# Synthesis of EPB/TiO$_2$ Activated Carbon Composite Using Microwaves Activation for Purification of Motor Vehicle Exhaust Emissions

## Wahyu Nur Aqni, Mega Nurhanisa, Dwiria Wahyuni

Department of Physics, Universitas Tanjungpura, Pontianak, 78124, Indonesia

**Article Info**

*Corresponding Author:*

Dwiria Wahyuni,
Email: dwiriawahyuni@physics.untan.ac.id

**ABSTRACT**

The palm oil plantation industry generates waste besides palm oil products, including empty palm bunch (EPB). This research examines the emission reduction capabilities of motor vehicle exhaust gases using a composite of activated carbon from EPB-AC/TiO$_2$. Surface morphology characterization of the composite is conducted using Brunauer-Emmett-Teller (BET) and Scanning Electron Microscope (SEM). EPB-AC exhibits an average reduction effectiveness of HC gas based on particle size (50, 100, 150, 200 mesh) sequentially at 34.49%, 37.43%, 39.98%, and 43.56%. The average effectiveness of EPB-AC in reducing CO gas sequentially is 70.29%, 71.30%, 72.86%, and 74%. For CO$_2$ gas, EPB-AC has an average reduction sequentially at 52.6%, 54.25%, 56.52%, and 58.54%. On the other hand, the EPB-AC/TiO$_2$ composite exhibits an average reduction effectiveness of HC gas based on particle size sequentially at 42.38%, 43.42%, 45.1%, and 46.57%. The average effectiveness of the EPB-AC/TiO$_2$ composite in reducing CO gas sequentially is 71.24%, 73.52%, 75.54%, and 76.9%. For CO$_2$ gas, the EPB-AC/TiO$_2$ composite has an average reduction sequentially at 54.93%, 54.25%, 59.76%, and 63.05%. Therefore, the best reduction results occur at a particle size of 200 mesh.

## 1. INTRODUCTION

West Kalimantan, in 2022, had an oil palm plantation area of 1.4 million hectares, which is 11% of the area of oil palm plantations in Indonesia (BPS Kalimantan Barat, 2022). Besides producing vegetable waste in the form of cruel palm oil (CPO), oil palm also produces a large amount of waste. An oil palm that weighs 1 ton can have 23% empty palm bunch (EPB) waste, 6.5% palm shell, 13% fiber, 4% palm sludge waste, and 50% liquid waste (Wimarsela et al., 2021). EPB waste can be used as fertilizer, but its abundant amount makes it necessary for alternative uses, such as raw material for producing activated carbon.

Activated carbon can be synthesized using materials that contain lignocellulose, such as lignin, hemicellulose, and cellulose. EPB contains 22.6% lignin, 45.8% cellulose, 71.8% hemicellulose, 25.9% pentose, and 1.6% ash (Zairinayati & Khosamtun, 2022). Activated carbon can be used as an adsorbent because it has a large surface area, between 300 and 3,500 m$^2$/g, and a high absorption capacity of 25% to 100% by weight of activated carbon (Kurniawan et al., 2014). This EPB material is processed through several stages to become activated carbon. These stages include dehydration, carbonization, and activation. The activation stage can use chemical activation or physical activation. Chemical activation

can use phosphoric acid (H$_3$PO$_4$), sodium chloride (NaCl), and potassium hydroxide (KOH). In contrast, physical activation uses inert gas and microwaves.

A microwave is a device that applies the principle of electromagnetic waves with a frequency of 300 MHz up to 300 GHz that are not ionized, of which spectrum is between those of x-rays and infrared rays (Taufik et al., 2021). Using microwaves to activate carbon can reduce reaction time, increase production yields, and improve material properties (Udyani et al., 2019). Carbon activation in coconut shells using microwaves can produce activated carbon with a surface area of more than 900 m$^2$/g (Zhang et al., 2013). Activation carbon with microwaves on peanut shells can have a BET surface area of 153 m$^2$/g (Awitdrus et al., 2018). A catalyst such as titanium dioxide (TiO2) must be used to maximize the adsorption ability of activated carbon.

The application of catalysts on activated carbon can enhance its adsorption capacity. Catalysts on activated carbon offer advantages such as the ability to break down complex organic compounds, being regenerable at low temperatures (Tri Basuki, 2007), non-toxic, stable at low temperatures and atmospheric pressure, inexpensive, and widely available (Monika et al., 2021). TiO$_2$ is a semiconductor material that can be combined with activated carbon due to its high bandgap energy. TiO$_2$ has three main structures: anatase, rutile, and brookite, with bandgap energies of 3.2 eV, 3.02 eV, and 2.96 eV, respectively (Milawati et al., 2021). The composite of activated carbon and TiO$_2$ (AC/TiO$_2$) has adsorption capabilities that also depend on the particle size of activated carbon. Smaller particle sizes lead to larger surface areas and higher adsorption capacity (Panjai et al., 2010). AC/TiO$_2$ has been proven to reduce carbon monoxide (CO) and hydrocarbon (HC) emissions by 74.83% and 67.1%, respectively, which is higher than the reduction of CO and HC using activated carbon without TiO$_2$ with 67.4% and 59.91%, respectively (Yuliusman et al., 2019). Motor vehicle exhaust gases consist of hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO$_2$), oxygen (O$_2$), and nitrogen oxides (NO$_x$), which are harmful to human health and can even cause death. CO has a high binding affinity to hemoglobin in the blood, preventing oxygen transport within the body, and in high amounts, it can cause paralysis and death. Reductions in HC and CO concentrations have been successfully achieved by 54% using a composite of activated carbon and TiO$_2$, with an optimal composition of 15% TiO$_2$ (Arsyad et al., 2023).

While previous studies have investigated the use of composites in degrading motor vehicle exhaust gases, the effect of activated carbon particle size in such composites has not yet been explored. In response to this gap, this study examines the degradation of motor vehicle exhaust emissions using microwave-activated EPB/TiO2 composites. Specifically, it analyzes the effectiveness of these composites in reducing HC, CO, and CO2 emissions, considering the influence of activated carbon particle size. Additionally, the study evaluates the reusability of the composites. Doing so aims to provide new insights into developing more efficient and sustainable composite materials for reducing motor vehicle exhaust emissions.

