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Recycling of water treatment plant sludge for copper adsorption from aqueous solutions

Daur ulang lumpur instalasi pengolahan air untuk adsorpsi tembaga dari larutan air

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ABSTRAK

Penelitian terkini telah mencari berbagai bahan adsorben yang murah, tersedia dalam jumlah banyak, dan efektif untuk menghilangkan logam berat, salah satunya adalah lumpur Instalasi Pengolahan Air (IPA). Penelitian ini bertujuan untuk mengkaji potensi daur ulang lumpur Instalasi Pengolahan Air menjadi adsorben untuk penyisihan Cu (II). Adsorben lumpur dikarbonisasi dengan menggunakan furnace pada suhu 600^0C selama 2 jam. Penelitian ini dilakukan secara batch. Efektivitas adsorben dianalisis dengan memvariasikan dosis, waktu kontak, dan aktivasi adsorben lumpur terhadap penyisihan Cu (II). Isoterm adsorpsi dianalisis menggunakan model Langmuir dan Ferundlich, dan studi kinetik menggunakan model pseudo orde satu dan pseudo orde dua. Hasil penelitian menunjukkan efisiensi penyisihan Cu (II) untuk adsorben lumpur aktivasi dan non-aktivasi mencapai 98,6-99,9%. Penambahan dosis tidak mempengaruhi peningkatan kapasitas adsorpsi Cu (II). Aktivasi adsorben meningkatkan kapasitas adsorpsi Cu (II) dengan waktu kontak untuk mencapai kesetimbangan pada 60-90 menit, lebih singkat dibandingkan dengan adsorben non-aktivasi yaitu 90-120 menit. Model isoterm adsorpsi untuk kedua jenis adsorben cocok dengan model Langmuir, yang mengindikasikan proses adsorpsi terjadi dalam satu lapisan pada permukaan yang homogen. Kinetika adsorpsi mengikuti pseudo orde dua dengan nilai koefisien korelasi yang tinggi. Lumpur pengolahan air merupakan produk sampingan industri yang berpotensi menjadi material adsorben yang efektif dan rendah biaya untuk penyisihan logam Cu.

Kata kunci: adsorben lumpur, logam berat, penyisihan Cu

ABSTRACT

Recent studies have explored various adsorbent materials that are low-cost, available in quantity, and effective for heavy metal removal, one of them is the Water Treatment Plant (WTP) sludge. The study aimed to investigate the potential of recycling Water Treatment Plant sludge into an adsorbent for Cu (II) removal. The sludge adsorbent was carbonized by using a furnace at 600°C for 2 hours. This study was conducted in batches. The adsorbent effectiveness was analyzed by varying the dosage, contact time, and activation of the sludge adsorbent on Cu (II) removal. The adsorption isotherm was analyzed using the Langmuir and Ferundlich models, and the kinetic study used pseudo-first-order and pseudo-second-order models. The results showed the removal efficiency of Cu (II) for both activated and non-activated sludge adsorbents reached 98.6–99.9%. The addition of dosage did not affect the increase in Cu (II) adsorption capacity. Activation of the adsorbent increased the adsorption capacity of Cu (II) with the equilibrium time at 60–90 min, shorter than the non-activated adsorbent at 90–120 min. The adsorption isotherm model for both adsorbent types fitted well to the

Langmuir model, indicating the adsorption process occurs in a single layer on a homogeneous surface. The adsorption kinetics followed pseudo-second-order with a high correlation coefficient. Water treatment sludge, an industrial by-product, has the potential to be an effective and low-cost adsorbent material for Cu removal.

