JURNAL ILMU LINGKUNGAN
Volume 23 Issue 3 (2025) : 647-657 ISSN 1829-8907

Synthesis and Characterization Analysis of Banana Peel Carbon Activated as Adsorption of Copper (Cu)

Mira Ayu Rahmawati[1], Abdul Ngalimus Salam[1], Wahyudi Nandana Munte[3], Nidya Chitraningrum[2], dan Lita Rahmasari[1*]

[1]Faculty of Teacher Training and Education, Universitas Sebelas Maret, Surakarta, Indonesia; e-mail: lita@staff.uns.ac.id
[2]Research Center for Biomass and Bioproducts, National Research and Innovation Agency, Bogor, Indonesia
[3]Department of Physics, University of Riau, Simpang Baru, Pekanbaru, Indonesia

ABSTRAK

Karbon aktif merupakan bahan berpori yang banyak digunakan dalam berbagai aplikasi industri dan lingkungan, terutama sebagai adsorben dalam pengolahan limbah cair dan pemurnian gas. Kulit pisang, sumber karbon yang melimpah dan terbarukan merupakan bahan baku karbon aktif yang ramah lingkungan dan berkelanjutan. Optimalisasi proses aktivasi sangat penting untuk meningkatkan karakteristik dan kinerja adsorpsi dari karbon aktif. Penelitian ini bertujuan untuk mengevaluasi pengaruh aktivasi KOH terhadap sintesis dan karakterisasi karbon aktif berbasis kulit pisang. Proses karbonisasi dan aktivasi kimia dilakukan, dilanjutkan dengan morfologi dan karakterisasi struktur kimia dilakukan dengan menggunakan Field Emission Scanning Electron Microscopy (FE-SEM), Energy Dispersive X-ray (EDX), dan Fourier Transform Infrared Spectroscopy (FTIR). Analisis menunjukkan bahwa karbon aktif yang diperoleh memiliki struktur pori yang berkembang dengan baik dengan tingkat porositas 74,80% dan mengandung gugus fungsi O-H, C-H, C=O, dan C-Cl, yang berperan dalam interaksi ion logam. Sifat hidrofilik karbon aktif diamati melalui analisis sudut kontak, sedangkan kapasitas adsorpsi terhadap ion tembaga (Cu) ditentukan menggunakan Atomic Absorption Spectrophotometer (AAS). Hasil penelitian menunjukkan bahwa efisiensi adsorpsi tertinggi sebesar 99,99% dicapai oleh karbon aktif dengan konsentrasi 20% dan waktu kontak 15 menit. Dengan karakteristik pori yang baik dan efisiensi adsorpsi yang tinggi, karbon aktif berbasis kulit pisang berpotensi menjadi adsorben yang efisien dan berkelanjutan dalam aplikasi pengolahan limbah logam berat. Penelitian ini memberikan wawasan lebih lanjut tentang pemanfaatan limbah biomassa untuk menghasilkan bahan fungsional yang bernilai tinggi.

Kata Kunci: Adsorpsi, Tembaga (Cu) , Aktivasi Karbon, Kulit Pisang, Karbonisasi, Kalium Hidroksida

ABSTRACT

Activated carbon is a porous material widely used in various industrial and environmental applications, especially as an adsorbent in liquid waste treatment and gas purification. Banana peel, an abundant and renewable carbon source, is an environmentally friendly and sustainable raw material for activated carbon. However, optimization of the activation process is essential to improve the characteristics and adsorption performance of activated carbon. This study aims to evaluate the effect of KOH activation on the synthesis and characterization of banana peel-based activated carbon. Carbonization and chemical activation processes were carried out, then morphology and chemical structure characterization were performed using Field Emission Scanning Electron Microscopy (FE-SEM), Energy Dispersive X-ray (EDX), and Fourier Transform Infrared Spectroscopy (FTIR). The analysis showed that the activated carbon obtained has a well-developed pore structure with a porosity level of 74.80% and contains O-H, C-H, C=O, and C-Cl functional groups, which play a role in metal ion interactions. The hydrophilic nature of the activated carbon was studied through contact angle analysis, while the adsorption capacity towards copper ions (Cu) was determined using an Atomic Absorption Spectrophotometer (AAS). The results showed that the highest adsorption efficiency of 99.99% was achieved on activated carbon with 20% concentration and 15 minutes contact time. With good pore characteristics and high adsorption efficiency, banana peel-based activated carbon has the potential to be an efficient and sustainable adsorbent in heavy metal waste treatment applications. This research provides further insight into the utilization of biomass waste to produce functional materials of high-added value.

Keywords: Adsorption, Copper (Cu), Activated Carbon, Banana Peel, Carbonization, Potassium hydroxide

Citation: Rahmawati, M. A., Salam, A. N., Munte, W. N., Chitraningrum, N., dan Rahmasari, L. (2025). Synthesis and Characterization Analysis of Banana Peel Carbon Activated as Adsorption of Copper (Cu). Jurnal Ilmu Lingkungan, 23(3), 647-657, doi:10.14710/jil.23.3.647-657

1. INTRODUCTION

The banana tree provides leaves, fruits, and stems for various uses. It is easy to locate banana trees throughout practically all of Indonesia (Agarry, 2019). Fruits from banana plants come in various sizes, some of which are small, such as milk bananas, and which have a length of around 10–15 cm. When bananas are ripe or unripe, various processing methods can be applied (Haider, 2022). When the banana fruit is not fully ripe, it can be transformed into banana chips and banana rolls. One can process the banana fruit into banana cake and fried bananas and sell or consume it raw when ripe. Considering that Indonesia consumes many bananas, an average of 24.71 grams per person per day, and that the country can produce 11,232,397 quintals of bananas in 2021, there is a lot of banana peel waste and little other use for banana peels besides animal feed (Allwar, 2019).

Activated carbon is a porous solid containing 85% to 95% carbon. High temperatures will treat the raw material for producing activated carbon (Arsad, 2010). Activated carbon is created using a variety of raw materials and is subsequently applied as an adsorbent for deodorizing, purifying water, and purifying garbage. Using activated carbon can increase the capacity and power capacity of batteries. Potassium hydroxide (KOH) is one of the activators that is typically employed in the carbon activation process to create activated carbon. Utilize banana peels to create activated carbon, benefiting both the environment and the local community (Aulia, 2018).

Manufacturers produce activated carbon from carbon-containing materials or charcoal, treating it specially to achieve high adsorption power (Damayanti and Hidayah, 2023). Activated carbon can absorb gases, certain chemical compounds, or selective adsorption properties, depending on the size or volume of the pores and surface area. The adsorption capacity of activated carbon is very large, which is 25-1000% by weight of activated carbon (Darwesh et al, 2022). Activated carbon is often used to reduce organic contaminants and synthetic organic chemical particles, but activated carbon is also effective for reducing inorganic contaminants such as radon, mercury, and other toxic metals. Activated carbon's particle size influences adsorption speed but not adsorption capacity, which correlates with the carbon's surface area (Erlina et al, 2015).