## 2. METHOD

### 2.1 Synthesis of activated carbon

EPB is first cleaned from dirt and then washed using running water. After cleaning, the EPB is torn into fibers. Furthermore, the EPB is dried in the oven for 12 hours at a temperature of 110$^{\circ}$C, aiming to remove the water content contained in EPB and achieve a constant mass (Wahyuningsih et al., 2017). The dried EPB was then carbonized using a furnace at 500$^{\circ}$C for 3 hours. After carbonization, the EPB was mashed using a pestle and mortar and then sieved to separate the EPB carbon particles into different sizes. The particle sizes used were 50, 100, 150, and 200 mesh.

EPB carbon was sieved according to the required particle size and then activated using a microwave with a power of 600 watts for 1 minute. The activation stage is carried out by adding distilled water and EPB carbon in a ratio of 6:1. Furthermore, the EPB-activated carbon was washed using distilled water once. After washing, the EPB-activated carbon was dried again using an oven at 150$^{\circ}$C for 3 hours.

### 2.2 Manufacture of filter composite

Activated carbon is then composited with titanium dioxide (TiO$_2$) with a concentration of 15% (Arsyad et al., 2023). The composite stage is carried out using a mixer for 30 minutes (Winoko &

Wicaksono, 2021). After the EPB/TiO$_2$ activated carbon composite has been mixed, 2.5 g of polyvinyl alcohol (PVA) is dissolved in 25 ml of distilled water using a hotplate until the PVA solution has a concentration of 10%. After that, the EPB/TiO$_2$ activated carbon composite was mixed into the PVA solution for 30 minutes at 190°C and using a speed of 700 rpm. Furthermore, the EPB/TiO$_2$ activated carbon composite is molded with a solid cylindrical shape to become an air filter. After molding, the EPB/TiO2 activated carbon composite filter was made into five holes with a diameter of 0.3 cm. Furthermore, the composite filter was dried using an oven for 3 hours at 120°C (Tri Basuki, 2007).
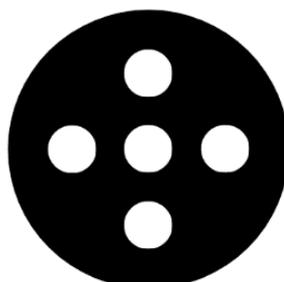


**Figure 1** EPB/TiO$_2$ activated carbon composite filter

## 2.3 Characterization of EPB/TiO₂ composite filter and effectiveness measurement

SEM and BET characterization aims to determine the morphology of the surface of the EPB/TiO$_2$ activated carbon composite. SEM images consist of activated carbon surfaces with 15% TiO$_2$ and without TiO$_2$. BET characterization data reveals the surface area of activated carbon before and after compositing with TiO$_2$.

The effectiveness experiment used a gas analyzer on two-wheeled motorized vehicles of the Honda Revo brand manufactured in 2008. The experiment is conducted by starting the motor vehicle engine for 5 minutes under idle conditions. Then, the test tube is connected to the motor exhaust. The probe of the gas analyzer is then inserted into the test tube. Finally, the experiment was conducted without and with various composite filters for 5 minutes, with data taken every 30 seconds.
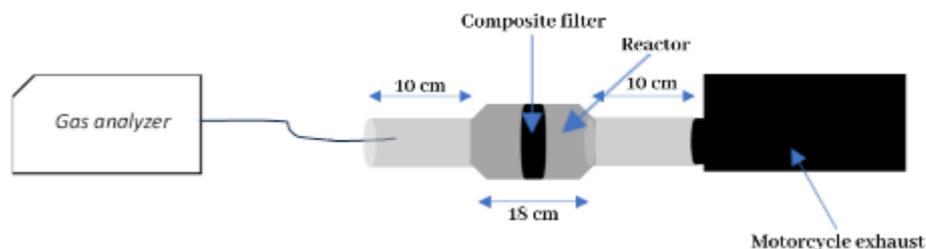


**Figure 2** Schematic of emissions testing



**Figure 3** (A) Result of EPB dehydration, (B) Result of carbonization ($T = 500°C$; $t = 3$ hours), and (C) Result of microwave activation ($P = 600$ watts; $t = 15$ minutes)

## 2.4 Data analysis

The results of testing motor vehicle exhaust emissions using a gas analyzer made a comparison chart using OriginLab. Each graph was made for CO, CO$_2$, and HC gas parameters to calculate the percentage of reducing power of the EPB/TiO$_2$ activated carbon composite filter using equation (1).

$$\text{Efficiency (\%)} = \frac{(G_0 - G_n)}{G_0} \times 100\% \qquad (1)$$

where $G_0$ is the gas emission without a composite filter (% or ppm), and $G_n$ is the gas emission with a composite filter (n = 1, 2, 3, 4, and 5) (% or ppm).

## 3.  RESULTS AND DISCUSSION

### 3.1  Synthesis of EPB/TiO$_2$ activated carbon composite

The EPB/TiO$_2$ activated carbon composite is synthesized in 2 stages. The first stage synthesizes activated carbon from EPB, and the second stage manufactures composite filters. The synthesis stage of activated carbon is divided into dehydration, carbonization, and activation. The results of these three steps are shown in Figure 3, where Figure 3(A) illustrates the dehydrated EPB, Figure 3(B) shows the carbonized EPB (conducted at 500°C for 3 hours), and Figure 3(C) presents the results of microwave activation with 600 watts of power for 15 minutes.

The results of EPB that have been dehydrated through drying in the sun with marked EPB brittleness if pressed are shown in Figure 3(A). The mass of EPB before dehydration is 2.2 kg, and EPB's after dehydration is 1.885 kg. The dehydrated EPB was then carbonized with the results shown in Figure 3(B). Carbonization in this research was carried out five times with a total mass of 239 g.

**Table 1** Results of the percentage gain of carbonization of EPB

| Nth carbonization | Mass of EPB (g) | Carbon mass (g) | Gain (%) |
|---|---|---|---|
| 1 | 0.18 | 0.03 | 16.6 |
| 2 | 0.432 | 0.045 | 10.42 |
| 3 | 0.285 | 0.04 | 14.04 |
| 4 | 0.643 | 0.086 | 13.38 |
| 5 | 0.345 | 0.038 | 11.01 |
| Average gain | | | 13.09 |

Table 1 shows the average percentage of carbonization results of EPB, which is 13.09%, with a mass shrinkage of 86.91%. Mass shrinkage may occur due to temperature factors, carbonization time, and the release of volatile matter (Sumila et al., 2023). The amount of volatile matter released in the EPB through high temperature and long time is the cause of the decrease in carbonization yield. Another factor affecting the small carbonization yield is the presence of combustion residue in ash. Ash is another product of combustion carried out during carbonization that should be discarded. The ashes can appear due to the pan lid not being tightly closed so that the reaction with O$_2$ occurs.

