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Potassium Permanganate Confined in Porous Carbon Pretreated Using Wet Ozone Oxidation for Hydrogen Sulfide Removal (H_2S)

Kalium Permanganat Terimpregnasi dalam Karbon Aktif Teraktivasi Oksidasi Ozon Basah untuk Penghilangan Hidrogen Sulfida (H_2S)

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ABSTRAK

Kontaminan gas merupakan masalah besar pada proses industri dan lingkungan, terutama hidrogen sulfida (H_2S). Gas ini tidak berwarna, tidak berbau, korosif terhadap jaringan pipa gas alam, merusak katalis logam, dan menyebabkan hujan asam. Selain itu, gas ini sangat mudah terbakar dan sangat beracun, sehingga perlu dihilangkan meskipun dalam konsentrasi kecil. Salah satu metode untuk menghilangkan H_2S, yang belum dipelajari secara luas, adalah oksidasi dengan kalium permanganat ($KMnO_4$) yang diimpregnasikan pada karbon berpori atau dinamai nano-confinement $KMnO_4$. Cangkang sawit (PKS) digunakan sebagai bahan baku karbon berpori, yang melimpah, terbarukan, dan murah. Proses produksi nano-confinement KMnO4 terdiri atas eberapa langkah. Langkah pertama adalah pirolisis cangkang sawit dalam tungku pada suhu 800°C, diikuti oleh aktivasi karbon uap. Ini menghasilkan karbon berpori cangkang sawit (CPKS). Tahap kedua adalah pembuatan karbon berpori dari cangkang sawit yang cenderung hidrofilik dengan cara oksidasi praperlakuan menggunakan ozonasi basah, yang selanjutnya dinamakan CKPS-Oz. Kalium permanganat yang teremban dalam karbon berpori dari cangkang sawit ($KMnO_4$/CPKS-Oz) diproduksi dengan cara impregnasi secara basah variasi KMnO4 sebesar 5, 10, dan 20% wt. Hasil uji kinerja menunjukkan bahwa $KMnO_4$/CPKS-Oz mampu menghilangkan H_2S hingga 98% dan lebih efektif dibandingkan hanya menggunakan $KMnO_4$ (67%). Penelitian ini menunjukkan bahwa kombinasi antara oksidasi ozon basah dan impregnasi $KMnO_4$ ke dalam karbon aktif dari tempurung kelapa sawit (CPKS) menghasilkan peningkatan kapasitas oksidasi gas H_2S secara signifikan. Metode ini merupakan pendekatan baru yang belum banyak dilaporkan dalam pemanfaatan CPKS untuk penghilangan gas H_2S.

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ABSTRACT

A gas contaminant is a big problem in the process industry and environment, especially hydrogen sulfide (H_2S). It is colorless, odorless, corrosive to natural gas pipelines, damages metal catalysts, and causes acid rain. Moreover, it is extremely flammable and highly toxic, so it needs to be removed even in small concentrations. One method to remove H_2S, which has yet to be studied widely, is oxidation by nano-confinement permanganate potassium ($KMnO_4$) in a porous carbon support. Palm kernel shells (PKS) were used as a raw material of porous carbon, which is abundant, renewable, and cheap. The production process of nano-confinement $KMnO_4$ consists of several steps. The first step is the pyrolysis of palm kernel shells in the furnace at 800°C, followed by steam activation of carbon. It produced palm kernel shells porous carbon (CPKS). The second step was to produce porous carbon of palm kernel shell that tends to be hydrophilic by pretreatment oxidation using wet ozone treatment, which was then named CKPS-Oz. Potassium permanganate confined in porous carbon from palm kernel shell ($KMnO_4$/CPKS-Oz) was produced by incipient wet-impregnation with $KMnO_4$ variations of 5, 10, and 20%wt. The performance test showed that $KMnO_4$/CPKS-Oz could remove H_2S up to 98% and was more effective than only using $KMnO_4$ (67%). This work presents a novel synergistic strategy by integrating wet ozone oxidation and $KMnO_4$ confinement within palm kernel shell–derived porous carbon (CPKS), providing a sustainable and highly efficient material tailored explicitly for hydrogen sulfide (H_2S) removal from gas streams.

1. INTRODUCTION

1.1 Background

The presence of hydrogen sulfide (H_2S) has been reported in various settings such as the natural environment, the atmosphere, and process industries. Anaerobic bacteria decompose organic materials in order that the H_2S naturally presents in undersea vents, volcanoes, sulfur springs, and stagnant bodies of water (Goldnik & Turek., 2016). In addition, H_2S is also found in caustic liquors, coal/biomass gasification, the oil-gas industry, cowsheds, and biogas (Sitthikhankaew et al., 2014). In general, H_2S in gas contaminants has small concentrations but should be removed. This is because low concentrations of H_2S in the range of 1 to 350 ppm can cause eye irritation, respiratory problems, and even fatality (Sitthikhankaew et al., 2014). In addition, in the process industry, H_2S causes damage to the metal catalyst and corrosion of pipes and tanks (Wang et al., 2019).