Adsorption is the phenomenon that gases or liquids collect on the surface of a solid. Adsorption is also defined as the capture of molecules by the outer or inner surface of an adsorbent solid or by the surface of a solution (Gumarang, 2019). The adsorption process can be described as the process of material molecules sticking to the surface of the adsorbent due to van der Wall forces and chemical bonds on the surface of the solid. In adsorption, the interaction between the adsorbent and the adsorbate only occurs on the surface of the adsorbent (Hartanto et al, 2010). The effectiveness of adsorption is influenced by various factors, such as solution pH, initial concentration of Cu, contact time, activated carbon dosage, and temperature. The molecules bound to the interface are called adsorbates, while the surface that adsorbs the adsorbate molecules is called the adsorbent, such as zeolite, activated carbon, silica, and porous clay (Kwok, 1999). The adsorbent is a substance that adsorbs called, while the adsorbed substance is called adsorbate (Lestari, 2021). The adsorbing power of activated carbon can be influenced by the carbon content contained in the material (Meilinda, 2023). Therefore, activated carbon can be made from materials that contain a lot of carbon, such as wood, coconut shells, cassava peels, and banana peels (Nadew et al, 2023)

Potassium hydroxide (KOH) is a chemical compound that is a very basic metal base called a strong base and has a molar mass of 56.1056 g/mol. Potassium hydroxide is an inorganic compound commonly referred to as caustic potash [16]. Using a Potassium hydroxide (KOH) activator in the process of making activated carbon has the advantage of increasing the number of pores in the carbon electrode, resulting in a larger surface area (Nadew et al, 2018). The inorganic substance Potassium hydroxide is also known as caustic potash. Making activated carbon using a Potassium hydroxide (KOH) activator increases the number of pores in the carbon electrode, creating a greater surface area (Wells, 2012).

Based on research conducted by Hartanto et al (2010), the manufacture of activated carbon from oil palm bunches with activation of NaOH, NaCl, and HCl obtained activated carbon with the best pores and adsorption power, namely by NaOH activator at 500^0C. Other research conducted by Al Haider et al. (2022) proves that activated carbon with chemical activators will have greater porosity than activated carbon without chemical activation. Based on previous research conducted by Erlina et al (2015) that activated carbon from coconut shell using KOH activator can reduce copper metal levels by 83.57%, and research conducted by Shafirinia et al (2016) proves that activated carbon from banana peel waste using NaOH activator can reduce copper metal levels by 96%.

Researchers also created activated carbon from leftover banana peels using KOH activator, hoping it would have better adsorption characteristics. Based on the explanation above, researchers will utilize banana peel waste as an ingredient in making activated carbon using Potassium hydroxide (KOH) as the activator. Later, this activated carbon will be useful to reduce banana peel waste in the community and be useful for the surrounding environment and for industry.

2. MATERIAL AND METHODES

To make activated carbon, take the banana peel from the stump, clean it, and chop it into little pieces before draining it. After the peels have been drained, they will be placed in an oven set to 80°C. After drying, we will grind the banana peels in a disk mill and then sieve them through a 20-mesh screen. After that, it will undergo an hour-long combustion process in a furnace that operates at 500°C. After the sample passes through a 100-mesh filter, mash it. Next, we used Potassium hydroxide (KOH) to reach the activation stage. It is then dried and burned again at 800°C before being neutralized with hydrochloric acid (HCl) and dried again to produce activated carbon. Using the pyrolysis method, which is an oxygen-free burning process that raises the carbon content of charcoal, activating carbon can be produced.

3. PREPARATION OF MATERIALS

Peels from bananas that have been removed from the stump, rinsed under running wated, sliced into little pieces, and drained until no water is left to leak.

3.1. Activated Carbon Manufacturing

After draining, the banana peels will be baked at 80°C. The banana peels will be crushed and sieved through a 20-mesh screen after drying. After that, it will undergo an hour-long combustion process in a furnace that operates at 500°C. After that, the material is ground up untill it passes through a 100-mesh filter. After two hours of chemical activation with KOH, the sample will be dried for twenty-four hours at 105°C. Subsequently, the sample will be burned again with nitrogen gas flowing through an 800°C furnace. The sample will next be cleaned with distilled water and neutralized with HCl. Next, it was dried in an oven and sieved through a 200-mesh screen.

3.2. Activator Manufacturing

Chemical activation is one of the activation processes used to create activated carbon. Activating agents, like KOH, are employed in chemical activation to activate carbon. The process is straightforward: the chemical activation agent-containing solution is soaked into the biomass's surface, dried in an oven, and then activated in a furnace for about one hour. Higher final carbon yield, a one-step procedure, a generally lower activation temperature, and simpler porosity adjustment are benefits of the chemical activation approach (Anetha, 2022). There are two methods to carry out the carbonization and activation stages: either in a single-stage process where the carbonization and activation are carried out consecutively in the same reactor, or in a two-stage approach where the processes are separated in time (Alifaturrahma, 2018). The disordered carbon is eliminated during the first stage of the activation process, which allows the lignin to interact with the activating agent and promotes the formation of the microstructure. Large-size pores form in the later phase as the walls separating the pores burn away, causing the pores to grow. Micropore volume declines throughout this period, but trans pores and microporosity rise. Activation is therefore a crucial step in the creation of activated carbon.

Potassium hydroxide (KOH) crystals are combined with distilled water to create KOH activator. Combine 10 grams of crystal KOH with 100 milliliters of distilled water to make 10% KOH. Additionally, 20% of activators can be made by dissolving 20 grams of KOH in 100 milliliters of distilled water, and 40% of activators can be made by dissolving 40 grams of KOH in 100 milliliters of dried water. To activate carbon, it must first be burned in a furnace, weighed, and then immersed in a Potassium hydroxide (KOH) solution. There are three different concentrations of the activator: 10%, 20%, and 40. The ratio of the banana peel sample to the activator solution was used to carry out the activation process. Filter paper was used to filter the sample after it had been soaked. After that, the material was cleaned with distilled water until the pH was neutral, and it was dried at 105°C.

3.3. Activated Carbon

The carbon will be weighed at 30 grams, burned in the furnace machine, and then immersed in Potassium hydroxide (KOH) solution as part of the activation process. The three distinct activator concentrations are 10%, 20%, and 40%. For activation, a 1:6 ratio between the banana peel sample and the activator solution was utilized. After the sample was soaked, filter paper was used to filter it. After being cleansed with distilled water until the pH was neutral, the object was dried at 105°C.

3.4. Characterization

Morphology and chemical composition of activated carbon can be observed through testing using Field Emission Scanning Electron Microscope (FE-SEM) and Energy Dispersive X-ray (EDX) characterization. Fourier Transform Infrared Spectroscopy (FTIR) testing is also used in this study to identify the functional groups contained in activated carbon. In addition, the pH analysis of activated carbon that has been carried out shows a neutral pH that is at a value of 7, which indicates a balance in the concentration of hydrogen ions (H^+) and hydroxide (OH-) (Putri et al, 2022).