Before activation, EPB carbon was reduced in size using a pestle and mortar. The purpose of reducing the size of EPB carbon is to make it easier to obtain particle sizes of 50, 100, 150, and 200 mesh. Further, it homogenizes the particle size of EPB carbon, which is necessary during the activation. The carbon activation is conducted using microwaves for 15 minutes with 600 watts. The activation process of EPB carbon aims to open and enlarge the pore size of EPB carbon to adsorb motor vehicle exhaust emissions. Figure 3(C) shows the EPB carbon activation stage results. Activation was carried out by mixing carbon and distilled water in a ratio of 1:6 to maximize the activation process with microwaves and to prevent carbon burning during activation.

EPB/TiO$_2$ activated carbon composite filters were manufactured using 15% TiO$_2$, the optimum composition for degrading motor vehicle exhaust emissions (Arsyad et al., 2023). However, compositing activated carbon and TiO$_2$ using a mixer is considered less than optimal because the EPB/TiO$_2$ activated carbon is not mixed thoroughly. So, stirring is done manually using a spoon to incorporate EPB/TiO$_2$-activated carbon. After mixing, the EPB/TiO$_2$ activated carbon composite is then molded into a hollow solid cylinder shape. This composite filter follows the provisions of the main components of composite materials, namely matrix and filler. The matrix in charge of binding the filler in this research is a 10% PVA solution. At the same time, the EPB/TiO$_2$ activated carbon composite, which is the primary material, acts as a filler that functions as a filler of the matrix.
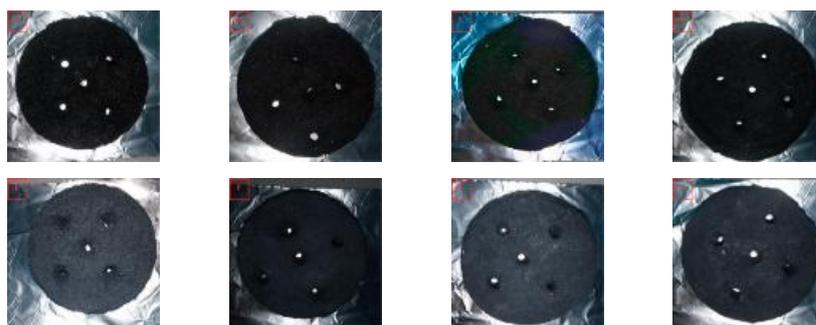
**Figure 4** (A) 50 mesh activated carbon filter, (B) 100 mesh activated carbon filter, (C) 150 mesh activated carbon filter, (D) 200 mesh activated carbon filter, (E) 50 mesh EPB/TiO₂ activated carbon composite filter, (F) 100 mesh EPB/TiO₂ activated carbon composite filter, (G) 150 mesh EPB/TiO₂ activated carbon composite filter, (H) 200 mesh EPB/TiO₂ activated carbon composite filter

Figure 4 shows the results of activated carbon and EPB/TiO₂ activated carbon composite in hollow solid cylinders. The honeycomb-activated carbon used for water purification inspired the open cylindrical shape. In addition, the hollow solid cylinder-shaped composite filter also aims to ensure that motor vehicle exhaust emissions passing through the filter can circulate properly in the test tube (Widihati et al., 2021). The activated carbon filter is black, and the EPB/TiO₂ activated carbon composite filter has a grayish color caused by adding 15% TiO₂ to the activated carbon. The size of the hole diameter on the filter is also not the same. During the process, the filter is still molded manually. Thus, the hole size is not the same, and when the filter is dried in the oven, the hole size is even smaller. In addition, both activated carbon filters and EPB/TiO₂ activated carbon composite have a light mass and a less dense surface due to the lightweight of the raw material EPB.
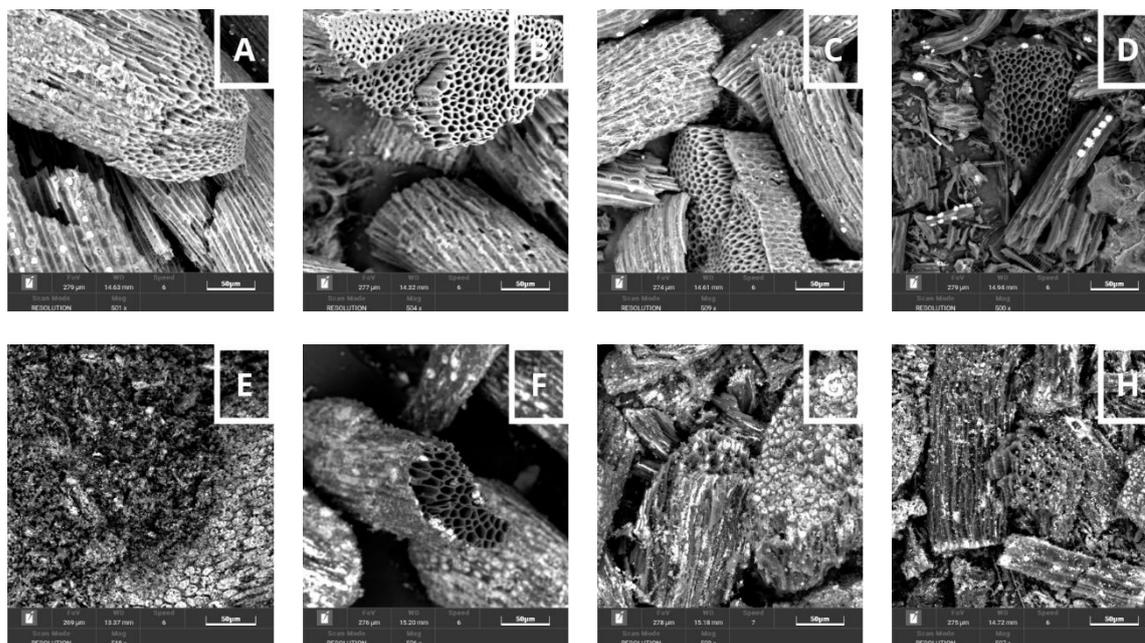


