

# Activated Carbon/MnO<sub>2</sub> Composite as Uranium Adsorbent in Solution

*Komposit Karbon Aktif/MnO<sub>2</sub> sebagai Adsorben Uranium dalam Larutan*

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## Article History

Submitted: 09<sup>th</sup> September 2022; Revised: 31<sup>th</sup> May 2024; Accepted: 03<sup>rd</sup> June 2024;

Available online: 22<sup>th</sup> July 2024; Published Regularly: June 2024

doi: [10.25273/cheesa.v7i1.13863.24-35](https://doi.org/10.25273/cheesa.v7i1.13863.24-35)

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## Abstract

This research aimed to make an adsorbent from activated carbon/MnO<sub>2</sub> (AC/MnO<sub>2</sub>) composite and examine its characteristics, adsorption capacity, and mechanism for uranyl ions. Carbon was made from Oil Palm Empty Fruit Bunches (OPEFB) through sodium acetate's carbonization and activation processes. The AC/MnO<sub>2</sub> composite was made using the in-situ deposition method, namely by oxidizing Mn<sup>2+</sup> compounds to Mn<sup>4+</sup> under alkaline conditions at a temperature of ±80°C. An FTIR spectrophotometer was used to characterize the adsorbent, and a UV-Vis spectrophotometer was used to determine the content of uranyl. The results of FTIR analysis showed that MnO<sub>2</sub> in Mn-O and Mn-O-Mn absorption was bound to activated carbon. It was also discovered that AC/MnO<sub>2</sub> adsorbent reduced uranium content in solution in the form of uranyl ion for adsorbent mass of 2.5 grams and a contact time of 60 minutes, leading to adsorption percentages of 65.5%. The adsorption mechanism followed the Langmuir adsorption isotherm equation by forming a single layer. Meanwhile, the adsorption kinetics followed pseudo-second-order with a value of k = 6.7 g/mg.min.

**Keywords:** activated carbon; adsorbent; MnO<sub>2</sub>; oil palm empty fruit bunch; uranyl ion

## Abstrak

Penelitian ini bertujuan untuk membuat adsorben komposit karbon aktif/MnO<sub>2</sub> serta mempelajari karakteristik, kemampuan adsorpsi dan mekanisme adsorpsinya terhadap ion uranil. Karbon dibuat dari tandan kosong kelapa sawit melalui proses karbonisasi dan diaktivasi dengan natrium asetat. Komposit karbon aktif/MnO<sub>2</sub> dibuat dengan teknik pengendapan in-situ, yaitu dengan mengoksidasi senyawa Mn<sup>2+</sup> menjadi Mn<sup>4+</sup> dalam kondisi basa pada suhu ±80 °C. Karakterisasi adsorben dilakukan menggunakan spektrofotometer FTIR. Konsentrasi uranil dianalisis menggunakan spektrofotometer UV-Vis. Hasil analisis FTIR diperoleh serapan Mn-O dan Mn-O-Mn, yang mengindikasikan MnO<sub>2</sub> telah berhasil terikat pada karbon aktif. Adsorben karbon aktif/MnO<sub>2</sub> mampu menurunkan kadar uranium dalam larutan bentuk ion uranilnya dengan menggunakan massa adsorben sebanyak 2,5 gram dan waktu kontak 60 menit diperoleh persentase adsorpsi 65,5%. Mekanisme adsorpsi mengikuti persamaan isotherm adsorpsi Langmuir dengan membentuk lapisan monolayer. Kinetika adsorpsi mengikuti pseudo orde dua dengan nilai k = 6,7 g/mg.min.

**Kata kunci:** adsorben; ion uranil; karbon aktif; MnO<sub>2</sub>; tandan kosong kelapa sawit

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### 1. Introduction

Liquid waste containing uranyl compounds is generated from industries using uranium, with the possibility of entering the environment through various activities [1]. Although several methods have been applied to remove uranium from wastewater [2], only adsorption using activated carbon proved to be relatively cheap and easy to implement. The use of organic materials as carbon sources is profitable due to its cost-effectiveness and accessibility such as oil palm empty fruit bunches (OPEFB). Additionally, the high lignocellulose content in OPEFB has the potential to produce carbon [3] through carbonization and is activated by immersing in sodium acetate solution [4]. This activated carbon is often applied as an adsorbent, which has been modified with metal oxides such as MnO<sub>2</sub> [5].

MnO<sub>2</sub> is a group of metal oxides with a strong affinity for heavy metals [6]. The direct application of MnO<sub>2</sub> as an adsorbent has the weakness of relatively low stability [7]. Therefore, activated carbon with relatively high stability and an easy composite can be used as a matrix or buffer for MnO<sub>2</sub> [8].