Field Emission Scanning Electron Microscope (FE-SEM) testing is an electron microscope analysis method used to examine the surface morphology of samples with high resolution. The atomic number of the elements present on the specimen's surface determines how intense these additional electrons are. The resolution of electron microscopy is between 0.1 and 0.2 nm. We can also obtain a variety of reflections with electrons that are helpful for characterizing (Anggraini et al, 2022). Elastic and non-elastic reflections are the two forms of reflections that occur when electrons strike an object. Through the photoelectric effect, electrons are produced from the cathode (electrode gun) and accelerated in the direction of the anode. Usually, tungsten or lanthanum hexaboride (LaB6) filament is utilized. The electrons are deflected by the scanning coil into a series of smaller beam arrays known as scanning beams, which are then focused on the sample surface by an objective (magnetic) lens (Rahmah, 2016).

Electrons lose energy in collisions with atoms of the substance. This causes scattering and adsorption at depths ranging from 100 nm to 2 µm in the contact zone. The processed signal in an FE-SEM is the outcome of detecting electrons that are departing from the sample surface. A new technique known as Field Emission Scanning Electron Microscopy (FE-SEM) emerged in 1936 when Erwin Muller introduced Field Emission Microscopy, a type of electron microscope that allowed for higher-resolution images. This development was made possible by the advancement of technology used in SEM. Field Emission Scanning Electron Microscopy (FE-SEM) is an advanced technology used to capture images of the microstructure of materials.

A chemical analysis technique called Energy Dispersive X-ray (EDX) is used to ascertain the chemical element makeup of samples, particularly solid materials. By detecting and quantifying the X-rays produced by the interaction between the sample and X-rays aimed at the sample, Energy Dispersive X-Ray (EDX) testing aims to gather information on the composition of elements present in the sample. The characterization of materials using energy-dispersive X-rays (EDX), which are released when a substance collides with electrons, is known as EDX. Since X-rays are released via electron transitions in the atomic shell layer, the energy level is dependent on the energy level of the atomic shell (Shafirinia et al, 2016). Therefore, it is feasible to determine the mass percentage of the constituent atoms in the material by measuring the energy level and intensity of X-rays that are released. An EDX array comprises four primary parts: the analyzer, light beam source, pulse processor, and X-ray detector. Nonetheless, the SEM contains the most widely used EDX system. To generate and focus an electron beam, the SEM is outfitted with a cathode, magnetic lens, and, since the 1960s, an element analysis feature (Yusuf et al, 2021).

The X-ray energy is transformed into a signal by a detector, which then sends the signal to an analyzer for data display and analysis of the degree of surface defect formation. This device shines a high-intensity beam of electron-charged particles, or x-rays, on the specimen. At first, the specimen's atoms possess exciting, ground-state electrons, each of which has a distinct energy level. Subsequently, the abruptly incoming high-energy photons excite the inner shell electrons and drive them out of the shell, creating an electron hole. Higher energy electrons from the outer shell fill the hole; X-rays result from the energy differential between the lower-energy skin and the high-energy shell.

A chemical analysis technique called Fourier Transform Infrared Spectroscopy (FTIR) is used to examine how molecules in a sample interact with infrared light. This technique enables the measurement of a material's infrared spectrum as well as the detection of chemical bonds within molecules. An analytical technique known as Fourier Transform Infrared Spectroscopy (FTIR), also known as infrared spectroscopy, is based on the idea that when a chemical compound interacts with electromagnetic radiation, a polyatomic chemical bond or functional group of a chemical compound will vibrate. Another name for this method is vibrational spectroscopy. FTIR spectroscopy simply needs basic preparation of the sample, is non-destructive, and analyzes swiftly. The concept of radiation interference between two beams to create an interferogram is the foundation of the FTIR spectrophotometer. A signal that is generated as a function of the path length difference between two beams is called an interferogram. The Fourier transform is a mathematical technique that can be used to swap the two domains, frequency and distance (Suthers et al, 2019). The three vibrational spectroscopy types that are most frequently used in the pharmaceutical industry are Raman, mid/ end infrared, and near-infrared spectroscopy. As a region with a high concentration of fundamental vibrations, the mid-infrared spectrum is crucial for qualitatively investigating biological systems. The middle infrared is the same region as the Raman spectrum. Chemical structure confirmation is primarily employed in the near-infrared range and is rarely used in the far infrared (Wiberg et al, 2001).

Because they use little to no solvents or chemical reagents to prevent potential hazards and lower analysis costs, the three techniques and instruments in the method are interesting methods that can be used for research, product quality assurance, and green chemical analysis. The far infrared spectrum (<400 cm^{-1}), the middle infrared spectrum (400–4000 cm^{-1}), and the near-infrared spectrum (400–1300 cm^{-1}) are the three wave number zones that make up IR spectra. Although the far and near-infrared spectra are also useful in revealing details about the material under study, the mid-infrared spectrum is the one that is most frequently employed in sample analysis. There are four sections in the mid-IR spectrum: (i) the fingerprint region (600-1500 cm^{-1}), (ii) the triple bond region (2000-2500 cm^{-1}), (iii) the double bond region (1500-2000 cm^{-1}), and (iv) the single bond region (2500-4000 cm^{-1}) (Wells, 2012).

The contact angle is the angle formed by two lines, where the first line is the boundary line between air and the liquid dropped, and the second line is the line between liquid and solid dropped. Contact angles can be used to determine if a surface can be wet (hydrophilic, $0° \leq \theta \leq 45°$) or not (hydrophobic, $90° \leq \theta \leq 180°$). Atomic adsorption spectrophotometer (AAS) analysis is used to establish metallic elements in rocks, soil, plants, food, and beverages, including meat and other materials. The atoms that adsorb radiant energy in AAS are atoms that are at the ground energy level (Kwok, 1999).

3.5. Adsorption Phenomone

Adsorption is a term that was coined by the German physicist Heinrich Kayser in 1881; it is still in common usage today. Adsorption is a separation process or surface phenomenon in which specific substances are extracted from fluid phases (e.g., liquids or gases). Typically, dissolved gas, liquid, or solid molecules, atoms, or ions adhere to the surface of the substance being adsorbed. In essence, the process involves the adsorption of ions or molecules from an aqueous solution onto the surfaces of substances, which serve as the absorbent. Adsorption should not be conflated with adsorption, which pertains to the uniform penetration and dispersion of one substance into another and is a bulk phenomenon.

Desorption, in which the adsorbate is liberated, is the term given to the reversible reaction of adsorption, which has been determined through research. Desorption is an essential property of a catalyst material, as it facilitates the separation of products generated on the surface (desorbed) after the reaction. This separation creates available surfaces for additional reactant molecules to recommend the process. This is essential to guarantee that the adsorption process will continue to occur within the free spaces. An alternative expression for the rate of change in the adsorbate is the disparity between adsorption and desorption. The terminology associated with the general mechanism of the adsorption–desorption process is depicted in Figure 1.

