properties of polymeric membranes by incorporation of microporous adsorbents," Journal of Membrane Science, vol. 80, no. 1, pp. 189-198, 1993/06/02/ 1993.

[12] P. M. Raja, "PEMBUATAN MEMBRAN SELULOSA ASETAT DARI TANDAN KOSONG KELAPA SAWIT TERMODIFIKASI MIKRO ZEOLIT ALAM UNTUK FILTRASI AIR SUNGAI," Journal Agro Estate, vol. 1, no. 1, pp. 27-33, 2017.

[13] M. Elma, D. K. Wang, C. Yacou, and J. C. D. d. Costa, "Interlayer-Free P123 Carbonised Template Silica Membranes for Desalination with Reduced Salt Concentration Polarisation," Journal of Membrane Science, vol. 475, pp. 376-383, 2015.

[14] G. Q. Lu et al., "Inorganic membranes for hydrogen production and purification: A critical review and perspective," Journal of Colloid and Interface Science, vol. 314, no. 2, pp. 589-603, 2007/10/15/ 2007.

[15] V. Rachmawati and A. Damayanti, "Pengolahan Limbah Cair Industri Pewarnaan Jeans Menggunakan Membran Silika Nanofiltrasi Aliran Cross Flow untuk Menurunkan Warna dan Kekeruhan," Jurnal Teknik ITS, vol. 8, no. 2, pp. D113-D117, 2013.

[16] M. Elma, D. K. Wang, C. Yacou, and J. C. D. d. Costa, "Interlayer-Free P123 Carbonised Template Silica Membranes for Desalination with Reduced Salt Concentration Polarisation," Journal of Membrane Science, vol. 475, pp. 376-383, 2015.

[17] G. Q. Lu et al., "Inorganic membranes for hydrogen production and purification: A critical review and perspective," Journal of Colloid and Interface Science, vol. 314, no. 2, pp. 589-603, 2007/10/15/ 2007.

[18] V. Rachmawati and A. Damayanti, "Pengolahan Limbah Cair Industri Pewarnaan Jeans Menggunakan Membran Silika Nanofiltrasi Aliran Cross Flow untuk Menurunkan Warna dan Kekeruhan," Jurnal Teknik ITS, vol. 8, no. 2, pp. D113-D117, 2013.

[19] M. Elma, D. K. Wang, C. Yacou, and J. C. D. d. Costa, "Interlayer-Free P123 Carbonised Template Silica Membranes for Desalination with Reduced Salt Concentration Polarisation," Journal of Membrane Science, vol. 475, pp. 376-383, 2015.

[20] G. Q. Lu et al., "Inorganic membranes for hydrogen production and purification: A critical review and perspective," Journal of Colloid and Interface Science, vol. 314, no. 2, pp. 589-603, 2007/10/15/ 2007.

[21] V. Rachmawati and A. Damayanti, "Pengolahan Limbah Cair Industri Pewarnaan Jeans Menggunakan Membran Silika Nanofiltrasi Aliran Cross Flow untuk Menurunkan Warna dan Kekeruhan," Jurnal Teknik ITS, vol. 8, no. 2, pp. D113-D117, 2013.

[22] M. Elma, D. K. Wang, C. Yacou, and J. C. D. d. Costa, "Interlayer-Free P123 Carbonised Template Silica Membranes for Desalination with Reduced Salt Concentration Polarisation," Journal of Membrane Science, vol. 475, pp. 376-383, 2015.

[23] G. Q. Lu et al., "Inorganic membranes for hydrogen production and purification: A critical review and perspective," Journal of Colloid and Interface Science, vol. 314, no. 2, pp. 589-603, 2007/10/15/ 2007.

[24] V. Rachmawati and A. Damayanti, "Pengolahan Limbah Cair Industri Pewarnaan Jeans Menggunakan Membran Silika Nanofiltrasi Aliran Cross Flow untuk Menurunkan Warna dan Kekeruhan," Jurnal Teknik ITS, vol. 8, no. 2, pp. D113-D117, 2013.

[25] M. Elma, D. K. Wang, C. Yacou, and J. C. D. d. Costa, "Interlayer-Free P123 Carbonised Template Silica Membranes for Desalination with Reduced Salt Concentration Polarisation," Journal of Membrane Science, vol. 475, pp. 376-383, 2015.
perak dalam larutan," *Pontianak: Jurusan Kimia, Fakultas Matematika dan Ilmu Pengetahuan Alam Universitas Tanjungpura*, 2009.

[23] R. K. Liew *et al.*, "Oil palm waste: an abundant and promising feedstock for microwave pyrolysis conversion into good quality biochar with potential multi-applications," *Process Safety and Environmental Protection*, vol. 115, pp. 57-69, 2018.

[24] A. Geng, "Conversion of Oil Palm Empty Fruit Bunch to Biofuels," 2013.

[25] A. B. D. Nandiyanto, R. Oktiani, and R. Ragadhita, "How to read and interpret FTIR spectroscopy of organic material," *Indonesian Journal of Science and Technology*, vol. 4, no. 1, pp. 97-118, 2019.

[26] I. Tan, M. Abdullah, L. Lim, and T. Yeo, "Surface modification and characterization of coconut shell-based activated carbon subjected to acidic and alkaline treatments," *Journal of Applied Science & Process Engineering*, vol. 4, no. 2, pp. 186-194, 2017.

[27] P. M. Abdul *et al.*, "Effects of changes in chemical and structural characteristic of ammonia fibre expansion (AFEX) pretreated oil palm empty fruit bunch fibre on enzymatic saccharification and fermentability for biohydrogen," *Bioresource Technology*, vol. 211, pp. 200-208, 2016.

[28] M. Bakhtiar, N. Sari, A. B. Yaacob, M. Yunus, and K. B. Ismail, "Characterization of oil palm Empty Fruit Bunch (EFB) biochar activated with potassium hydroxide under different pyrolysis temperature," *Journal of Engineering Science and Technology*, vol. 14, no. 5, pp. 2792-2807, 2019.

[29] S. Yavari, A. Malakahmad, N. B. Sapari, and S. Yavari, "Synthesis optimization of oil palm empty fruit bunch and rice husk biochars for removal of imazapic and imazapyr herbicides," *Journal of environmental management*, vol. 193, pp. 201-210, 2017.

[30] R. Idrus, B. P. Lapanporo, and Y. S. Putra, "Pengaruh suhu aktivasi terhadap kualitas karbon aktif berbahan dasar tempurung kelapa," *Prisma Fisika*, vol. 1, no. 1, 2013.

[31] C.-H. Ooi, W.-K. Cheah, Y.-L. Sim, S.-Y. Pung, and F.-Y. Yeoh, "Conversion and characterization of activated carbon fiber derived from palm empty fruit bunch waste and its kinetic study on urea adsorption," *Journal of environmental management*, vol. 197, pp. 199-205, 2017.

[32] D. Prahas, Y. Kartika, N. Indraswati, and S. Ismadji, "Activated carbon from jackfruit peel waste by H3PO4 chemical activation: Pore structure and surface chemistry characterization," *Chemical Engineering Journal*, vol. 140, no. 1-3, pp. 32-42, 2008.

[33] N. H. A. Rani, N. F. Mohamad, S. Matahi, and S. A. S. A. Kadir, "Preparation and characterization of activated carbon made from oil palm empty fruit bunch," *Key Engineering Materials*, 2014.

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