Keywords: sludge adsorbent, heavy metals, Cu removal

INTRODUCTION

Water contamination by heavy metals has become a global concern. Heavy metals cause harmful, toxic, and carcinogenic effects on various forms of life (Wang et al., 2019a), both for living things and ecosystems. Metals have high toxicity with a specific gravity of more than 4 g/cm3, including mercury (Hg), chromium (Cr), copper (Cu), cadmium (Cd), lead (Pb), and several other metals found in waters in concentrations exceeding the threshold (Zamora-Ledezma et al., 2021). Sources of heavy metal pollution in waters mostly come from industrial waste such as the metallurgical industry, chemical industry, tanneries, mining activities, agricultural activities (pesticides and chemical fertilizers), and domestic activities (Vareda et al., 2019). Among these heavy metals, Cu was a basic micronutrient required by organisms at low levels (Kul, 2021). Copper (Cu) was required for the formation of hemoglobin in the process of transporting oxygen in living things including humans. However, Cu becomes toxic if it exceeds a certain tolerance level in organisms and causes bioaccumulation in the food chain (Mehmood et al., 2019). Exposure to Cu in humans will cause symptoms of dizziness, nausea, abdominal cramps, diarrhea, and chronic effects of tissue and organ damage (Gupta et al., 2017). Heavy metal pollution in water bodies was a serious environmental problem and requires effective treatment to remove toxic heavy metals from water to maintain water quality.

Various methods of heavy metal removal from water have been widely performed, such as chemical precipitation, membrane filtration, ion exchange, electrolysis, coagulation, precipitation, photocatalysis, adsorption, phytoremediation, and others (Joseph et al., 2019; Y. Zhu et al., 2019).

However, these methods have some disadvantages, such as low effectiveness, high energy requirements, difficult operation and maintenance, high cost, and the production of toxic by-products (Crini & Lichtfouse, 2019; Zaimee et al., 2021). Among these methods, one of the most widely used for heavy metal removal was adsorption. Adsorption has the advantages of more efficiency, low cost, easy operation, and high reversibility (Burakov et al., 2018). The adsorbent should have good performance, including a large surface area, good thermal stability, high adsorption capacity, and easy separation (Kuroki et al., 2019; Zamora-Ledezma et al., 2021). Some adsorbents used for heavy metal removal in water include activated carbon, zeolites, clay minerals, industrial by-products, agricultural waste, biomass, and polymeric materials (F. Zhu et al., 2021). Activation of adsorbents through chemical or thermal processes will increase the micropore structure, and surface area of the adsorbent thus increasing its adsorption ability. Activated adsorbents have been applied in various wastewater treatments and were effective in heavy metal removal (Deliyanni et al., 2015). To lower the cost of producing activated carbon, low-cost and readily available materials must be identified. Using wastes such as agricultural waste, industrial by-products, and sludge from water and wastewater treatment plants could be an alternative material for adsorbents.

The increase in clean water consumption by Indonesians has led to an increase in clean water production by the Water Treatment Plant (WTP). This water treatment process produces a by-product in the form of sludge. The sludge in the Water Treatment Plant comes from sedimentation and filtration backwash. The increasing quantity of WTP sludge becomes an environmental problem and requires great attention in handling for disposal or reuse utilization (Militaru et al., 2020). Common reuse of sludge was for landfilling and application as fertilizer for agriculture and forestry. However, this poses a risk of secondary pollution to the environment due to the metal content in the sludge (Ahmad & Azam, 2019; Geng et al.,

2020). Recycling sludge into adsorbents was becoming a more attractive alternative due to the high carbon content of sludge (Xu et al., 2015), easy operation, high removal efficiency, energy savings (Wang et al., 2019a), environmental friendliness, low cost, and its potential to avoid secondary pollution (Burakov et al., 2018; Zamora-Ledezma et al., 2021). Calcined water treatment sludge adsorbent was able to remove Cu2+ by more than 80% (Shahin et al., 2019). In another study, the adsorption capacity of sludge adsorbent at 298 K removed maximum Cd(II), Cu(II), and Zn(II) of 1.53, 2.76, and 1.23 mg/g (Du et al., 2020). The objective of this research was to investigate the potential of recycling WTP sludge as an adsorbent for the removal of Cu(II) metal in aqueous solution. This study analyzed the effect of dosage, contact time, and activation of sludge adsorbent on the effectiveness of Cu(II) removal.

MATERIALS AND METHODS

Preparation of Sludge Adsorbent

The sludge used in this study was collected from the Sludge Drying Bed at the Water Treatment Plant (WTP). The sludge was dried in the sun to reduce its moisture content and then dried in an oven in the laboratory at 105^0C for 48 hours (Tang et al., 2019).