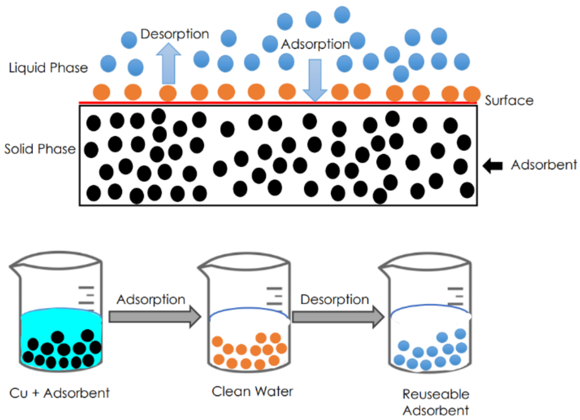

Figure 1. The Mechanism of Metal Ions Adsorption-Desorption Process in Water.

4. RESULTS AND DISCUSSION

Based on the results of the characterization that has been carried out, the morphology, porosity, functional groups, and adsorption capacity of activated carbon from banana peels on metals can be identified.

4.1. FE-SEM Characterization Analysis

Field Emission Scanning Electron Microscope (FE-SEM) is a characterization to determine the surface morphology of activated carbon. It uses an electron beam accelerated with an anode and focused on the sample to indicate the presence of pores on activated carbon made from waste banana peels. The scanning coil directs the concentrated electron beam to cover the entire sample. As the electrons strike the sample, it releases fresh electrons that the detector picks up and transmits to the monitor. This characterization aims to examine the morphology of activated carbon, which is essentially the surface shape of the material. Using a Field Emission Scanning Electron Microscope (FE-SEM), the morphological results of activated carbon at a 2000× magnification are shown in Figure 2.

a.

b.

c.

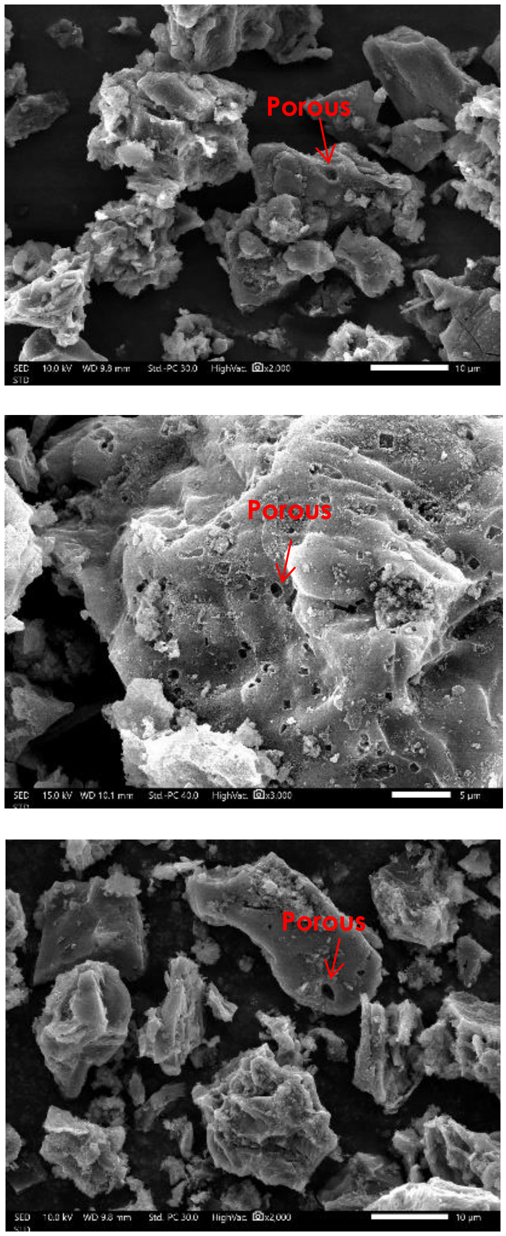

Figure 2. Morphology of activated carbon with (a) 10% KOH activation; (b) 20% KOH activation; and (c) 40% KOH activation

Figure 2 displays the morphology of activated carbon. Samples of activated carbon made from leftover banana peels activated with 10% KOH, shown in Figure 2(a), exhibit numerous pores forming on their surface. Because high concentrations of activators can change the size of pores on activated carbon, Figure 2(b) shows a sample of activated carbon from banana peel waste that was activated with 20% KOH and had bigger pores than activated carbon that was activated with 10% KOH. Similarly, Figure 2(c) depicts an activated carbon sample from banana peel waste with 40% activation and a larger pore that is more evenly distributed on the surface of activated carbon compared to activated carbon with 10% KOH and 20% KOH activator concentrations. The Field Emission Scanning Electron Microscope (FE-SEM) data displays the nanoscale pore size.

In addition, we can calculate the average porous size from the image above. The pores are categorized as macropores after the number of pores and pore width are known. Pores larger than 50 nm are referred to as macropores. Figure 3 and Table 1 show the average porous size with activation.

a.

b.

c.

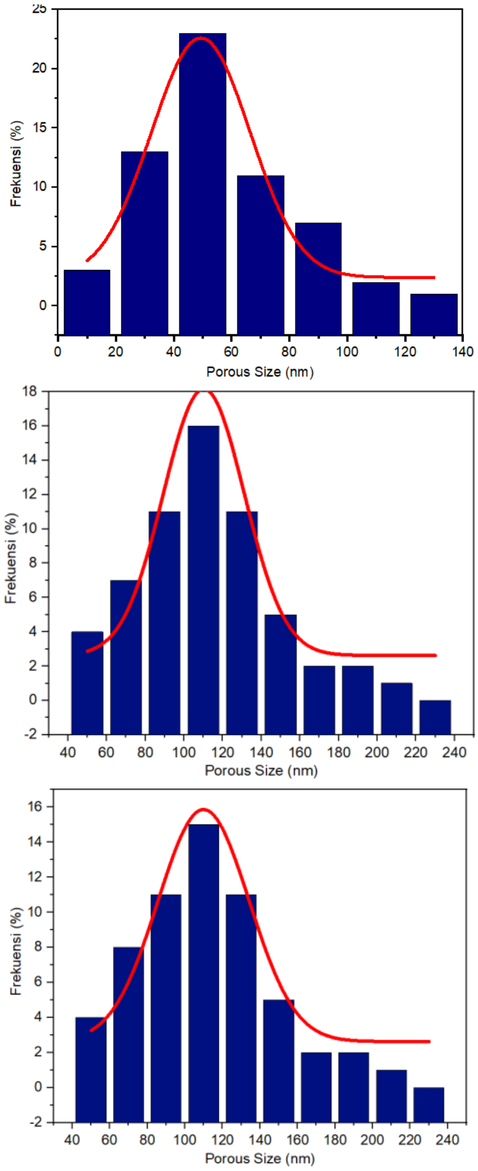

Figure 3. Porous Size Results on Activated Carbon with (a) 10% KOH Activation; (b) 20% KOH Activation; and (c) 40% KOH Activation

Table 1 shows that the activated carbon data with 10% KOH activator had an average porous size of 49.34 nm, activated carbon with a 20% KOH concentration has an average porous size of 110.26 nm. The 40% KOH-concentrated activated carbon was obtained with an average porous size of 109.95 nm. The higher the surface area of the pores of activated carbon, the higher its adsorption capacity. Additionally, a thorough estimate of the porosity of activated carbon is provided in Table 1, which displays the porosity of waste banana peel activated carbon using a Potassium hydroxide (KOH) activator. Porosity, which has a value between 0 and 1, or as a percentage between 0 and 100%, is the amount of empty space between materials and is expressed as the fraction of the volume of empty space to the entire volume. Using Origin software, one may determine the porosity of activated carbon. The subsequent is the porosity of activated carbon is calculated, and the results are shown in Table 2.