Several methods to remove H_2S from gas contaminants have been studied, such as aerobic bio-scrubber for H_2S removal from biogas (San-Valero et al., 2019), adsorption using zeolites (Cosoli et al., 2008), metal oxides (Vaziri & Babler, 2019), and activated carbon (Figueiredo et al.,1999; Melo et al., 2006; Ducom et al.,2016; Sigot et al.,2016). Another method that has yet to be widely observed is oxidation using potassium permanganate ($KMnO_4$). Potassium permanganate is a strong oxidizing agent. It rapidly reacts with organic or inorganic compounds such as hydrogen sulfide. However, research showed the low ability of $KMnO_4$ to oxidize low concentrations of hydrogen sulfide due to its macro size (Matos et al., 2017). The solution is to reduce the size of $KMnO_4$ to nanoparticles. However, grinding is less effective in reducing the size because $KMnO_4$ can agglomerate to form macroparticles. The best method for synthesizing $KMnO_4$ nanoparticles is to immerse $KMnO_4$ particles into the surface of porous adsorbents (Goldnik & Turek., 2016).

Research showed that nanoparticles of $KMnO_4$ can be impregnated into the porous carbon synthesized from palm kernel shells, but the application of the material for H_2S removal is limited. A previous paper from our preliminary study discussed the potential of $KMnO_4$ impregnated in porous carbon (Suhirman et al., 2021). However, more detailed studies of the effect of ozone surface oxidation in the confinement of $KMnO_4$ on porous carbon have yet to be discussed. This paper presents the influence of wet ozone oxidation in the preparation of $KMnO_4$ confined in porous carbon for removing hydrogen sulfide. The porous carbon was synthesized from palm kernel shells, abundantly available as byproducts of the oil palm industry. Before being used for support, porous carbon was surface-modified using wet ozone oxidation at different times. Several material characterizations and performance tests were carried out to prove the successful material preparation and the effectiveness of H_2S removal. To date, limited studies have investigated the effect of ozone oxidation treatment on palm shell-based activated carbon for hydrogen sulfide (H_2S) removal. While various surface modifications have been applied to enhance adsorption capacity, the specific role of ozone as a surface oxidizing agent remains underexplored for this biomass-derived adsorbent. Although ozone treatment has been applied in modifying carbonaceous materials, its impact on palm shell-activated carbon and the resulting performance in H_2S adsorption has not yet been systematically addressed in the current literature (Ouyang et al., 2020).

2. METHODOLOGY

2.1 Materials

Palm kernel shells were supplied from Jambi, Indonesia. Potassium permanganate ($KMnO_4$) was obtained from Merck KGaA, Darmstadt-Germany. The analytical materials were an absorbent solution according to SNI 19-7117.7-2005, N,N-dimethyl-1,4-phenylenediammonium dichloride, and ferric chloride ($FeCl_3$).

2.2 Preparation of Porous Carbon from Palm Kernel Shells (CPKS-Oz)

According to the reference, CPKS-Oz was produced through several steps (Suhirman et al., 2021). The first step was to reduce the palm kernel shell size between 5 to 16 mesh. The next step was the pyrolysis of palm kernel shells in a furnace at 800°C, followed by steam activation of carbon. This step produced porous carbon from palm kernel shells (CPKS). Afterward, CPKS was oxidized using wet ozone in the ozone generator of the QLA-3G IONTECH model. The airflow rate of 16 L/min was converted into the ozone mass flow rate of 0.05 g/min. The initial carbon mass and water ratio was 1 g in 200 ml during ozone treatment. The wet ozone oxidation was performed with time variations of 60 and 120 min, and the result was named CPKS-Oz-duration. For instance, CPKS-Oz-60 was used for 60 minutes of oxidation. Subsequently, CPKS-Oz was filtered using a vacuum filter, dried in a desiccator for 24 hours, and then put in an oven at 110°C overnight.

2.3 Preparation of Potassium Permanganate Confined in Porous Carbon from Palm Kernel Shell ($KMnO_4$/CPKS-Oz)

Incipient wet impregnation was used to produce $KMnO_4$/CPKS-Oz. Firstly, CPKS-Oz was degassed in in a vacuum-sealed three-neck flask maintained at 110 °C, and subsequently cooled to room temperature. Then, CPKS-Oz was cooled until it reached room temperature, and $KMnO_4$ was added to the three-neck flask at a variation of 5%, 10%, and 20%. The material was dried in an oven at 110°C overnight and kept safe in the vacuum box. The result was named 5%$KMnO_4$/CPKS-Oz-60 for CPKS-Oz-60, which was impregnated using 5% $KMnO_4$. Other variations were also given analogous names.