Previous research on uranium removal in wastewater has been carried out using phytoremediation technology, ion exchange, solvent extraction, chemical precipitation-crystallization, and film separation [2]. Despite widespread application, these methods are less effective and uneconomical for handling large amounts of waste containing small quantities of uranyl ionic substances [2]. Therefore, using activated carbon composite adsorbent from OPEFB is more economical and easier to obtain with easy-to-apply work procedures.

In this research, activated carbon adsorbent was made from OPEFB composited with MnO<sub>2</sub> to form an AC/MnO<sub>2</sub> adsorbent composite. The process started by mixing activated carbon with MnO<sub>2</sub> (AC/MnO<sub>2</sub>) using an in-situ deposition method. Subsequently, Mn<sup>2+</sup> was oxidized from MnSO<sub>4</sub> to Mn<sup>4+</sup>, namely MnO<sub>2</sub> using KMnO<sub>4</sub> oxidizer in an alkaline environment with NaOH. MnO<sub>2</sub> composite on activated carbon formed Mn-O bonds, which would absorb uranyl ions in solution for the formation of coordination bonds [9].

The reduction of the uranium content of uranyl compounds in solution was carried out using an AC/MnO<sub>2</sub> composite adsorbent. The test parameters examined were adsorbent mass and time variations, including type of adsorption isotherm and kinetics. The AC/MnO<sub>2</sub> adsorbent was characterized using a Fourier-Transform Infrared (FTIR) spectrophotometer.

### 2. Research Methods

#### 2.1 Tools and Materials

The equipments used were a 100 mesh sieve, laboratory glassware, desiccator, Fourier Transform Infrared (FTIR) SHIMADZU 820 IPC, oven, vortex, shaker, UV-Vis spectrophotometer (Shimadzu 2810-UV-Vis), and furnace. The materials used in this experiment were aquademin, CH<sub>3</sub>COONa, HCl, H<sub>2</sub>C<sub>2</sub>O<sub>4</sub>.2H<sub>2</sub>O, HNO<sub>3</sub>, H<sub>2</sub>SO<sub>4</sub>, KMnO<sub>4</sub>, MnSO<sub>4</sub>.H<sub>2</sub>O, NaOH, NH<sub>4</sub>SCN, SnCl<sub>2</sub>, OPEFB obtained from PT Patiware in Bengkayang and UO<sub>2</sub>(CH<sub>3</sub>COO)<sub>2</sub>.2H<sub>2</sub>O.

#### 2.2 Carbonization of OPEFB

OPEFB was cut into small pieces measuring ±5 cm and strung. Subsequently, it was soaked in hot water for 10 minutes, drained, and the fibers

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were dried in the sun [10]. The dried OPEFB fiber obtained was weighed and put into the furnace. The carbonization process was carried out at a temperature of  $\pm 350^{\circ}\text{C}$  for 1 hour under closed conditions [11]. The results obtained were weighed, crushed, and sieved using a 100-mesh sieve [12].

### 2.3 Carbon Activation

Activation was carried out by mixing 72 g of carbon into 250 mL of 1 N CH<sub>3</sub>COONa, followed by stirring for 1 hour and heating at a temperature of  $\pm 120^{\circ}\text{C}$ . Activated carbon obtained was filtered, washed using distilled water [13], dried in an oven at a temperature of  $\pm 105^{\circ}\text{C}$  for 2 hours, and weighed.

### 2.4 Activated Carbon (AC) Composite with MnO<sub>2</sub>

The procedure for making activated carbon composite with MnO<sub>2</sub> was carried out using an in-situ deposition lens with a mass ratio of KA:MnO<sub>2</sub> (1 : 1.2) [9]. In this research, 20 g of activated carbon was mixed with 0.552 M MnO<sub>2</sub> made from a mixture of MnSO<sub>4</sub> and KMnO<sub>4</sub>. 28 g of MnSO<sub>4</sub> and 18 g of KMnO<sub>4</sub> were dissolved in 500 mL of aquademin. The Solution was mixed with 10 g of NaOH and stirred at a temperature of  $\pm 80^{\circ}\text{C}$ . The mixture was allowed to cool to room temperature, filtered, washed with distilled water, left to dry for 24 hours. This was followed by calcination at  $\pm 250^{\circ}\text{C}$  for 3 hours, and the concentration of the separated filtrate was determined using permanganometric titration.