Table 1. Average Porous Size of Activated Carbon

Variation of KOH [%]	Average Porous Size [nm]
10	49.34
20	110.26
40	109.95

Source of data processed from lab test results of LPPT UGM

Table 2. Total Volume, Pore Volume, and Porosity of Activated Carbon

Variation of KOH [%]	Total Volume [cm^3/g]	Pore Volume [cm^3/g]	Porosity [%]
10	0.086	0.061	71.94
20	0.086	0.062	72.66
40	0.086	0.064	74.80

A sample of activated carbon made from waste banana peels with a 10% KOH activation has a porosity of 71.94%, as shown in Table 2. The porosity of the activated carbon from the banana peel waste sample with 20% KOH activation was higher than that of the sample with 10% KOH activation, which equaled 72.66%. The porosity of the sample with 40% activation was higher than that of the samples with 10% and 20% KOH activator concentration, which equaled 74.80%. This demonstrates that the porosity of activated carbon increases with increasing KOH activator levels.

The following studies compare the current research findings with earlier investigations into the porosity of activated carbon with chemical activation employing materials and chemical activation.

Table 3. Summary of Activated Carbon Porosity of Different Types of Chemical Activators

No.	Materials	Activation	Porosity	Ref.
1	Banana peel	ZnCl2 30%	36,67%	[5]
2	Banana peel	H2SO4 10 N	65,54%	[11]
3	Banana peel	ZnO 0,3 M	64,71%	[13]
4	Banana peel	KOH 5%	65,80%	[16]
5	Banana peel	KOH 40%	74,80%	This work

Table 3 tells us about earlier studies that used Potassium hydroxide (KOH) activator and leftover banana peel waste. Table 3 shows that, in this study, the activated carbon from banana peel waste with activator ZnCl2 30%, H2SO4 10 N, ZnO 0,3 M, and KOH 5% has a porosity of 75.80%, which is smaller than the activated carbon from banana peel waste with 40% KOH activation. Consequently, it can be concluded that this study successfully produced activated carbon from leftover banana peels, which has a higher adsorption capacity than that of earlier research.

4.2. EDX Characterization Analysis

Energy Dispersive X-ray (EDX) is a material characterization using X-rays emitted when the material collides with electrons. The energy level depends on the energy level of the atomic shell because X-rays are emitted from electron transitions from the atomic shell layer. So, by detecting the energy levels emitted from X-rays and their intensity, it is possible to know the atoms that make up the material and their mass percentage. The function of Energy Dispersive X-ray (EDX) is to see the percentage of single atoms in a material. Figure 3 is the result of the energy-dispersive X-ray (EDX) of activated carbon that was made. The content on activated carbon made from banana peel waste contains (Carbon) C, (Zinc) Zn, (Magnesium) Mg, (Oxygen) O, (Silicon) Si, (Potassium) K, (Sodium) Na, (Pospor) P, (Chlorine) Cl and (Calcium) Ca.

a.

b.

c.

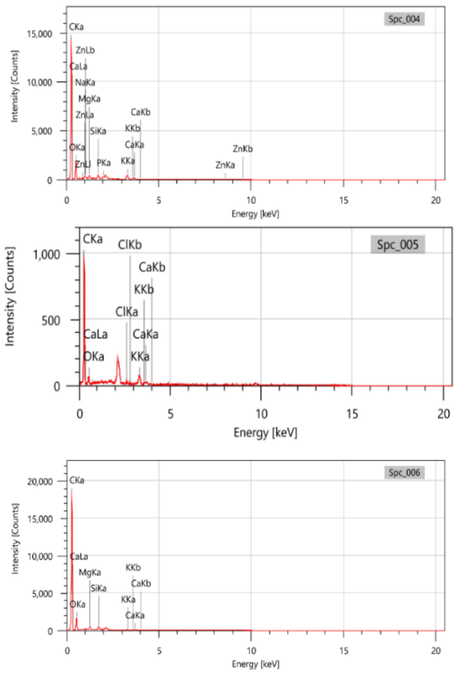

Figure 4. EDX Characterization Results on Activated Carbon with (a) 10% KOH Activation; (b) 20% KOH Activation; and (c) 40% KOH Activation

Based on Figure 4, it is known that various types of the composition of the constituent materials in activated carbon, each with a different amount of KOH activator variation, will have a different single atom. This can be influenced by the chemical activation process and the physical activation obtained by the sample. Based on Figure 4(a), it is known that activated carbon with 10% KOH activation contains 9 single atoms, namely carbon (C), zinc (Zn), magnesium (Mg), oxygen (O), silicon (Si), potassium (K), sodium (Na), phosphorus (P), and calcium (Ca). Furthermore, Figure 4(b) shows that activated carbon with 20% KOH activation contains 5 single atoms, namely carbon (C), oxygen (O), potassium (K), chlorine (Cl), and calcium (Ca), and the last is in Figure 4(c), which shows that activated carbon with 40% KOH activation contains six single atoms, namely carbon (C), magnesium (Mg), oxygen (O), silicon (Si), potassium (K), and calcium (Ca).

The information presented in Table 4 outlines the percentage composition of the activated carbon being studied. The table indicates that activated carbon activated with a 10% KOH concentration has a carbon content of 72.21% and an atomic number of 81.84%. Following this, the oxygen content is noted to be 16.37% by mass with an atomic number of 13.93%. This is followed by the magnesium content at 0.96% mass and an atomic number of 0.54%. Additionally, the table shows the potassium content at 6.03% mass and an atomic number of 2.10%, and the silicon content at 1.31% mass with an atomic number of 0.63%. Furthermore, it outlines the calcium content at 1.72% mass and an atomic number of 0.59%. The zinc content is indicated at 1.14% mass with an atomic number of 0.24%, followed by the sodium content at 0.12% mass and an atomic number of 0.07%. Lastly, the sample contains 0.14% phosphorus by mass and has an atomic number of 0.06%.

Table 4. EDX Characterization Results

Content	KOH 10%		KOH 20%		KOH 40%	
	Mass [%]	Atom [%]	Mass [%]	Atom [%]	Mass [%]	Atom [%]
C	72.2	81.8	76.3	84.5	81.5	87.2
O	16.3	13.9	15.2	12.6	13.4	10.7
Mg	0.96	0.54	-	-	1.20	0.63
Cl	-	-	0.97	0.36	-	-
K	6.03	2.10	5.90	2.01	1.01	0.33
Si	1.31	0.63	-	-	1.34	0.63
Ca	1.72	0.59	1.58	0.52	1.54	0.49
Zn	1.14	0.24	-	-	-	-
Na	0.12	0.07	-	-	-	-
P	0.14	0.06	-	-	-	-
Total	100	100	100	100	100	100

Source of data processed from lab test results of LPPT UGM

For activated carbon with 20% KOH activation concentration, the carbon content is 76.33% by mass with an atomic number of 84.46%, while the oxygen content is 15.22% by mass with an atomic number of 12.64%. Additionally, the chlorine content is 0.97% by mass with an atomic number of 0.36%, and the potassium content is 5.90% by mass with an atomic number of 2.01%. Lastly, the calcium content is 1.58% by mass with atoms of 0.52%.