The sample was carbonized using the furnace at 600^0C for 2 hours and then cooled in a desiccator. The sludge adsorbent in the form of charcoal was then filtered and sieved with 60 mesh to obtain sludge particles with a size < 250 µm. The sieved mud adsorbent was partially activated by soaking in a 5% NaOH solution for 24 hours. Then filtered with Whatman 42 filter paper and washed using distilled water until the pH was neutral so that the activator did not damage or interfere with the adsorption. The filtering results were heated in an oven at 100^0C for 1 hour and then cooled in a desiccator. The cooled activated sludge adsorbent was stored in an airtight container.

Characterization of Sludge Adsorbent

Characterization of sludge adsorbent includes moisture, ash, and volatile content based on the Indonesian National Standard (SNI 06-3730-1995).

Moisture Content

A total of 1 g of sludge adsorbent was put into a cup that had been weighed and then put into the oven at 115 ^{0}C for 3 hours. It was then cooled in a desiccator to a constant temperature and weighed. The moisture content was determined by the difference between the total percentage and the sum of the percentage of moisture content.

Ash Content

A total of 1 g of sludge adsorbent was put into a cup that had been weighed and then put into the furnace at 600^0C until the entire sample became ash. Next, it was cooled in a desiccator to a constant temperature and then weighed. Ash content was determined by the difference between the initial and final adsorbent weight percentages.

Volatile Content

A total of 1 g of sludge adsorbent was put into a cup that had been weighed and then put into an oven at 900^0C for 15 minutes. Then it was cooled in a desiccator and weighed. Volatile content was determined by the difference in percentage between the initial and final adsorbent weights.

Batch Experiment

The synthetic solution of Cu(II) was made by dissolving 1 mg of CuSO4 powder into 1 liter of distilled water so that the concentration was 1 mg/L (Gupta et al., 2017). Experiments were conducted in batches with a volume of CuSO4 solution in each sample of 100 ml. The effectiveness of Cu(II) adsorption was studied through variations in adsorbent dosage and contact time on activated and unactivated sludge adsorbents. The effect of dosage was tested in the range of 1.5, 2, 2.5, 3, and 3.5 mg at a contact time of 90 minutes, with a stirring speed of 100 rpm and a neutral pH. The effect of contact time was tested in the range of 60, 75, 90, 105, and 120 minutes at a dose of 2.5 mg with a stirring speed of 100 rpm and neutral pH. Then the solution was separated by filtering the filtrate using the Whatman 42 paper.

Removal Analysis and Adsorption Capacity

After the batch experiment, the concentration of each sample was tested using a UV-vis spectrophotometer. The removal efficiency (R) of Cu(II) and adsorption capacity (q_e) were calculated using equations (1) and (2) (Hayati et al., 2017; Rajabi et al., 2016).

$$R(\%) = \frac{(C_0 - C_e)}{C_0} x100 \quad (1)$$

$$q_e = \frac{(C_0 - C_e)}{m} xV \quad (2)$$

where C_o and C_e (mg/L) were the initial and final sample concentrations after adsorption. V was the volume of solution (L) and m was the mass/dosage of adsorbent (g) used.

Isotherm and Adsorption Kinetics

The adsorption isotherm aims to determine the form of adsorption of Cu(II) ions by a sludge adsorbent. Adsorption isotherms show how adsorbate molecules were distributed between the liquid phase and the solid phase when the adsorption process reaches equilibrium. Adsorption isotherms were important for describing how solutes interact with adsorbents and for optimizing the use of adsorbents (Sadegh et al., 2015). This study utilized two isotherm models, namely the Langmuir and Freundlich models, which were written with the following equations (Kasman et al., 2023; Zhou et al., 2019).

Freundlich models:

$$q_e = K_f \, C_e^{\,1/n} \quad (3)$$

Where Kf and n were Freundlich constants, which were the characteristic constants of the system. Equation (3) could be linearized in logarithmic form, and the Freundlich constants could be determined.

$$\log q_e = \log K_f + (1/n) \log C_e \quad (4)$$

Langmuir models:

$$q_e = q_0 \frac{b.C_e}{1 + b.C_e} \quad (5)$$

where q_e was the equilibrium concentration of Cu(II) on the adsorbent (mg/g), q_o was the adsorption capacity of the adsorbent (mg/g), C_e was the equilibrium iron concentration in solution (mg/L), and b was the equilibrium adsorption constant (L/mg). Furthermore, this study used first-order and second-order pseudo-kinetic models (Duan et al., 2020; Yari et al., 2015) to determine the mechanism of adsorption of solutes by sludge adsorbents and adsorption constants.