**Figure 5.** SEM images: (A) 50-mesh AC, (B) 100-mesh AC, (C) 150-mesh AC, (D) 200-mesh AC, (E) 50-mesh EPB/TiO₂ composite, (F) 100-mesh EPB/TiO₂ composite, (G) 150 mesh EPB/TiO₂ composite, and (H) 200 mesh EPB/TiO₂ composite

### 3.2 Morphology of EPB/TiO₂ activated carbon composite

The surface morphology of the EPB/TiO₂ activated carbon composite is observed using Scanning Electron Microscope (SEM), and its surface area is measured using Brunauer Emmet Teller (BET). The morphology observation includes the distribution of carbon pores formed by microwave activation and the distribution of TiO₂ on the surface of activated carbon. The SEM images of the

morphology of the EPB/TiO2 activated carbon composite are shown in Figure 5. The pore size is measured using ImageJ.
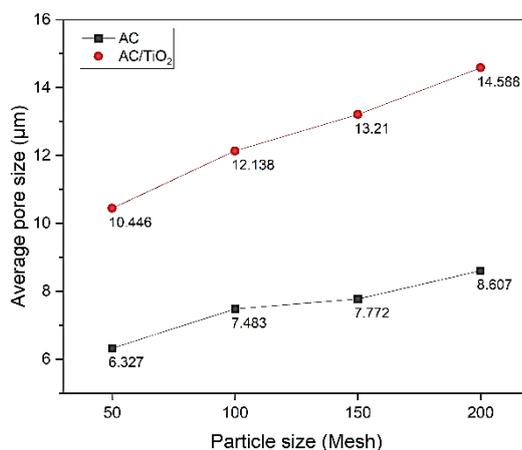


**Figure 6.** Relation between the average pore size activated carbon and EPB/TiO$_2$ activated carbon composite with the particle size

Figure 6 shows that the particle size of 50 mesh has the smallest average pore size of activated carbon, which is 6.33 µm. In comparison, the 200-mesh activated carbon has the largest average pore diameter of 8.61 µm. The results indicated that the particle size affects the pore size of the activated carbon obtained. The reduction in particle size will cause the formation of space between particles due to the size reduction process. In this case, the activation process (Musthofa et al., 2023). The activated carbon with a small particle size, will produce large and many activated carbon pores (Fauzia & Purnama, 2021). Figure 5(E)-(H) shows the SEM images of the EPB/TiO$_2$ activated carbon composite.

Figure 6 also shows the average pore size of the EPB/TiO$_2$ activated carbon composite relative to the particle size. It can be seen that the smallest average pore size of the EPB/TiO$_2$ activated carbon composite is that of the 50 mesh, which is 10.45 µm. In contrast, the largest is of the 200-mesh size, 14.59 µm. In EPB/TiO$_2$ activated carbon composites, particle size also affects the average pore size. The smaller particle size will have a larger pore size because the activation process tends to open more pores and increase porosity due to the higher surface area of smaller particles (Musthofa et al., 2023). During activation, smaller particles are more exposed to chemical agents or thermal treatment, which facilitates the removal of volatile matter and the creation of additional micro or mesopores. In addition, the surface of the EPB/TiO$_2$ activated carbon composite shows that TiO$_2$ is not evenly distributed and clustered at several points on its surface. We suppose using a simple mixing method is not optimal as it was done manually.
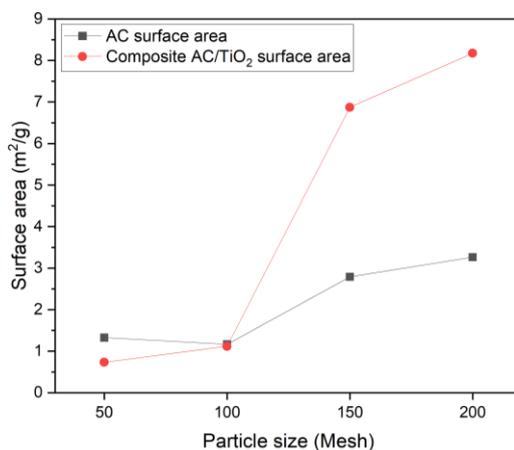


**Figure 7** The surface area of activated carbon and EPB/TiO$_2$ activated carbon composite

The surface area of the activated carbon EPB/TiO$_2$ composite was measured using BET, as shown in Figure 7. On EPB/TiO$_2$ activated carbon composites sized 50 to 200 mesh, surface area results vary with particle size. The largest surface area is shown by 200 mesh activated carbon. The smaller the particle size of activated carbon, the more activated carbon pores will increase and expand the activated carbon's surface (Elmariza et al., 2015). The EPB/TiO$_2$ activated carbon composite has the same results as activated carbon in terms of its surface area. Hence, the addition of TiO2 affects the size of the surface area of activated carbon.

## 3.3 Reduction of motor vehicle exhaust emission by filter composite

Filter composites were tested for their effectiveness in reducing motor vehicle exhaust emissions on Honda Revo motorcycles of the 2008 manufacturing year. The test was conducted with five repetitions, with the contact time between adsorbent and adsorbate limited to 5 minutes and data taken every 30 seconds. We observed that the HC gas has a high sensitivity to the surrounding air compared to CO and CO$_2$ gases, resulting in the HC value quickly changing at the given time intervals.
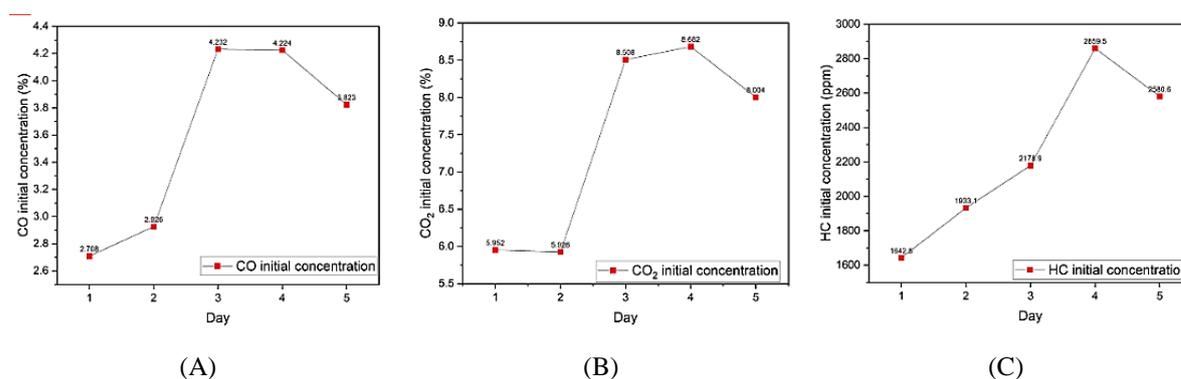