2.4 Hydrogen Sulfide (H_2S) Removal Measurement

The H_2S removal test was performed in a 180 ml batch reactor. A mixture of H_2S and nitrogen was added to the batch reactor to remove the ambient air and to produce a pressure of 1.1 atm with 110 ppm of the initial concentration of H_2S in the batch reactor. The removal process was done using 20%$KMnO_4$/CPKS-Oz as adsorbents. During the oxidation process, samples were taken every 15 minutes in the first hour and every 30 minutes for the next two hours. Then, those samples were analyzed using a UV-VIS spectrophotometer. A similar approach was also applied, employing CPKS and bulk $KMnO_4$ as adsorbents.

2.5 Analysis methods

The determination of H_2S concentration in this study was based on the methylene blue method initially developed by Cline, where hydrogen sulfide reacts with N, N-dimethyl-p-phenylenediamine, and $FeCl_3$ under acidic conditions to form methylene blue, which can be measured spectrophotometrically at 670 nm (Cline, 1969). The H_2S concentration in each sample was determined by measuring its absorbance using a UV-Vis Spectrophotometer at a 670 nm wavelength. The sample was prepared by taking 5 ml of solution from the batch reactor using a 1 ml IM-BP syringe SGE (Trajan Scientific) – Australia. Then, it was dissolved in 20 ml of absorbent solution (SNI 19-7117.7-2005), 2 ml of N-Dimethyl 1,4-phenylenediammonium dichloride, and 1 ml of $FeCl_3$. It was placed in a dark box for 30 min; then its absorbance was measured.

2.6 Characterization Methods

CPKS and $KMnO_4$/CPKS-Oz were analyzed for their pore structure using an N2-sorption analyzer by Quantachrome (NOVA 2000) from Quantachrome Instruments industry-USA. The sample was prepared by taking 0.1 g and degassing under vacuum at 125°C overnight. Based on the N2-sorption analyzer, the curve p/po range 0 to 0.45 was adsorption and 0.45 to 1 was desorption. In addition, the distribution of $KMnO_4$ on CPKS-Oz and the morphology of CPKS and $KMnO_4$/CPKS-Oz were observed by Scanning Electron Microscope (SEM-Energy Dispersive X-ray Spectroscopy Mapping JEOL 6510 LA) from JEOL Ltd.-Japan. The sample was prepared by taking 0.01 g and filling in the paper carbon before being degassed under vacuum at 125°C for 3 min, at 1000x magnification and 0.2 kV Voltage.

3. RESULTS AND DISCUSSION

3.1 Characteristics of Porous Carbon and $KMnO_4$ Confined in Porous Carbon

Table 1 presents the characteristics of CPKS and $KMnO_4$/CPKS-Oz. As shown, the surface area of $KMnO_4$/CPKS-Oz is smaller compared to that of CPKS. This indicates that wet ozone oxidation reduced the surface area. In contrast, the micropore of porous carbon increased due to pretreatment using wet ozone oxidation. The amount of $KMnO_4$ mass added in the impregnation process affected the characteristics of the carbon produced. The more $KMnO_4$ was used, the less the total pore volume due to $KMnO_4$ filling the carbon pores, reducing the pore volume and the surface area. It can also be observed that the longer the impregnation time, the more $KMnO_4$ was confined in the carbon. However, the wet ozone oxidation time extension from 60 to 120 min reduced the specific surface area. This corresponds with the literature that a prolonged treatment defected the material surface (Choo et al., 2013). Prolonged oxidation using wet ozone increases the number of oxygen-containing functional groups on the carbon surface, consequently decreasing specific surface area, micropore volume, and adsorption capacity (Valdés et al., 2001). The fluctuation of the % micropore surface area at different $KMnO_4$ concentrations, as shown in Table 1, is mainly attributed to the competing effects between pore formation and pore destruction during the oxidation process.