### 2.5 Standardization of KMnO<sub>4</sub> Solution

The 25 mL of distilled water was put into a container of 1.25 mL of 8 N H<sub>2</sub>SO<sub>4</sub> solution and heated to  $\pm 70^{\circ}\text{C}$ . This was

followed by the addition of 2.5 mL of 0.1 N H<sub>2</sub>C<sub>2</sub>O<sub>4</sub> and titrated with a 0.1 N KMnO<sub>4</sub> 0,1 N until the solution changed color from clear to pink. The titration was carried out in duplicate and the volume was recorded [14].

### 2.6 Permanganometric Titration of the Filtrate

Oxalic acid weighed  $\pm 0.15$  g and was dissolved in 50 mL of distilled water in an Erlenmeyer. Approximately 5 mL of filtrate was added and heated to a temperature of  $\pm 60^{\circ}\text{C}$  to  $\pm 70^{\circ}\text{C}$ . Subsequently, 5 mL of 4 N H<sub>2</sub>SO<sub>4</sub> was added and diluted to 100 mL with distilled water. The solution was titrated with 0.1 N KMnO<sub>4</sub> until it turned pink. This procedure was carried out in duplicate [15].

### 2.7 Determination of Water Content (SNI 06-3730-1995)

Empty porcelain cups were dried in an oven at  $\pm 105^{\circ}\text{C}$  for 30 minutes, cooled in a desiccator, and weighed ( $W_0$ ). Porcelain cups were used to weigh samples of activated carbon and AC/MnO<sub>2</sub> composite, consisting of 1 g ( $W_1$ ). This showed the water content of activated carbon and the AC/MnO<sub>2</sub> composite. A porcelain cup containing the sample was placed in an oven at a temperature of  $\pm 105^{\circ}\text{C}$  for 2 hours, cooled in a desiccator and weighed ( $W_2$ ). Equation (1) is a formula for calculating water content.

$$\text{Water Content} = \frac{W_1 - W_2}{W_1 - W_0} \times 100\% \dots(1)$$

### 2.8 Preparation of Uranium Solution

A total of 0.4464 g of uranyl acetate compound was weighed and 10 mL of 2.5 N HNO<sub>3</sub> solution was added until dissolved. This was followed by dilution

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with aquamine in a 250 mL measuring flask, achieving uranium concentration of 1000 ppm. A total of 10 mL of a 1000 ppm uranyl acetate solution was pipetted and diluted in a 100 mL volumetric flask using a 0.05 N HNO<sub>3</sub> solution. The uranium content in this solution was 100 ppm [16].

**2.9 Calibration Curve Determination**

A total of 10, 25, 50, and 75 mL of 100 ppm uranyl acetate solution were taken into a 100 mL volumetric flask (uranyl acetate solution concentration 10, 25, 50, and 75 ppm). Approximately 5 drops of concentrated HCl, 15 mL of aquademin, 8 mL of 4 M NH<sub>4</sub>SCN 4 M, and 2 mL of 5% SnCl<sub>2</sub> 5%, were added to each measuring flask and diluted with aquademin to the limit mark. The Solution was stirred until homogeneous and left for 30 minutes to allow the formation of a perfect yellow color [16]. Measurement was carried out with a UV-Vis spectrophotometer at a wavelength of 306 nm.

**2.10 Determination of AC/MnO<sub>2</sub> Mass**

The 4 black glass bottles were each filled with 50 mL of 100 ppm uranyl acetate solution. Subsequently, 1 g of adsorbent was added to each bottle, 1.5g, 2 g, and 2.5 g, stirred with a shaker at 225 rpm for 60 minutes and left for 1 night [17]. The mixture obtained was filtered with filter paper. 5 mL of each filtrate obtained was taken, followed by the addition of 5 drops of concentrated HCl, 15 mL of aquademin, 8 mL of 4 M NH<sub>4</sub>SCN, and 2 mL of 5% SnCl<sub>2</sub> 5%, which were diluted with aquademin to the limit mark. The solution was stirred until homogeneous and left for 30 minutes to allow the formation of a perfect yellow color [16]. This was followed by

measuring the solution with a UV-Vis spectrophotometer at a wavelength of 306 nm.

**2.11 Determination of Adsorbent Contact Time**

There are 3 black glass bottles filled with 50 mL of 100 ppm uranyl acetate solution. This was followed by the addition of 2.5 g of adsorbent to each bottle and stirred with a shaker at a speed of 225 rpm with a time variation of 40, 50, and 60 minutes [18]. The mixture obtained was filtered with filter paper. 5 mL of each filtrate obtained was taken, followed by the addition of 5 drops of concentrated HCl, 15 mL of aquademin, 8 mL of 4 M NH<sub>4</sub>SCN 4 M, and 2 mL of 5% SnCl<sub>2</sub>, which were diluted with aquademin to the limit mark. Solution was stirred until homogeneous and left for 30 minutes to allow the formation of a perfect yellow color [16]. This was followed by measuring solution with a UV-Vis spectrophotometer at a wavelength of 306 nm.