(A)            (B)            (C)

**Figure 8** (A) The initial concentration of CO gas, (B) The initial concentration of CO$_2$ gas, (C) The initial concentration of HC gas

As seen in Figure 8, CO and HC gas have an average initial concentration value below the quality standards for motor vehicle exhaust emission. In contrast, CO$_2$ gas has exceeded the quality standards for motor vehicle exhaust emissions based on the Minister of Environment Regulation of 2017 concerning the Implementation of Emission Standards for Motor Vehicles (Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia, 2017). The quality standards for exhaust emissions of the two-wheeled motorized vehicle of manufacturing year <2010 in the regulation for CO$_x$ gas parameters is 4.5%, and for HC gas is 6,000 ppm.
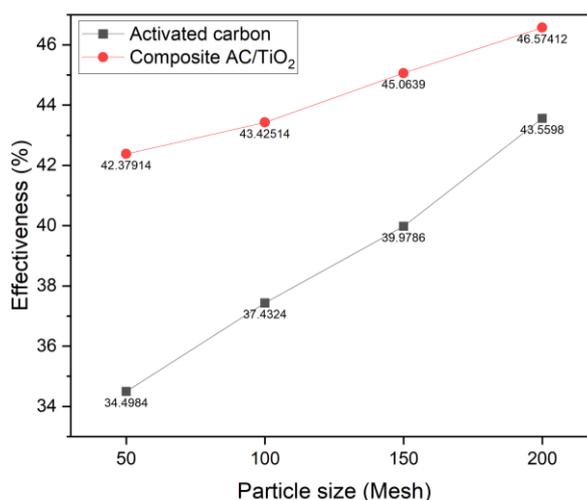


**Figure 9** HC gas reduction effectiveness about particle size

Figure 9 shows the effect of particle size on the effectiveness of HC gas emission reduction. The reduction effectiveness of the composite filter to reduce HC exhaust emissions is calculated by equation (1). The composite filter is more effective in reducing. HC gas emission with the increase of particle size and the addition of $TiO_2$. On activated carbon filters and EPB/$TiO_2$ activated carbon composites, the best effectiveness is to reduce HC gas emissions by 43.56%, and the EPB/TiO2 activated carbon composite filter reduces HC gas emissions by 46.57%. Reviewing Figures 6(A), 6(B), and seven shows that the 200-mesh activated carbon has a large pore and surface area. Those physical characteristics cause the high reduction effectiveness of the 20 mesh composite filter because the pores absorb more HC gas.

Meanwhile, the effectiveness of the EPB/$TiO_2$ activated carbon composite is better than that of activated carbon in reducing HC gas emissions. The EPB/$TiO_2$ activated carbon composite filter has a larger pore and surface area than activated carbon. In addition to the large pores, the EPB/$TiO_2$ activated carbon composite catalyst process can oxidize HC gas into $H_2O$ and $CO_2$ (Setiyono & Widjanarko, 2018). The catalyst reaction can be seen in the equation (2):

$$HC + O_2 \rightarrow CO_2 + H_2O \tag{2}$$

A catalytic reaction that converts HC gas into $H_2O$ and $CO_2$ with the help of $O_2$. This reaction is evidenced by water droplets attached to the composite filter and test tube and $CO_2$ gas, which increase relativity every time interval during the test.
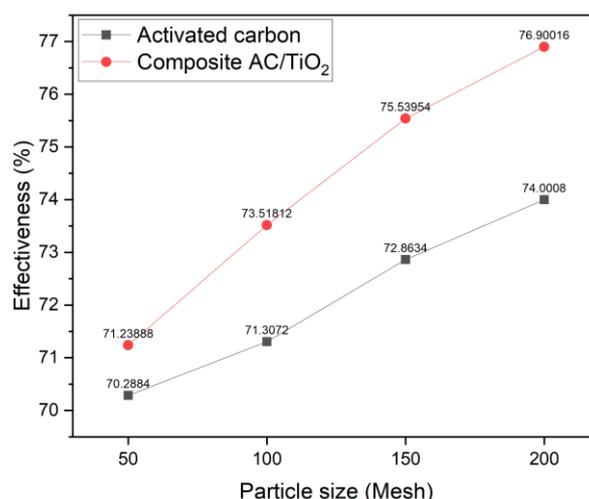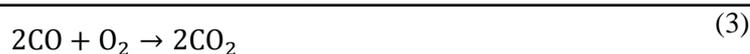


**Figure 10** CO gas reduction effectiveness in relation to particle size

The composite filter's effectiveness in reducing CO gas emission can be calculated using equation (1). Figure 10 shows the effectiveness of the composite filter in reducing CO gas emissions based on particle size. Particle size influences the efficacy of composite filters in reducing CO gas emissions; the smaller the particle size, the more effective the composite filter will be. The optimal value of activated carbon and EPB/$TiO_2$ activated carbon composite filters was obtained at a particle size of 200 mesh, 74%, and 76.9%, respectively. The high effectiveness of the 200 mesh particle size is due to the larger surface area than that of the other particle sizes, resulting in more substances being adsorbed (Syauqiah et al., 2020). In addition, SEM images in Figure 5(D) and (H) show that activated carbon and EPB/TiO2 activated carbon particles at 200 mesh size have large pores that absorb more CO gas emissions. CO reduction is getting faster due to the pores on activated carbon and EPB/$TiO_2$ activated carbon composite that can absorb CO gas emissions (Setiyono & Widjanarko, 2018). It can also be seen in Figure 10 that the EPB/$TiO_2$ activated carbon composite filter has a better reduction ability than the activated carbon filter. This is due to a catalytic reaction on the EPB/$TiO_2$ activated carbon composite filter, causing its effectiveness to be better than the activated carbon filter. The catalyst reaction in the EPB/$TiO_2$ activated carbon composite filter is due to the $TiO_2$ compound that reacts with $O_2$ to $CO_2$ (Setiyono & Widjanarko, 2018). The catalyst reaction equation can be seen in equation (3):