Table 1. Pore properties of CPKS and $KMnO_4$/CPKS-Oz with wet ozone pretreatment

Adsorbents	The specific surface area [a] (m^2/g)	Micropore surface area [b] (%)	Total pore volume [a] (cc/g)	Micropore volume [c] (%)	Average pore diameter (nm)
CPKS	701.00	62.47	0.51	43.50	2.96
5%$KMnO_4$/CPKS-Oz-60	565.40	82.79	0.35	56.30	2.44
10%$KMnO_4$/CPKS-Oz-60	519.40	85.31	0.29	62.54	2.23
20%$KMnO_4$/CPKS-Oz-60	483.00	84.12	0.26	66.38	2.28
5%$KMnO_4$/CPKS-Oz-120	490.80	71.29	0.40	38.53	3.30
10%$KMnO_4$/CPKS-Oz-120	477.00	74.34	0.30	45.06	2.94
20%$KMnO_4$/CPKS-Oz-120	423.80	32.22	0.25	19.61	5.14

[a] determined by Multi-Point Brunauer–Emmett–Teller (BET)
[b] determined by *t-plot* method
[c] determined by Pore volume at 0.99 P/P_o

At lower $KMnO_4$ concentrations, mild oxidation promotes the development of new micropores and the removal of impuritiesincreasing micropore surface area. This explains the initial rise from 62.47% to 85.31%. However, as the $KMnO_4$ concentration increases further, excessive oxidation begins to occur. This leads to the deposition of oxygen-containing functional groups inside the pores, causing pore blockage, and in some cases, partial collapse of the micropore structure. This results in a gradual decline in the micropore surface area to 71.29% and 74.34%. At the highest concentration, over-oxidation becomes dominant, causing severe structural damage to the carbon framework. This excessive oxidation can destroy the microporous network or convert micropores into mesopores or macropores, which is reflected in the significant drop in the % micropore surface area to 32.22%. This trend is consistent with previous studies, which reported that while $KMnO_4$ treatment initially enhances porosity, over-oxidation at high concentrations negatively affects micropore development (Wang et al., 2019).

3.2 Effect of Wet Ozone Oxidation on Morphology of Materials

CPKS had a rigid structure and a uniform surface (Figure 1). The large cavities were evenly distributed with several smaller voids. The contact angle measurement showed the surface was hydrophobic, with a contact angle of 134°. Hence, surface modification to increase wettability is necessary before impregnating $KMnO_4$. This is in line with previous studies which reported that raw activated carbon, particularly from biomass sources such as coconut shells, tends to exhibit hydrophobic characteristics due to the presence of non-polar carbonaceous structures and limited oxygen-containing functional groups on the surface (Lua & Yang., 2004). This observation aligns with recent findings reporting that raw biomass-derived activated carbons typically possess a low concentration of oxygen-containing functional groups, resulting in limited hydrophilicity. Therefore, oxidative treatment (wet ozon) is often employed to introduce polar functionalities, thereby improving wettability and adsorption performance for subsequent surface modification or impregnation processes (Ningrum et al., 2021).

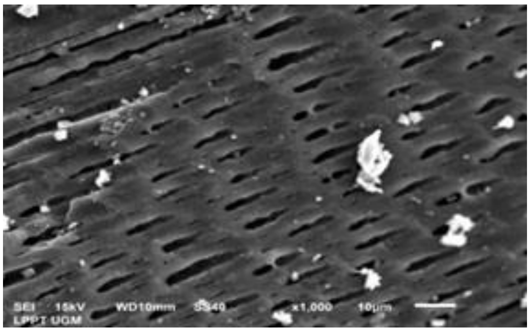

Figure 1. The Morphology of material carbon from palm kernel shell (CPKS).

Figure 2 shows the different morphology between $KMnO_4$/CPKS-Oz and CPKS. Comparing each Scanning Electron Microscope image, the higher the mass percent of $KMnO_4$, the smaller the cavity formed on the carbon surface. This is because $KMnO_4$ filled the cavity. This phenomenon is attributed to the deposition of $KMnO_4$ particles into the pores, thereby reducing surface porosity and altering the morphology (Liu et al., 2020). The presence of $KMnO_4$ promotes the formation of manganese oxides that accumulate within micro- and mesopores, leading to partial or total blockage (Shen et al., 2017).