The data shows that activated carbon with a 40% KOH activation concentration has a carbon content of 81.54% by mass and an atomic number of 87.19%. Additionally, it has an oxygen content of 13.37% by mass and an atomic number of 10.73%, as well as a magnesium content of 1.20% by mass and an atomic number of 0.63%. The potassium content is 1.01% by mass with an atomic number of 0.33, followed by silicon at 1.34% by mass and an atomic number of 0.49, and finally, calcium at 1.54% by mass and an atomic number of 0.49. According to the provided Table 4, it can be inferred that higher KOH activation concentrations result in increased carbon content in the material, while the oxygen content in activated carbon decreases.

4.3. FTIR Characterization Analysis

Fourier Transform Infrared Spectroscopy (FTIR) spectroscopy or infrared spectroscopy is an analytical method based on the principle of interaction of a chemical compound with electromagnetic radiation that will produce a vibration (vibration) of a polyatomic chemical bond or functional group of chemical compounds. This technique is also called vibrational spectroscopy. FTIR spectroscopy can quickly analyze, is non-destructive and only requires simple sample preparation. FTIR spectrophotometer is based on the idea of radiation interference between two beams to produce an interferogram. An interferogram is a signal produced as a function of the change in path length between two beams. The two domains (distance and frequency) can be inverted by a mathematical method called the Fourier transform.

Figure 5 is Fourier Transform Infrared Spectroscopy (FTIR) test data, which serves to determine the functional groups contained in activated carbon. Fourier Transform Infrared Spectroscopy (FTIR) works by spectroscopic analysis techniques that focus on the interaction between molecules in the sample with infrared light. This technique utilizes the Fourier Transform interferometry principle to produce an infrared spectrum of the sample. The following are the results of the Fourier Transform Infrared Spectroscopy (FTIR) test with FTIR resolution 4 cm^{-1}.

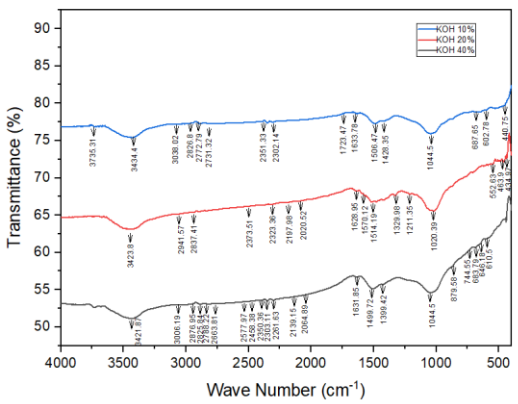

Figure 5. FTIR Characterization Results on Activated Carbon

Based on Figure 4, we can see the results of testing activated carbon samples using Fourier Transform Infrared Spectroscopy (FTIR) testing. The black graph is a graph of activated carbon with 40% KOH activation, the graph with red color is a graph of activated carbon with 10% KOH activation, and the blue graph is a graph of activated carbon with 10% KOH activation. In the first graph, the black graph shows that the wave number 3432.83 cm^{-1} is the O-H functional group, then at wave numbers 2938.02 cm^{-1} and 2826.80 cm^{-1} is the C-H functional group, and at wave numbers 1723.47 cm^{-1} and 1633. 78 cm^{-1} is the C=O functional group, at wave number 1044.50 cm^{-1} is the C-O functional group, then at wave number 687.65 cm^{-1} and 602.78 cm^{-1} is the C-Cl functional group, and the last is at wave number 440.75 cm^{-1} is the S-S functional group. In the second graph, namely the red graph, there are 6 peaks on the graph, namely at wave number 3414.18 cm^{-1} and wave number 3296.27 cm^{-1}, namely the O-H functional group, at wave number 2905.97 cm^{-1}, namely the C-H functional group, and at 708.57 cm^{-1}, 681.14 cm^{-1}, and 663.87 cm^{-1} has a functional group that is C-Cl. And the last is the blue graph, which has many functional groups, namely at wave number 3421.87 cm^{-1}, namely the O-H functional group, then at wave number 2876.95 cm^{-1} and 2825.84 cm^{-1}, which has the C-H functional group, at wave number 2350.36 cm^{-1} and 2303.11 has the functional group C≡N, then at wave number 1631. 85 cm^{-1} has a C = C functional group, then at wave number 1499.72 cm^{-1} has a C=O functional group and at wave number 1399.42 cm^{-1} has a C = O functional group, at wave number 1044. 50 has an O-H functional group bond, and at wave numbers 744.55 cm^{-1} −610.50 cm^{-1} has a C-S functional group.

4.4. Contact Angle

The contact angle is formed by a liquid when dripped on a surface that forms a tangent to its line of contact with a line through the base of the droplet liquid. Based on the contact angle test on activated carbon from banana peel waste with KOH activator, the results were obtained according to Figure 6.

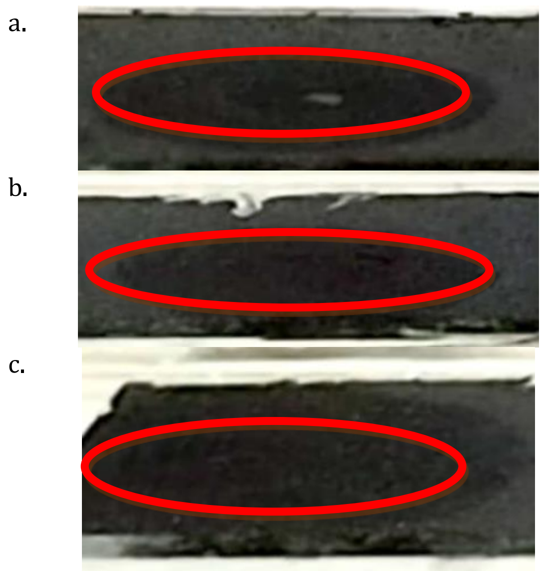

Figure 6. Contact Angle Test Results on Activated Carbon: a) 10% KOH Activation; b) 20% KOH Activation; and c) 40% KOH Activation

Figure 6 shows that the three activated carbons do not form a contact angle or can be called superhydrophobic where activated carbon with hydrophilic properties is suitable if applied as an adsorbent.

Table 5. The Duration Required for the Liquid to be Adsorbed

KOH [%]	Time [seconds]
10	7
20	3
40	5

Table 5 shows the duration required for the liquid to completely drip on activated carbon. Activated carbon with 20% KOH activation has the fastest time in adsorbing liquids. This shows that activated carbon with 20% KOH activation has better adsorption capacity than activated carbon with 10% KOH activation and 40% KOH.