$$2CO + O_2 \rightarrow 2CO_2 \qquad (3)$$

The catalyst reaction causes CO gas to turn into $CO_2$ gas. This follows the data obtained in the research, namely that $CO_2$ gas has a higher concentration than CO gas in composite filters.
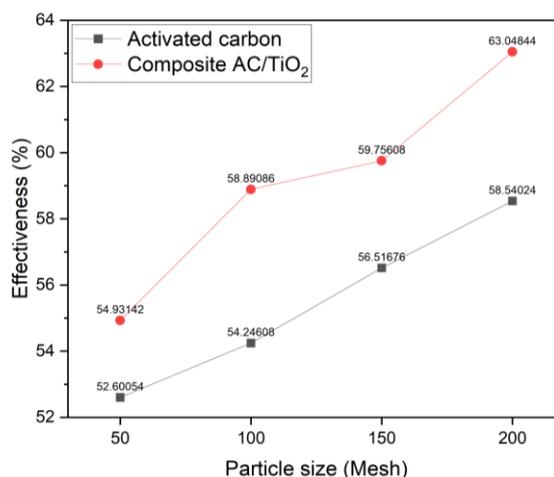


**Figure 11** $CO_2$ gas reduction effectiveness in relation to particle size

Figure 11 shows that the effectiveness is directly proportional to the particle size used. The highest $CO_2$ gas emission reduction effectiveness is found in the 200-mesh particle size of the activated carbon filter and EPB/TiO₂ activated carbon composite filter, which are 58.54% and 63.05%, respectively. The high effectiveness of the 200-mesh particle size compared to other particle sizes is due to the larger surface area. Upon reviewing Figure 7, it is known that 200 mesh activated carbon has a surface area of 3.265 $m^2$/g, and the EPB/TiO₂ activated carbon composite has a surface area of 8.174 $m^2$/g. It was concluded that the smaller the particle size, the more surface area of activated carbon and the more substances that can be adsorbed (Nafi, 2016). In addition, as shown in Figure 11, the EPB/TiO₂ activated carbon composite filter is more effective at reducing $CO_2$ gas emissions than the activated carbon filter. This is due to the larger surface area of the EPB/TiO₂ activated carbon composite compared to the activated carbon filter, which is caused by the insertion of $TiO_2$ on the surface of activated carbon (Peñas-garz et al., 2019).

### 3.4 Reusability of EPB/TiO₂ activated carbon composite filter in reducing motor vehicle exhaust gas emissions

Activated carbon and EPB/TiO₂ activated carbon composite filters were also tested for their reusable adsorbent potential on motor vehicle exhaust emissions. Activated carbon and EPB/TiO₂ activated carbon filters are reheated using an oven for 15 minutes at 150°C after each test. This heating aims to reopen the pores on the surface of the composite filter.

Figure 12 displays the performance of reusable adsorbents, such as activated carbon and EPB/TiO₂ composite filters, has been evaluated for their effectiveness in reducing motor vehicle exhaust emissions. The activated carbon filter demonstrates a decrease in hydrocarbon (HC) adsorption over repeated use due to pore saturation and thermal damage. However, the activated carbon filter remains stable over five repetitions in reducing CO and $CO_2$ gas emissions. This stability of activated carbon's effectiveness in reducing CO and $CO_2$ gases is due to the smaller size of CO and $CO_2$ molecules than the pores of activated carbon, which facilitates their adsorption. Additionally, the attractive force between CO and $CO_2$ molecules and the activated carbon surface enhances adsorption efficiency. (Widyastuti et al., 2013). This finding aligns with prior studies highlighting the role of pore size and surface interactions in gas adsorption. Widyastuti et al. (2013) demonstrated that activated carbon with a microporous structure effectively adsorbs smaller gas molecules like CO and $CO_2$ due to higher surface interactions. Similarly, Elmariza et al. (2015) reported that including $TiO_2$ in activated carbon composites further enhances stability by preventing pore collapse and repeated adsorption cycles. These

comparisons underscore that the observed stability in this study is consistent with existing literature and highlights the role of pore structure and composite design in maintaining adsorption performance.
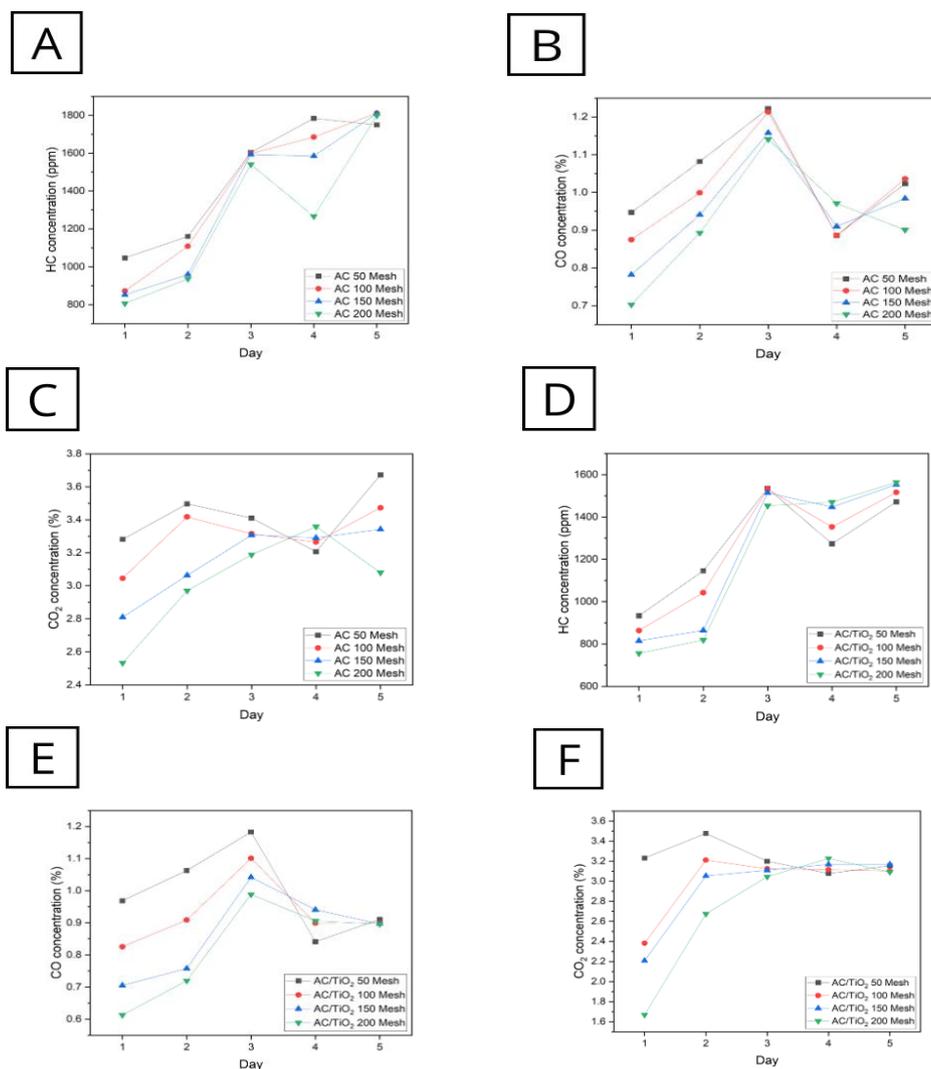