RESULTS

Characterization of Adsorbent

Sludge adsorbent characterization was conducted to determine the quality of the adsorbent before being used in Cu(II) removal experiments. The characterization of sludge adsorbent in this study includes tests of moisture content, ash content and volatile content based on SNI 06-3730-1995 (Table 1). The test results of moisture content, ash content, and volatile content obtained values that were below the maximum limit of the Indonesian National Standard that has been set.

Table 1. Sludge adsorbent characterization

Content	Result (%)	SNI 06-3730-1995 (%)
Moisture content	1.96	Max 15
Ash content	5.94	Max 10
Volatile content	5.85	Max 25

Effect of Adsorbent Dosage

Adsorbent dosage or mass was one of the factors that affected Cu metal removal. In this study, five dose variations of activated and non-activated sludge adsorbents were used to see the effect of an additional dose on Cu removal. The results of Cu removal with various doses on both activated and non-activated adsorbents obtained high removal results, amounting to 96.9–99.8% on non-activated adsorbents and 98.6–99.9% on activated adsorbents (Table 2). In the non-activated adsorbent, the removal began to be constant at a dose of 2.5–3.5 g. While in the activated adsorbent, the highest removal was achieved at the lower adsorbent dose of 2 g.

Table 2. Effect of adsorben dosage on Cu(II) removal

Dosage (g)	Contact time (min)	Initial concentration (C_0) (mg/L)	Final concentration (C_e) (mg/L)	Removal efficiency (%)
Non-activated sludge adsorbent				
1.5	90	1	0.031	96.9
2	90	1	0.019	98.1
2.5	90	1	0.0012	99.8
3	90	1	0.0012	99.8
3.5	90	1	0.0012	99.8
				Activated sludge adsorbent
1.5	90	1	0.014	98.6
2	90	1	0.0012	99.8
2.5	90	1	0.0012	99.8
3	90	1	0.004	99.6
3.5	90	1	0.001	99.9

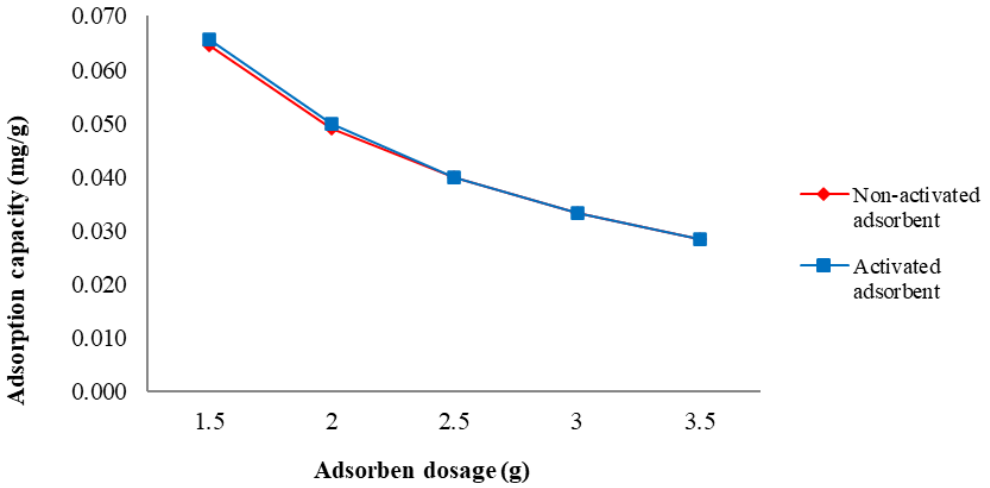

Figure 1. Effect of dosage on adsorption capacity

The adsorption capacity (qe) of the two types of adsorbents reached similar values, with a decreasing trend as the adsorbent dose increased (Figure 1). The adsorption capacity reached equilibrium at a 1.5 g adsorbent dose of 0.065 mg/g on non-activated adsorbent and 0.066 mg/g on activated adsorbent. Furthermore, it decreased for each increase in adsorbent dose up to 3.5 g to 0.029 mg/g on both adsorbents. Activation of the adsorbent did not have a significant effect on the effectiveness of Cu(II) absorption.