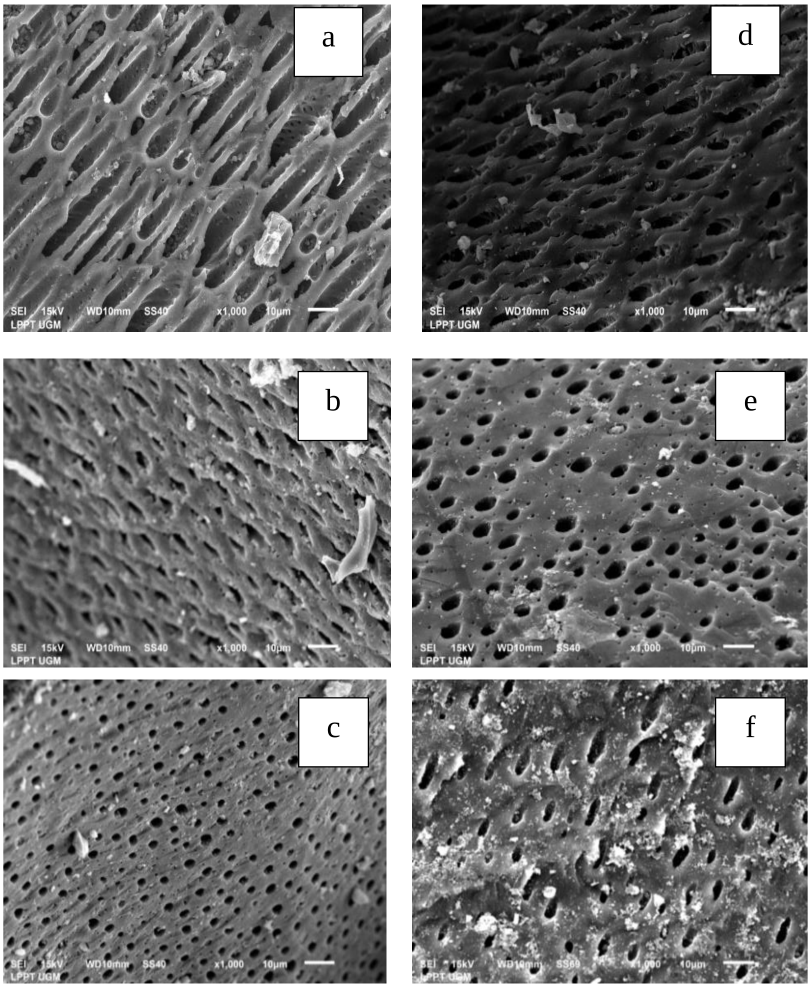

Figure 2. Morphology of CPKS-Oz for 60 min oxidation with (a) 5% $KMnO_4$, (b) 10% $KMnO_4$, and (c) 20% $KMnO_4$; CPKS-Oz for 120 min oxidation with (d) 5% $KMnO_4$, (e)10% $KMnO_4$ and (f) 20% $KMnO_4$.

3.3 Effect of Wet Ozone Oxidation on Impregnation of Materials

CPKS only contained carbon (C) and oxygen (O) atoms (Figure 3). When ozone interacts with water molecules, it can generate hydroxyl radicals (·OH), which possess a stronger oxidative potential than ozone alone. These radicals can effectively cleave carbon-carbon double bonds and insert oxygen-containing groups onto the surface. Studies on biochar and activated carbon have shown that wet ozone significantly enhances surface functionalization. For instance, increased concentrations of carboxylic and hydroxyl groups were observed following treatment, which in turn improved adsorption performance toward aqueous pollutants (Zhou et al., 2016). After oxidation with wet ozone confined with $KMnO_4$, there were K and Mn elements in $KMnO_4$/CPKS-Oz (Figure 4). This proves that $KMnO_4$ was successfully impregnated in porous carbon. Energy Dispersive X-ray Spectroscopy mapping was further carried out to see the dispersity of $KMnO_4$. It can be observed that the optimum condition was obtained by conducting wet ozone oxidation using 20% $KMnO_4$ for 60 min, resulting in a high surface area and K and Mn elements. It is shown by the number of compound K, Mn, O, and C atoms, where data are visually indicated by the strength of green, red, blue, and white tones, as depicted in Figure 5. Wet ozone oxidation using 20% $KMnO_4$ for 120 120 minutes is not optimum because over-oxidation may lead to the blockage or destruction of micro- and mesopores, thereby reducing the active surface area (Valdés et al., 2002).