The determination of the Langmuir adsorption isotherm model was carried out by plotting the x curve as Q<sub>e</sub> and y as Q<sub>e</sub>/C<sub>e</sub>. The data obtained was calculated using Equation 1. The determination of the Freundlich isotherm plots the x curve as Log C<sub>e</sub> and y as Log Q<sub>e</sub>. The Data was calculated using equation (2) and (3).

$$Q_e/C_e = kQ_0 - kQ_e \dots\dots\dots(2)$$

$$\text{Log } Q_e = \text{Log } kF + 1/n \text{ Log } C_e \dots\dots\dots(3)$$

- where:  
 C<sub>e</sub> : equilibrium concentration of adsorbate (mg/L)  
 Q<sub>e</sub> : the amount of adsorbate in adsorbent at equilibrium (mg/g)  
 Q<sub>0</sub> : adsorption capacity (mg/g)  
 K : Langmuir isotherm constant  
 kF : Freundlich isotherm constant  
 n : Adsorption intensity

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The adsorption kinetics model was determined to identify the rate of adsorbent absorption over a certain period. The first and second-order pseudo models were selected with the assumption that the adsorption of uranyl ions by the AC/MnO<sub>2</sub> composite is reversible. The first-order pseudo model was calculated using equation 4, while the second-order pseudo model used equation 5.

$$\log (q_e - q_t) = \log q_e - (k_1/2,303)t \dots\dots\dots(4)$$

$$t/q_t = (1/k_2 q_e^2) + t/q_e \dots\dots\dots (5)$$

where:

- q<sub>t</sub> : the amount of adsorbate adsorbed by adsorbent at time t (mg/g)
- q<sub>e</sub> : the amount of adsorbate adsorbed at equilibrium (mg/g)
- k<sub>1</sub> : pseudo rate constant 1 (min<sup>-1</sup>)
- k<sub>2</sub> : pseudo rate constant 2 (g min<sup>-1</sup> mg<sup>-1</sup>)

**3. Results and Discussion**

**3.1 Carbonization of OPEFB**

The Preparation of OPEFB was carried out by reducing its size and distribution to expand its surface and increase heat transfer during the carbonization process. Soaking in hot water removed impurities and oil from the fiber, thereby preventing heat inhibition during the carbonization process. In this research, drying was performed by sun-drying OPEFB to remove any remaining water in the fibers.

Carbonization was carried out in a furnace at a temperature of ±350°C for 1 hour to degrade lignocellulose and volatile substances such as CO, CO<sub>2</sub>, CH<sub>4</sub>, and H<sub>2</sub>. The final product obtained was carbon in the form of charcoal, with a by-product, namely tar. In carbonization process, water and remaining oil evaporated as well as the decomposition of wood components into liquid smoke [11], leaving carbon (C) in

the raw material. The results of OPEFB carbonization produced black charcoal with a brittle and light texture. The charcoal was crushed and sieved using a 100-mesh sieve to obtain a uniform size. The carbon yield from OPEFB obtained was 72%.

**3.2 Carbon Activation**

The process of carbon activation was carried out using sodium acetate to decompose tar and expand carbon pores by removing impurities [4]. The immersion process ensured the interaction and penetration of the sodium acetate solution into the carbon material. Heating was performed to accelerate the penetration process and open carbon pores [13].

The remaining salt attached to the charcoal surface was replaced by –OH groups when carbon was washed using distilled water, increasing in activated groups [19] through ion exchange reactions. The filtered filtrate was yellow due to the dissolution of most inorganic minerals, non-carbon compounds, and tar remaining in carbon pores. The activated carbon was dried at ±105°C for 2 hours to evaporate the remaining water. The yield of activated carbon obtained after the activation process was 98.1%.



**Figure 1.** (a) Carbon before activation, (b) Activated carbon

The by-products of the activation process were acetic acid and sodium hydroxide, causing physical and chemical changes to carbon. Visually, the activated carbon obtained had a smoother texture,

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and the color was slightly blacker than before activation, as shown in Figure 1.