**Figure 12** The reduction of gas emission by reusable composite filter: (A) reusable activated carbon against HC gas emissions, (B) reusable activated carbon against CO gas emissions, (C) reusable activated carbon against $CO_2$ gas emissions, (D) reusable activated carbon/TiO₂ composite against HC gas emissions, (E) reusable activated carbon/TiO₂ composite against CO gas emissions, and (F) reusable activated carbon/TiO₂ composite against $CO_2$ gas emissions

The EPB/TiO₂ activated carbon composite filter also shows similar reusable results to the activated carbon filter. Figure 12(D) shows that the EPB/TiO₂ activated carbon composite filter experiences a decrease in effectiveness in reducing HC gases. The decline in effectiveness is due to the saturation of the composite filter in reducing HC gases and repeated heating that damages the pores of the activated carbon. Like the activated carbon filter, the effectiveness of the composite filter tends to remain stable in reducing CO and $CO_2$ gases. This stability is attributed to the smaller particle size of CO and $CO_2$ gases and the surface of activated carbon. Therefore, the composite filter is more effective in repeatedly reducing CO and $CO_2$ gases. Moreover, adding TiO₂ causes catalytic reactions, making reducing CO and $CO_2$ gases easier. However, repeated heating can damage the shape of the composite filter, as evidenced by its cracking after being heated five times. The high dryness level in the composite filter causes damage to the composite filter.

# 4. CONCLUSION

Activated carbon filters and activated carbon/TiO₂ composites were successfully synthesized using EPB as the primary raw material, demonstrating their potential to reduce harmful motor vehicle exhaust emissions significantly. Among the tested configurations, the best reduction effectiveness was achieved with a particle size of 200 mesh, as this size optimized the balance between surface area and structural integrity, enhancing adsorption and pollutant degradation. Furthermore, the EPB/TiO₂ composite filter exhibited superior performance compared to the standard activated carbon filter, primarily due to the synergistic effects of TiO₂, which not only adsorbed pollutants but also facilitated photocatalytic oxidation, effectively targeting a wider range of toxic compounds. Another important finding is the reusability of these filters, as both the activated carbon and the EPB/TiO₂ composite materials can be regenerated through simple processes, making them cost-effective and sustainable solutions for long-term pollution control applications.

# REFERENCES

Arsyad, Y. M., Wahyuni, D., Nurhasanah, N., Siswo, B., Adriat, R., Prasetiono, A., & Hidayat, W. T. (2023). Effect of TiO 2 on Orange Peel Activated Carbon Composite in Reducing Carbon Monoxide and Hydrocarbon Gas Emissions. *Jurnal Ilmu Fisika*, *15*(2), 73–80.

Awitdrus, Mulfida, D., Farma, R., Saktioto, & Iwantono. (2018). Pengaktifan Kimia Berbantuan Gelombang Mikro Karbon Aktif dari Kulit Kacang dengan Waktu Pra-karbonisasi yang Berbeda. *Jurnal Fisika*, *8*(2), 43–50.

BPS Kalimantan Barat. (2022). Output Tabel Dinamis. In *Badan Pusat Statistik*.

Elmariza, J., Zaharah, T. A., & Arreneuz, S. (2015). Optimasi Ukuran Partikel, Massa dan Waktu Kontak Karbon Aktif Berdasarkan Efektivitas Adsorpsi β-Karoten pada CPO. *JJK*, *4*(2), 1–5.

Fauzia, E. A., & Purnama, H. (2021). The Effect Of Particle Size On The Characterization Of Activated Carbon From Tropical Black Bamboo (Gigantochloa Atroviolacea). *Techno (Jurnal Fakultas Teknik, Universitas Muhammadiyah Purwokerto)*, *22*(2), 99. https://doi.org/10.30595/techno.v22i2.10350

Kurniawan, R., Lutfi, M., & Agung, W. (2014). Karakterisasi Luas Permukaan Bet ( Braunanear , Emmelt dan Teller ) Karbon Aktif dari Tempurung Kelapa dan Tandan Kosong Kelapa Sawit dengan Aktivasi Asam Fosfat (H3PO4). *Jurnal Keteknikan Pertanian Tropis Dan Biosistem*, *2*(1), 15–20.

Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia. (2017). Peraturan Menteri LHK Nomor P 20 Tentang Baku Mutu Emisi Gas Buang Kendaraan Bermotor Tipe Baru Kategori M Katagori N dan Katagori O. In *Nomor P.20/Menlhk/Setjen/Kum.1/3/2017* (pp. 7–8).

Milawati, S., Syahbanu, I., & Sasri, R. (2021). Sintesis Komposit TiO2-SiO2 Menggunakan Metode Sol-Gel-Hidrotermal. *Jurnal Ilmu Dasar*, *22*(1), 51–58.