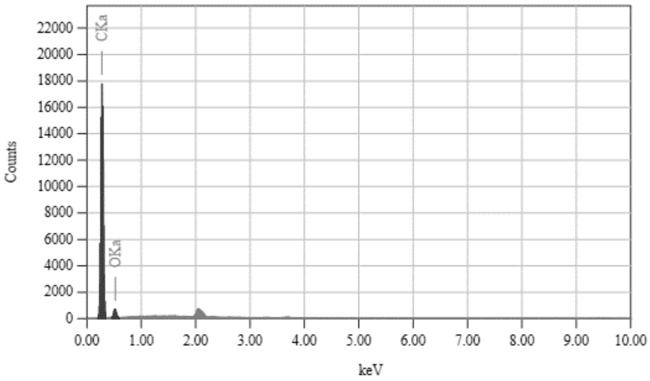

Figure 3. Scanning Electron Microscope EDX of material CPKS

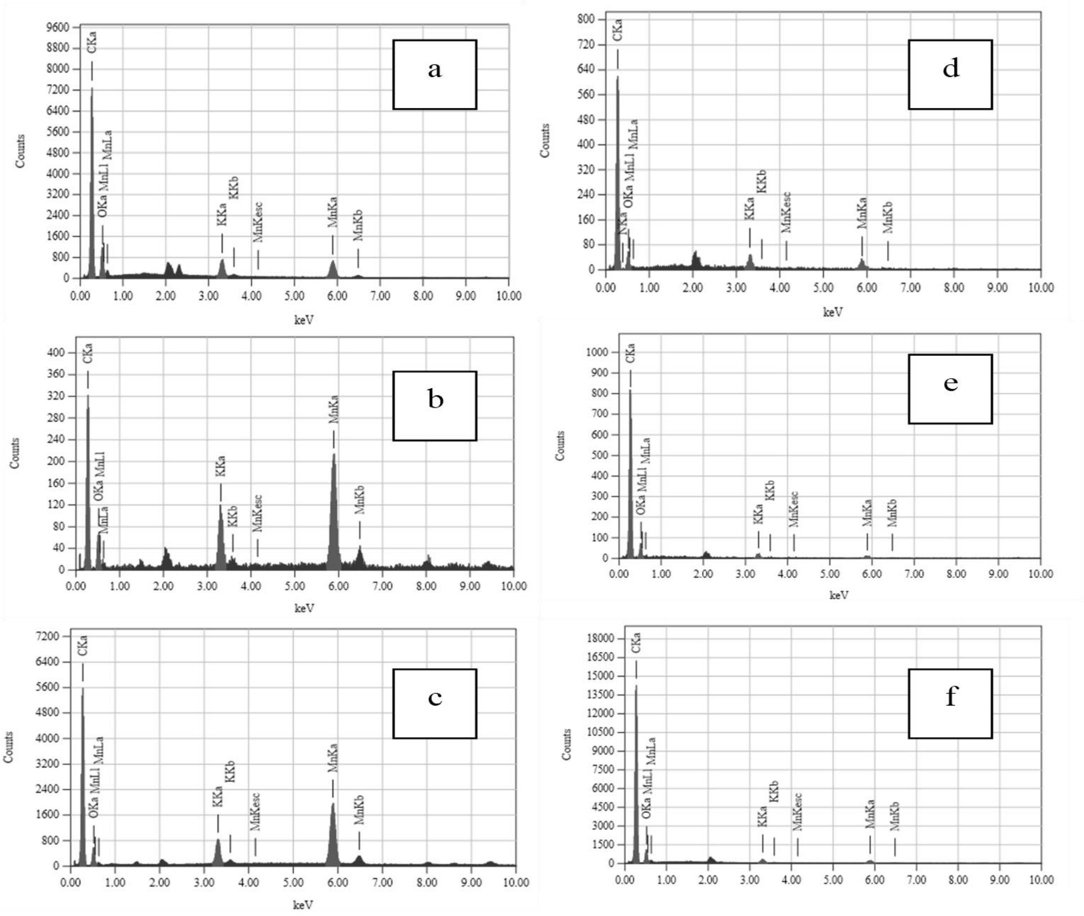

Figure 4. SEM EDX of CPKS-Oz for 60 min oxidation (a) 5% $KMnO_4$, (b) 10% $KMnO_4$, and (c) 20% $KMnO_4$; CPKS-Oz for 120 min oxidation (d) 5% $KMnO_4$, (e)10% $KMnO_4$ and (f) 20% $KMnO_4$