#### 3.3 AC/MnO<sub>2</sub> Composite

AC/MnO<sub>2</sub> composite was made by mixing activated carbon into MnO<sub>2</sub> solution using an in situ deposition method in a reaction mixture. During this process, the reaction between the oxidizing and reducing agents produced an exothermic reaction. The synthesis of MnO<sub>2</sub> occurred due to the oxidation reaction of Mn<sup>2+</sup> from MnSO<sub>4</sub>·H<sub>2</sub>O to Mn<sup>4+</sup> using the KMnO<sub>4</sub> oxidizer in alkaline conditions with NaOH to form a brown MnO<sub>2</sub> precipitate [20]. Heating to a temperature of ±80°C caused the release of water or hydroxide hydration. This led to the formation of the manganese oxide composite in the activated carbon structure [21]. The filtered composite was rinsed with distilled water to dissolve the remaining impurities, allowed to dry for 24 hours, and calcined at ±250°C for 2 hours.

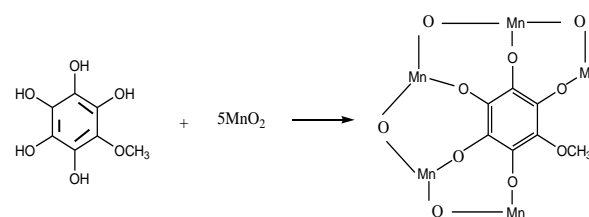
The calcination process was carried out to obtain high-purity oxide powder by releasing gases in the form of carbonates or hydroxides and decomposing compounds such as salts or dihydrates. H<sub>2</sub>O and OH were released in the temperature range of ±100°C to ±300°C [22].

Figure 2 shows the reaction between activated carbon from OPEFB and manganese dioxide. Due to the presence of a hydroxy group (-OH) MnO<sub>2</sub>, interaction can occur within activated carbon from OPEFB by forming Mn-O bonds on the surface [10]. The resulting activated carbon layered with MnO<sub>2</sub> has a blackish-brown color, as shown in Figure 3.

#### 3.4 Permanganometric Titration

Permanganometric titration was conducted to determine the remaining

concentration of MnO<sub>2</sub> in the filtrate. Initially, the KMnO<sub>4</sub> solution was standardized due to instability. In permanganometric titration, MnO<sub>4</sub><sup>-</sup> ions acted as a potent oxidizing agent, while C<sub>2</sub>O<sub>4</sub><sup>2-</sup> ion in oxalic acid was used as a reductor. In this research, back titration was carried out by mixing the filtrate with excess oxalic acid and titrated using KMnO<sub>4</sub> solution. The titration was conducted in an acidic environment for the optimal reaction of MnO<sub>4</sub><sup>-</sup> ions, and KMnO<sub>4</sub> would experience a reduction to produce colorless Mn<sup>2+</sup> ions. The reaction between KMnO<sub>4</sub> and oxalic acid tended to be slow at room temperature, resulting in difficulty in determining the endpoint of the titration. Therefore, heating was carried out before titration to accelerate the reaction, with KMnO<sub>4</sub> serving as an auto-indicator. The color change in permanganometric titration was colorless to pink [23], using 0.2 mL as the average volume of titrant. This titration was performed to show that the MnO<sub>2</sub> concentration obtained decreased from 0.5524 M to 0.0001 M.



**Figure 2.** Prediction of the reaction between activated carbon and MnO<sub>2</sub> [10]



**Figure 3.** Activated carbon after being layered with MnO<sub>2</sub> (AC/MnO<sub>2</sub>)

**Activated Carbon/MnO<sub>2</sub> Composite as Uranium Adsorbent in Solution****3.5 Characterization of Activated Carbon and AC/MnO<sub>2</sub> Composite**

Water content analysis was performed to determine the hygroscopic properties and quality of the adsorbent based on the percentage of water content obtained [24]. Moreover, less water content in the adsorbent contributes to improved absorption. This is because water molecules do not cover the pores, thereby increasing their capacity on the activated side [25]. Based on the results obtained in Table 1, the water content of activated carbon and AC/MnO<sub>2</sub> composite was still within the standard, with a value below 15% as stated in SNI 06-3730-1995.