Monika, I., Umar, D. F., Hardian, A., Astriana, R., & Sulistyohadi, F. (2021). Pengaruh Penambahan Katalis TiO2 terhadap Sifat Kimia Permukaan Komposit Karbon Aktif untuk Penyerapan Gas SO2. *Jurnal Teknologi Mineral Dan Batubara*, *17*(3), 153–165. https://doi.org/10.30556/jtmb.vol17.no3.2021.1140

Musthofa, A. M. H., Syafila, M., & Helmy, Q. (2023). Effect of Activated Carbon Particle Size on Methylene Blue Adsorption Process in Textile Wastewater. *Indonesian Journal of Chemistry*, *23*(2), 461–474. https://doi.org/10.22146/ijc.79784

Nafi, R. (2016). Kinetika Adsorpsi Pb ( II ) dengan Adsorben Arang Aktif dari Sabut Siwalan. *Jurnal Farmasi Dan Praktif*, *I*(2), 28–37.

Panjai, S., Mutita, N., & Maruemon, C. (2010). Biosorption of Lead (Pb2+) by Luffa Cylindrical Fiber. In *Environmental Research Journal* (Vol. 4, Issue 1, pp. 157–166).

Peñas-garz, M., Almudena, G. A., Bedia, J., Rodriguez, J. J., & Belver, C. (2019). Effect of Activating Agent on the Properties of TiO 2 / Activated Carbon Heterostructures for Solar Photocatalytic Degradation of Acetaminophen. *Materials*, *378*(12), 1–17. https://doi.org/10.3390/ma12030378

Setiyono, D. R., & Widjanarko, D. (2018). Penggunaan Serbuk TiO2 dan Karbon Aktif Sebagai Campuran Bahan Catalytic Converter Keramik untuk Mengurangi Polutan Berbahaya pada Kendaraan Bermesin Bensin. *Jurnal Rekayasa Kimia & Lingkungan*, *13*(2), 165–173. https://doi.org/10.23955/rkl.v13i2.11901

Sumila, Asri, A., Arsyad, Y. M., & Wahyuni, D. (2023). Uji Kinerja Karbon Aktif Tandan Kosong Kelapa Sawit ( TKKS ) Sebagai Reusable Adsorbent Logam Besi Pada Air Gambut. *Jurnal Fisika*, *8*(2), 17–22.

Syauqiah, I., Kusuma, F. I., & Mardiana, M. (2020). Adsorption of Zn and Pb Metal in Printing Waste of PT. Grafika Wangi Kalimantan Using Corn Cobs Charcoal as Adsorbent. *Jurnal Konversi*, *9*(1), 28–34. https://doi.org/10.20527/k.v9i1.9075

Taufik, M., Suci, T., Kasih, D., & Khair, M. (2021). Pembuatan Karbon Aktif Cangkang Kelapa Sawit ( Elaeis Guineensis ) dengan Aktivator Gelombang Microwave. *Chemistry Journal of Universitas Negeri Padang*, *10*(1), 40–44.

Tri Basuki, K. (2007). Penurunan Konsentrasi CO dan NO pada Emisi Gas Buang dengan Menggunakan Media Penyisipan TiO2 Lokal pada Karbon Aktif. *Jurnal Forum Nuklir*, *1*(1), 45–64. https://doi.org/10.17146/jfn.2007.1.1.3272

Udyani, K., Purwaningsih, D. Y., Setiawan, R., & Yahya, K. (2019). Pembuatan Karbon Aktif dari Arang Bakau Menggunakan Gabungan Aktivasi Kimia dan Fisika dengan Microwave. *Jurnal IPTEK*, *23*(1), 39–46. https://doi.org/10.31284/j.iptek.2019.v23i1.479

Wahyuningsih, P., Rahmawati, R., & Yulius, N. (2017). Apikasi Fotodegradasi Nanokomposit Arang Aktif Tandan Kosong Kelapa Sawit/TiO2 Terhadap Limbah Cair Kelapa Sawit. *Journal of Islamic Science and Technology*, *3*(2), 161–172. https://doi.org/10.22373/ekw.v3i2.2092

Widihati, I. A. G., Apriliyanto, I., & Sibarani, J. (2021). Karakterisasi Zeolit Mangan Termodifikasi TiO2 Serta Aplikasinya Sebagai Filter Gas Buang Kendaraan Bermotor Dalam Penurunan Kadar Gas CO, HC, dan Pb. *Jurnal Kimia*, *15*(1), 107. https://doi.org/10.24843/jchem.2021.v15.i01.p15

Widyastuti, A., Sitorus, B., & Jayuska, A. (2013). Karbon Aktif dari Limbah Cangkang Sawit Sebagai Adsorben Gas dalam Biogas Hasil Fermentasi Anaerobik Sampah Organik. *Jurnal Kimia Khatulistiwa*, *2*(1), 30–33. http://jurnal.untan.ac.id/index.php/jkkmipa/article/view/1746

Wimarsela, S., Junaidi, R., & Silviyati, I. (2021). Sintesis Silika Gel dari Abu Cangkang dan Serabut Kelapa Sawit Terimobilisasi Difenilkarbazon dengan Metode Sol-Gel. *Jurnal Penelitian Inovatif*, *1*(2), 165–174. https://doi.org/10.54082/jupin.24

Winoko, Y. A., & Wicaksono, A. G. (2021). Aktifasi Tempurung Kelapa untuk Mereduksi Emisi Gas Buang Motor Bakar. *Rang Teknik Journal*, *4*(1), 104–108. https://doi.org/10.31869/rtj.v4i1.2211

Yuliusman, Sari, M. P., & Nafisah, A. R. (2019). Modifying Low-Density Polyethylene based Activated Carbon using Titanium Dioxide for Carbon Monoxide and Hydrocarbon Adsorption. *AIP Conference Proceedings 2175*, *020028*(November). https://doi.org/10.1063/1.5134592

Zairinayati, & Khosamtun, K. (2022). Efektifitas Tandan Kosong Kelapa Sawit (Elais Guineensis Jacq) dalam Menurunkan Kadar COD Limbah Cair Kain Jumputan. *Indobiosains*, *4*(2), 61. https://doi.org/10.31851/indobiosains.v4i2.8433

Zhang, L., Mi, M., Li, B., & Dong, Y. (2013). Modification of Activated Carbon by Means of Microwave Heating and Its Effects on the Pore Texture and Surface Chemistry. *Research Journal of Applied Sciences, Engineering and Technology*, *5*(5), 1836–1840. https://doi.org/10.19026/rjaset.5.4946