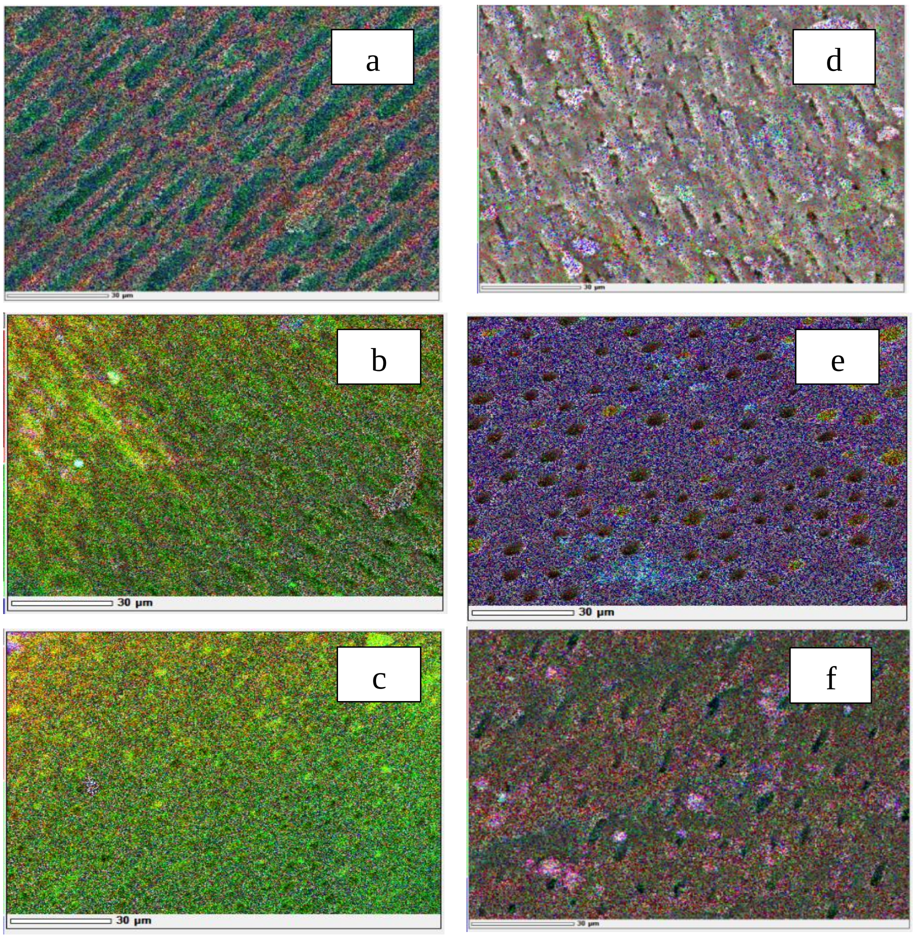

Figure 5. Result of $KMnO_4$/CPKS-Ox analysis by SEM EDX mapping at time 60-min (a) 5% (b) 10% (c) 20%; and at the time 120-min (d) 5% (e) 10% (f) 20% (shown of compound K, Mn, O and C atoms represented by green, red, blue, and white colors)

3.4 Performance Material for H_2S Removal

Wet ozone oxidation plays a significant role in modifying the surface CPKS. This treatment effectively introduces various oxygen-containing functional groups, such as hydroxyl (-OH), carbonyl (C=O), and carboxyl (-COOH) groups onto the carbon surface. The presence of these functional groups increases the surface polarity and enhances the chemical affinity of the activated carbon towards oxidizing agents, particularly potassium permanganate ($KMnO_4$). The increased density of oxygen functionalities serves as anchoring sites for $KMnO_4$ impregnation, improving both its dispersion and retention within the pore structure of the activated carbon. This surface modification optimizes the catalytic oxidation process by providing more active sites for H_2S oxidation. As a result, the synergistic interaction between the introduced functional groups and the impregnated $KMnO_4$ significantly enhances the efficiency and capacity of 20%$KMnO_4$/CPKS-Oz-60 for H_2S removal. (Zhang et al., 2018).

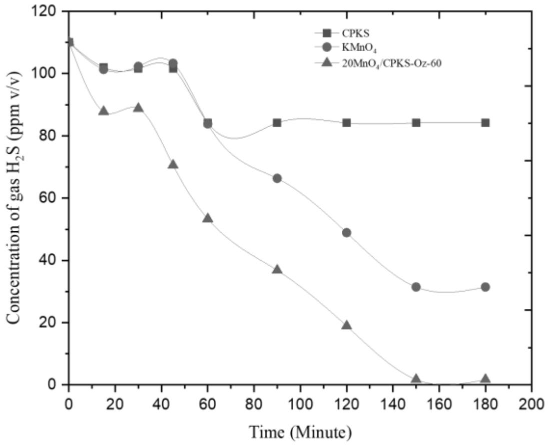

Figure 6. Removal of H_2S gas using CPKS, the bulk of $KMnO_4$ and 20%$KMnO_4$-Oz-60

Figure 6 compares the performance of 20%$KMnO_4$/CPKS-Oz-60, CPKS, and bulk $KMnO_4$ as an adsorbent for H_2S removal. It shows that 20%$KMnO_4$/CPKS-Oz-60; $KMnO_4$; CPKS could remove approximately 98%, 67%, and 23%, respectively. This study revealed that chemical adsorption between H_2S and $KMnO_4$/CPKS had a greater impact than physical adsorption. Smaller particle sizes were formed within the porous carbon-confined $KMnO_4$, leading to the observed, resulting in a higher surface area per weight of $KMnO_4$, and H_2S also reacted with $KMnO_4$. Hence, higher H_2S

adsorption could be achieved. Confining $KMnO_4$ within porous carbon enhances its dispersion and reduces particle size, thereby significantly increasing the reactive surface area. This modification improves the oxidative performance of $KMnO_4$ toward gaseous pollutants such as hydrogen sulfide (H_2S) (Zhang et al., 2018). The study revealed that impregnation of $KMnO_4$ into porous activated carbon ($KMnO_4$/AC) markedly improved H_2S removal efficiency in comparison to the bulk form. At a $KMnO_4$ loading of 20 wt%, the composite material achieved approximately 97% removal efficiency, while bulk $KMnO_4$ exhibited only about 65% removal under similar conditions (Zhang et al., 2018).