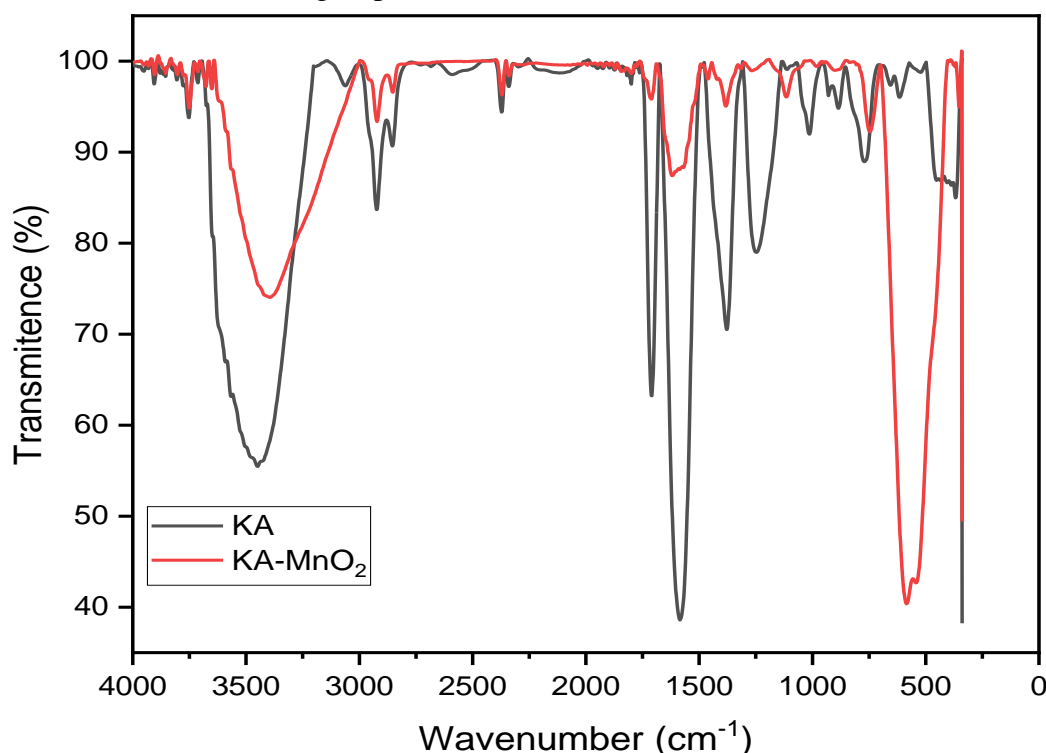
**Table 1.** Results of water content analysis

Sample	Water Content (%)
Water content	8.0
AC/MnO <sub>2</sub>	1.3

The activate carbon and AC/MnO<sub>2</sub> composites were characterized using FTIR to determine the functional groups and

bonds contained in the adsorbent, as shown in Table 2. The results of activated carbon analysis using FTIR in Figure 4, showed absorption at wave number 3448.7cm<sup>-1</sup> which indicated the presence of Stretching vibrations of O-H. The wave number at 1708 cm<sup>-1</sup> showed the presence of a C=O double bond [16], while 1585.4 cm<sup>-1</sup> indicated an aromatic C=C bond [26].

The results of AC/MnO<sub>2</sub> analysis using FTIR showed that the absorption at wave number 3394.7 cm<sup>-1</sup> was the stretching vibration of O-H. At 1618.2 cm<sup>-1</sup>, the presence of C=O bond vibrations was shown, while 1570 cm<sup>-1</sup> indicated C=C aromatic bonds [9],[25]. In the AC/MnO<sub>2</sub> composite, absorption wave numbers of 542 cm<sup>-1</sup>, 584.4 cm<sup>-1</sup>, and 746.4 cm-h showed the presence of Mn-O bonds and stretching vibrations of Mn-O-Mn bonds. According to Ying et al. [9] and Wang et al. [27], the absorption of stretching vibrations of Mn-O-Mn and Mn-O bonds was shown at wave numbers 500 cm<sup>-1</sup> to 800 cm<sup>-1</sup>.

**Figure 4.** FTIR spectrum from activated carbon characterization

**Activated Carbon/MnO<sub>2</sub> Composite as Uranium Adsorbent in Solution****Table 2.** FTIR characterization results

Wavelength number (cm <sup>-1</sup> )			
	3448.7	1708	1585.4
<b>Activated Carbon (AC)</b>	O-H	C=O	C=C
		C=C	aromatic
<b>AC/MnO<sub>2</sub></b>	3394.7	1618.2	542
		1570	584.4
			746.4
	O-H	C-O	Mn-O-Mn
	C=C	Mn-O	
	aromatic		

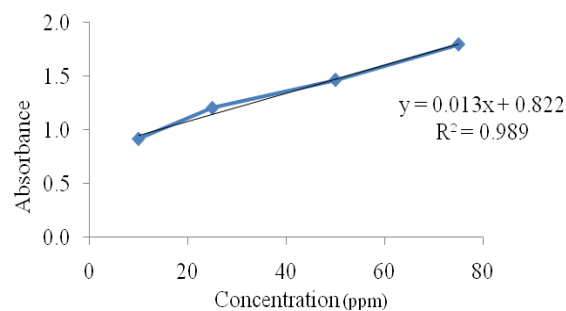
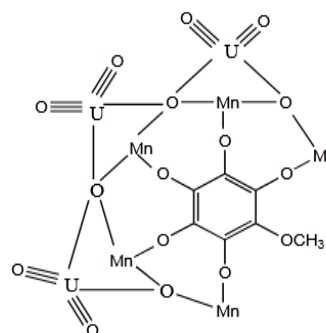
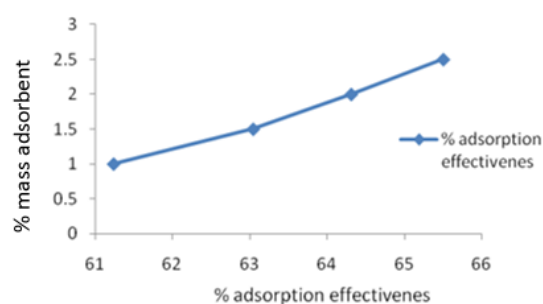
**3.6 Calibration Curve**