4.5. Adsorption of Activated Carbon to Copper (Cu) Metal

In accordance with the data in Table 5, the activated carbon used as a copper metal adsorbent is activated carbon with 20% KOH activation. Furthermore, the results of applying activated carbon in copper metal solutions will be tested using an Atomic Absorption Spectrophotometer (AAS) and calculated using isothermal adsorption calculations, namely isothermal of Langmuir and Freundlich.

Table 6. Atomic Absorption Spectrophotometer (AAS) Test Results

No.	Sample [ppm]	Contact Time [minutes]	Cu [mg/L]	Adsorbs [%]
1	100	15	0.0032	99.99
2	150	15	0.0452	99.95
3	100	30	18.27	81.73
4	100	45	0.0165	99.98
5	200	15	2.1615	97.83

Source of data processed from lab test results of LPPT UGM

Based on Table 6, the results were obtained that in a sample solution of 100 ppm with a contact time of 15 minutes, a copper content of 0.0032 mg / L was obtained, which means that activated carbon has an adsorbency of 99.99%. Furthermore, in Figure 7, Langmuir isothermal, and Figure 8 is Freundlich isotherm.

Langmuir isotherm is given by Equation:

$$\frac{c_e}{q_e} = \frac{c_e}{q_m} + \frac{1}{kq_m} \quad (1)$$

Freundlich isotherm is given by Equation:

$$\ln q_e = \ln k_f + \frac{1}{n} \ln c_e \quad (2)$$

The results are obtained:

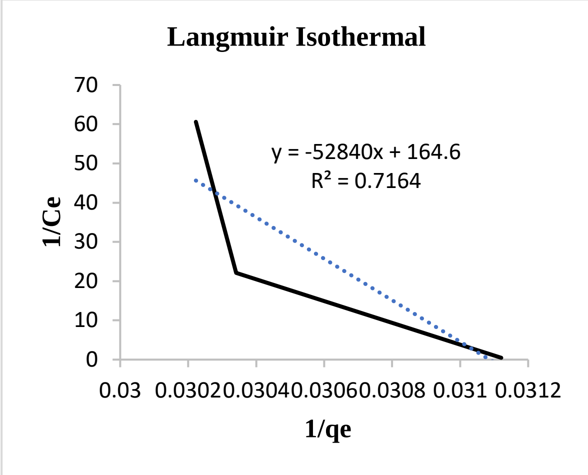

Figure 7. Langmuir Isothermal

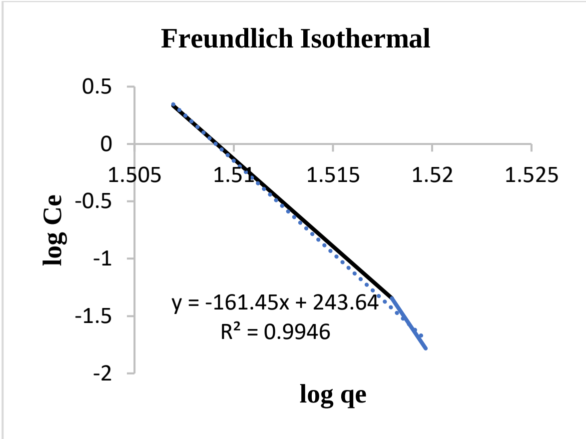

Figure 8. Freundlich Isothermal

Figure 7 and Figure 8 present the results of the linear transformation correlation constant and coefficient of the Langmuir isothermal and Freundlich isothermal models. Based on the data in the figure above, the highest correlation coefficient is the Freundlich coefficient, which is 0,9946, while the Langmuir coefficient is 0.7164. The Freundlich model describes the phenomenon of copper metal adsorption due to the Freundlich separation factor (KF > KL).

Table 7. Adsorption of Heavy Metals by Activated Carbon of Various Types of Chemical Activators

No.	Materials	Activation	App.	Adsorbs	Reff.
1	Banana peel	HCl 6M	Cu	98,87%	[24]
2	Banana peel	HCl 2N	Cu	81,78%	[25]
3	Banana peel	KOH 15%	Cu	98,90%	[26]
4	Banana peel	HCL 1N	Cu	80,00%	[27]
5	Banana peel	KOH 20%	Cu	99,99%	This Work

According to the data in Table 7, earlier research has shown that banana peel treated with a 15% KOH activator and banana peel residues treated with a 6M HCl activator 1N and 2N HCl had a lower capacity to adsorb copper metals compared to activated carbon derived from bananas treated with a 20% KOH activator, which had a purity of 99.99%. This could be attributed to the smaller pore size of the activated carbon and the enhanced adsorption capability of banana peel waste activated carbon with a 20% KOH solution, which is more optimal compared to previous similar experiments.

5. CONCLUSION

Drawing from the aforementioned research, it can be inferred that activated carbon with 40% KOH has a higher porosity than activated carbon with 10% or 20% KOH. Consequently, activated carbon with 40% KOH chemical activation has the highest adsorption power, with a porosity of 74.80%. The results of FTIR testing, which show functional group data on activated carbon with 40% KOH activation has the most carbon bonds, and EDX data, which indicates that even activated carbon with 40% KOH activation has the maximum carbon content, which is 87.19%, support this. The results from the contact angle show that activated carbon with 20% KOH activation has a fairly fast adsorption capacity of 3 seconds, and the AAS test results show that activated carbon with 20% KOH activation with a sample of 100 ppm and a contact time of 15 minutes can adsorb copper metal up to 99.99%.

This study successfully synthesized and characterized banana peel-based activated carbon for copper (Cu) metal adsorption. However, there are some limitations that need to be considered. First, the adsorption experiments were conducted under controlled laboratory conditions, which may not fully reflect the conditions of industrial effluents that have varying pH, temperature, and competing ions. Secondly, although the characterization results confirm the presence of functional groups and pore structure, the adsorption kinetics and isotherm models have not been analyzed in depth, so the understanding of the adsorption mechanism is still limited. In addition, the challenge of scalability of banana peel-based activated carbon for large-scale applications remains an obstacle, given the variation in raw material composition and the need for a more efficient and low-cost activation process.

Future research should focus on optimizing the adsorption process by investigating the effect of different operational parameters, such as adsorbent dosage, contact time, and temperature. In addition, kinetics and isotherm studies should be conducted to provide a deeper understanding of the adsorption mechanism and capacity. The development of regeneration techniques to improve reusability and economic sustainability is also crucial for more environmentally friendly implementation. This research will contribute to the development of biomass-based activated carbon as an efficient and environmentally friendly adsorbent for heavy metal removal.

ACKNOWLEDGMENT

The authors thank Universitas Sebelas Maret for the support of the HIBAH MBKM of Universitas Sebelas Maret research fund with contract number 934/UN27/HK/2023 in 2023, the Institute for Research and Community Service (LPPM) of Universitas Sebelas Maret with contract number 228/UN27.22/PT.01.03/2023 in 2023, and the HIBAH ESMART Research Group of Universitas Sebelas Maret with contract number 194.2/UN27.22/PT.01.03/2024 in 2024.