If presented as a standalone paragraph, it should be paraphrased into no fewer than two sentences., the application of aqueous H_2O_2 significantly accelerated the degradation rate of H_2S by reducing its half-life by 75%; however, its removal efficiency was still lower than that achieved by oxidative scrubbing or photocatalytic methods, as complete H_2S elimination could not be reached without additional oxidation processes (Liu et al., 2020).

Table 2. Adsorption performance of different adsorbents

Adsorbents	Adsorption capacity (mg/g)	Ref
CPKS	6.85	This work
20%$KMnO_4$/CPKS-Oz-60	29.52	This work
Activated carbon impregnated with urea	272	(Adib et al., 2000)
Activated carbon impregnated with 5% $KMnO_4$	84.87	(Papurello et al., 2019)
Activated carbon impregnated with 2% potassium iodide	27.04	(Papurello et al., 2019)
Coconut shell activated carbon treated with zinc acetate	1.7	(Zulkefli et al., 2019)
Sawdust activated carbon	6.2	(Kazmierczak-Razna et al., 2015)

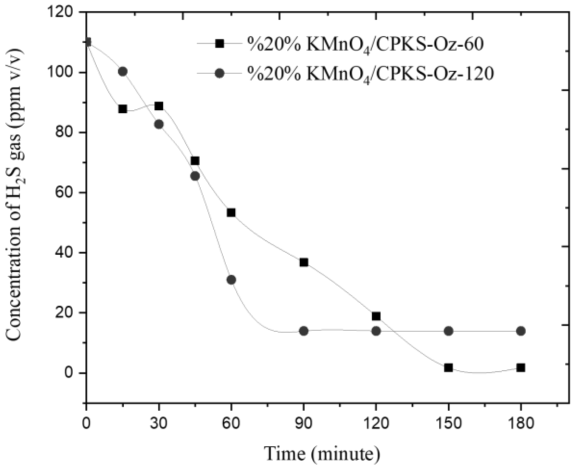

Figure 7. Removal of H_2S gas using 20% $KMnO_4$/CPKS-Oz with two different oxidation time

Figure 7 shows a performance comparison of 20%$KMnO_4$/CPKS-Oz-60 and 20%$KMnO_4$/CPKS-Oz-120 for H_2S removal. A 20%$KMnO_4$/CPKS-Oz-60 material can reduce up to 98%, while 20%$KMnO_4$/CPKS-Oz-120 can decrease up to 87% of H_2S gas concentration. This is consistent with the Scanning Electron Microscope Energy Dispersive X-ray Spectroscopy Mapping analysis, which shows that 20% $KMnO_4$ is more evenly dispersed in porous carbon subjected to wet ozone pre-oxidation treatment for 60 min than porous carbon subjected to pre-oxidation treatment with wet ozone for 120 min. The 120 minutes may be due to over-oxidation and surface saturation effects. The 120 minutes of oxidation can damage the pore surface of porous carbon, thereby reducing the micropore area and oxygen functional groups entering the micropore surface (Adib et al., 2000). The lower H_2S removal observed at 20%$KMnO_4$/CPKS-Oz-120 may be attributed to over-oxidation of CPKS at 120 minutes used ozon. Extended oxidation for 120 minutes can damage the pore structure of porous carbon, leading to a significant reduction in micropore area and limiting the availability of oxygen functional groups within the micropores (Adib et al., 2000). Consequently, the reduced micropore volume decreases the amount of $KMnO_4$ that can be deposited and stored within the activated carbon, thereby limiting the oxidation capacity and resulting in slower H_2S removal. Therefore, to increase hydrophilicity, it is essential to preserve textural porosity parameters during oxidation treatment. It is necessary to include some discussion or explanatory remarks related to Table 2.

4. CONCLUSION

Potassium permanganate was successfully confined in porous carbon synthesized from palm kernel shell pretreated using wet ozone oxidation. Kalium (K), Mangan (Mn), and Oxygen (O) were detected using Scanning Electron Microscope- Energy Dispersive X-ray Spectroscopy. The $KMnO_4$ confined to porous carbon has a lower surface area than pristine carbon. A short oxidation of 60 min had advantages compared to an extended treatment of 120 min. The hydrogen sulfide removal up to 98% could be achieved using 20%$KMnO_4$/CPKS-Oz-60.

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