Calibration curve shows the relationship between absorbance (Y) and concentration (X), obtaining an equation expressed as  $Y = aX \pm b$ . In this research, a 100 ppm uranyl acetate solution was made into 10, 25, 50, and 75 ppm in acidic conditions using concentrated HCl. The function of the solution was to avoid the decomposition of the NH<sub>4</sub>SCN and SnCl<sub>2</sub> solution, to form a yellow uranyl thiocyanate compound complex [16]. The linear equation of the curve obtained from a concentration of 10, 25, 50, and 75 ppm was  $y = 0.013x + 0.822$  with a value of  $R^2 = 0.989$ , as shown in Figure 5.

**3.7 Effect of AC/MnO<sub>2</sub> Adsorbent Mass**

Based on the results in Figure 7, the highest percentage effectiveness of adsorption of uranyl ions was at a mass variation of 2.5 g adsorbent with an adsorption percentage of 65.5%. The amount of mass used affected the adsorbate absorption process due to the availability of activated sites on adsorbent, which could bind the adsorbate effectively. The adsorption mechanism occurred in activated carbon pores. An interaction was also observed between uranyl ion and the AC/MnO<sub>2</sub> adsorbent. Specifically, the positively charged uranyl ion was adsorbed

with the negatively charged AC/MnO<sub>2</sub> adsorbent. Uranyl ion was bound by two oxygen atoms in manganese dioxide through a Mn-O bond, forming a coordination bond in activated carbon pore [10]. The structure predictions in Figure 6 were made based on the illustrations of Wang et al. [27] and Ying et al. [9].

**Figure 5.** Calibration curve**Figure 6.** Prediction of the Chemical Structure of AC/MnO<sub>2</sub> with Uranyl Ions (UO<sub>2</sub>)<sup>2+</sup>.**Figure 7.** The curve of the influence of adsorbent mass on the % effectiveness of uranyl adsorption



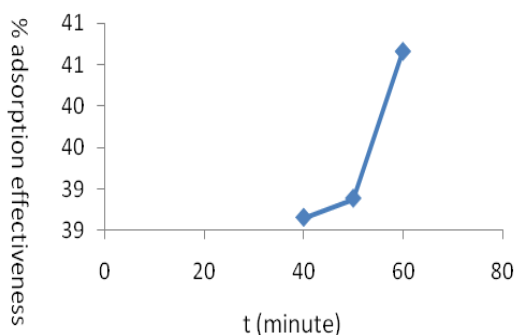
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**3.8 Effect of AC/MnO<sub>2</sub> Adsorbent Contact Time**

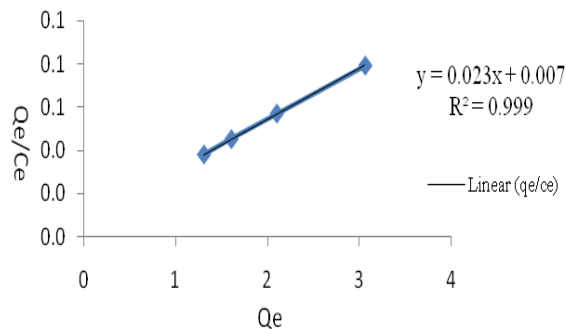
Based on the results in Figure 8, the highest percentage effectiveness of uranyl ion adsorption occurred when using a contact time of 60 minutes with an adsorption percentage of 40.6%. The time spent interacting between adsorbent and the adsorbate caused bonds to form between the AC/MnO<sub>2</sub> composite and uranyl. This led to a decrease in the concentration of uranyl in solution after adsorption, while percentage effectiveness increased.