REFERENCES

Agarry, S. E., “Anthracene Bioadsorption from Simulated Wastewater by Chemically Treated Unripe Plantain Peel Bioadsorbent: Batch Kinetics and Isothermal Modeling Studies,” Polycycl. Aromat. Compd., vol. 39, no. 1, pp. 23–43, Jan. 2019, doi: 10.1080/10406638.2016.1255650.

Al Haider, S. A., Al Fatlawi, S., & Nasir, M. J., “Utilizing Activated Carbon Developed from Banana Peels as Permeable Reactive Barrier in Copper Removal from Polluted Groundwater,” J. Ecol. Eng., vol. 23, no. 1, pp. 83–90, Jan. 2022, doi: 10.12911/22998993/143973.

Allwar, A., Setiawan, A., Ermawan, H. A., & Alviansah, T. “Removal of Cu(II) ions from aqueous solution by activated carbon produced from banana fruit bunch (Musa paradisiaca),” Desalin. Water Treat., vol. 172, pp. 139–147, Dec. 2019, doi: 10.5004/dwt.2019.24668.

Arsad, E. “Technology of Processing and Utilization of Activated Carbon for Industry,” J. Ris. Ind. Has. Hutan, vol. 2, no. 2, p. 43, Dec. 2010, doi: 10.24111/jrihh.v2i2.1146.

Auliya, R. “Synthesis and Characterization of Activated Carbon from Banana Peel (Musa Paradisiaca L.) As An Adsorbent of Polycyclic Aromatic Hydrocarbon Phenanthrene Compounds,” 2018.

Damayanti and Hidayah, “The Effect of Commercial Adsorbents on the Reduction of Phosphates and Anionic Surfactants (Detergents) in Laundry Waste Water,” Envirous, vol. 2, no. 1, pp. 18–26, Aug. 2023, doi: 10.33005/envirous.v2i1.54.

Darweesh, M. A., Elgendy, M. Y., Ayad, M. I., Ahmed, A. M., Elsayed, N. K., & Hammad, W. A., “Adsorption isotherm, kinetic, and optimization studies for copper (II) removal from aqueous solutions by banana leaves and derived activated carbon,” South African J. Chem. Eng., vol. 40, pp. 10–20, Apr. 2022, doi: 10.1016/j.sajce.2022.01.002.

Erlina, Umiatin, and Esmar B. “Effect of KOH solution concentration on coconut shell activated carbon for Cu metal adsorption.,” Proc. Natl. Semin. Phys., vol. 4, 2015.

Gumarang, P. “Synthesis and analysis of substance changes (Evolution) in Marshmallow-based activated carbon material.,” Diss. UIN Sunan Gunung Djati Bandung, 2019.

Hartanto, Singgih, and Ratnawati "Making activated carbon from palm oil shells by chemical activation method.," Indones. J. Mater. Sci., vol. 12, no. 1, pp. 12–16, 2010.

Kwok, D. Y., & Neumann, “Contact angle measurement and contact angle interpretation,” Adv. Colloid Interface Sci., vol. 81, no. 3, pp. 167–249, 1999.

Lestari, “Adsorption of lead levels in activated banana peel adsorbents,” Acad. Pharm. Surabaya, 2021.

Maslukah, L., Zainuri, A., Wirasatriya, A., and Salma, A., “Spatial Distribution of Chlorophyll-a and Its

Relationship with Dissolved Inorganic Phosphate Influenced by Rivers in the North Coast of Java," J. Ecol. Eng., vol. 20, no. 7, pp. 18–25, Jul. 2019, doi: 10.12911/22998993/108700.

Meilinda. K. A., "Study of Photocatalysis Overhaul of Methanyl Yellow Dye Using Activated ZnO-Carbon Catalyst Composite Banana Peel Irradiated by UV Light.," 2023.

T. T. Nadew, M. Keana, T. Sisay, B. Getye, and N. G. Habtu, "Synthesis of activated carbon from banana peels for dye removal of an aqueous solution in textile industries: optimization, kinetics, and isotherm aspects," Water Pract. Technol., vol. 18, no. 4, pp. 947–966, Apr. 2023, doi: 10.2166/wpt.2023.042.

Nadew, T. T., Keana, M., Sisay, T., Getye, B., & Habtu, N. G., "Making activated carbon from coconut shell charcoal with ZnCl2 and Na2CO3 activators as adsorbents to reduce phenol levels in wastewater," ITS Eng. J., vol. 2, no. 1, pp. F116–F120, 2018, doi: https://doi.org/10.12962/j23373539.v2i1.2437.

Priambodo, I., "Effect of KOH Solution Concentration, Holding Time, and Chemical Activation Temperature on the Manufacture of Activated Carbon from Banana Peels for the Development of Hydrogen Storage," Furn. J., vol. 2, no. 2, 2016.

Rahmah, A., "Effect of KOH Concentration in the Manufacture of Plantain Peel Activated Carbon as an EDLC Type Supercapacitor Electrode Application," Diss. Brawijaya Univ., 2016.

Shafirinia, R., Wardhana, I. W., & Oktiawan, "The Effect of Adsorbent Size Variation and Flow Discharge on The Reduction of Chrome (Cr) And Copper (Cu) With Activated Charcoal from Banana Peel Waste in The Liquid Waste of The Chrome Electroplating Industry," Dr. Diss. Diponegoro Univ., 2016.

Alifaturrahma, P., & Hendriyanto, "Utilization of kepok banana peel as an adsorbent to set aside Cu metal," Sci. J. Environ. Eng., vol. 8, no. 2, pp. 105–111, 2018.

Anetha, O., "Adsorbent Made from Kepok Banana Peel (Musa Paradisiaca, L.) For Laboratory Liquid Waste Treatment," Dr. Diss. Lampung State Polytech., 2022.

Putri, D. P., Wahida, S. A., & Marlinda, "Utilization of Kepok Banana Skin (Musa Paradisiaca L.) As an adsorbent to reduce COD (Chemical Oxygen Demand) levels in laundry wastewater.," J. Information, Sci. Technol., vol. 5, no. 02, pp. 71–77, 2022.

Angraini, N., Agustina, T. E., & Hadiah, "The Effect of pH in Laboratory Wastewater Treatment with Adsorption Method to Reduce Heavy Metal Levels of Pb, Cu, and Cd.," J. Environ. Sci., vol. 20, no. 2, pp. 345–355, 2022.

Yusuf, J. Y., Soleimani, H., Chuan, L. K., Sanusi, Y. K., & Adebayo, L. L. "Physicochemical properties and microwave absorption performance of Co3O4 and banana peel-derived porous activated carbon composite at X-band frequency," J. Alloys Compd., vol. 888, p. 161474, Dec. 2021, doi: 10.1016/j.jallcom.2021.161474.

Suthers, I. M., Richardson, A. J., & Rissik, D. "The importance of plankton. Plankton: A Guide to Their Ecology and Monitoring for Water Quality," pp. 1–13, 2019.

Wiberg, Egon, and Nils Wiberg "Inorganic chemistry," Acad. Press, 2001.

Wells, A. F., "Structural inorganic chemistry," Oxford Class. Texts Ph, 2012.