**3.9 Determination of the Adsorptions Isotherm and Kinetics Models**

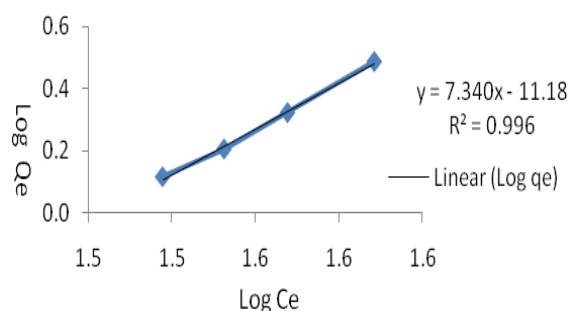
The adsorption isotherm model was examined to determine the adsorption mechanism that formed. In this research, the adsorption isotherms used in the solid-liquid phase were the Langmuir and the Freundlich, with the curve results presented in Figures 9 and 10. The adsorption isotherm of uranyl ions using the AC/MnO<sub>2</sub> adsorbent was based on the concentration of the sample solution absorbed by adsorbent. In this context, the Langmuir isotherm type was obtained as shown by the R<sup>2</sup> value, which was close to one (0.999) with a positive constant (K<sub>L</sub>), 0.023 L/mg.



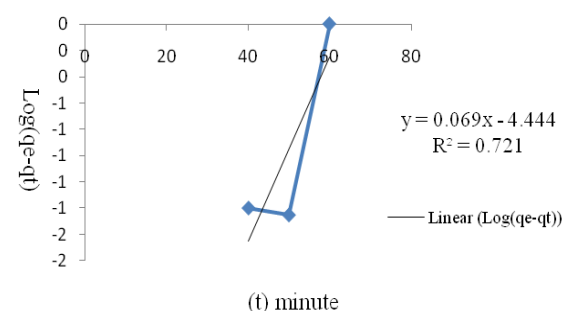
**Figure 8** The effect of adsorbent contact time on the % effectiveness of uranyl adsorption.



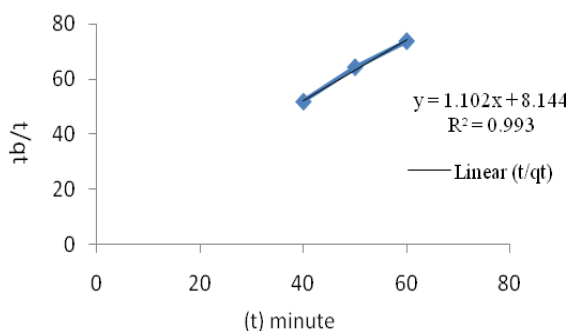
**Figure 9.** Langmuir isotherm model curve for uranyl adsorption.



**Figure 10.** Freundlich isotherm model curve for uranyl adsorption



**Figure 11.** Pseudo-first order uranyl adsorption kinetics curve



**Figure 12.** Pseudo-second order uranyl adsorption kinetics curve

## Activated Carbon/MnO<sub>2</sub> Composite as Uranium Adsorbent in Solution

Uranyl adsorption process with AC/MnO<sub>2</sub> adsorbent from OPEFB in this research followed the Langmuir isotherm equation. Linearity in the Langmuir isotherm equation shows that chemical adsorption occurs. Uranyl ions bound to the AC/MnO<sub>2</sub> adsorbent form a monolayer.

A mass transfer is observed from the adsorbate as well as a sharing of electrons between the AC/MnO<sub>2</sub> adsorbent and uranyl ions. Therefore, the adsorption mechanism includes physicochemical interactions. Generally, adsorption kinetics state the speed of the adsorbate absorption process by the adsorbent. It is expressed as a function of concentration versus time to obtain a rate constant value (k). Adsorption kinetics are determined based on pseudo-first-order, as in Figure 11, and pseudo-second-order, as in Figure 12.

The appropriate adsorption kinetic model is shown from the R<sup>2</sup> value, which is closest to 1, namely the pseudo-second-

order with a value of 0.993 and rate constant (k<sub>2</sub>) of 6.7 g/mg.minute. This reaction rate constant describes the adsorption equilibrium that occurs when the reactant comes into contact with adsorbent surface and forms a product in the form of uranyl ions, bound to the surface of the AC/MnO<sub>2</sub> adsorbent.

## 4. Conclusion

In conclusion, this research showed that the formation of AC/MnO<sub>2</sub> adsorbent was due to the presence of hydroxy groups (-OH) on activated carbon from OPEFB. Therefore, MnO<sub>2</sub> could interact by forming Mn-O bonds on the surface of activated carbon. The reduction in uranium content of uranyl compounds in solution using the AC/MnO<sub>2</sub> adsorbent led to an adsorption percentage of 60.5%, with a Langmuir isotherm constant (K<sub>L</sub>) value of 0.023 L/mg and using pseudo-second order.

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