Effect of Contact Time

The removal of Cu(II) at five variations of contact time obtained high efficiency for both types of adsorbents. The removal efficiency of Cu(II) reached 99%, indicating that the sludge adsorbent has high effectiveness in removing Cu(II) in solution (Table 3). In the non-activated adsorbent, the removal efficiency of Cu(II) at 60 to 120 minutes of contact time was 99.6–99.9%. While for the activated adsorbent, 60 min contact time had a higher removal efficiency of 99.8% and decreased to 98.6% at 120 min contact time.

The effect of contact time on adsorption capacity gave different values compared to adsorbent dosage. In non-activated adsorbent, the adsorption capacity increased starting from 60 minutes of stirring contact time until it reached equilibrium at 90 minutes of contact time with a value of 0.04 mg/g and remained constant until 120 minutes of contact time. The activation adsorbent obtained the opposite results, where the equilibrium adsorption capacity was reached at a shorter contact time of 60 minutes constant up to 90 minutes at 0.04 mg/g. Furthermore, it decreased at contact times of 105 and 120 minutes (Figure 2). Activation of the adsorbent provides an advantage in achieving a higher adsorption capacity at a shorter contact time.

Table 3. Effect of contact time on Cu(II) removal

Contact time (min)	Dosage (g)	Initial concentration (C_0) (mg/L)	Final concentration (C_e) (mg/L)	Removal efficiency (%)
Non-activated sludge adsorbent				
60	2.5	1	0.004	99.6
75	2.5	1	0.0023	99.7
90	2.5	1	0.0012	99.8
105	2.5	1	0.0012	99.8
120	2.5	1	0.001	99.9
				Activated sludge adsorbent
60	2.5	1	0.0011	99.8
75	2.5	1	0.0012	99.8
90	2.5	1	0.0012	99.8
105	2.5	1	0.009	99.1
120	2.5	1	0.014	98.6

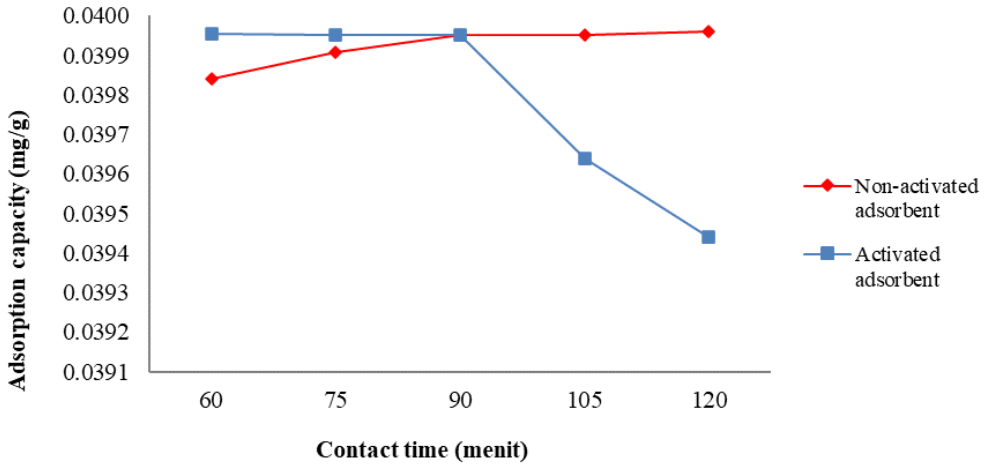

Figure 2. Effect of contact time on adsorption capacity

Freundlich and Langmuir Isotherm

The adsorption isotherm model of the non-activated adsorbent was analyzed using the Freundlich and Langmuir models. The Freundlich isotherm correlation coefficient on the non-activated adsorbent obtained the equation y = 0.0021x-1.404 with a value of R^2 = 0.973, which shows a very strong correlation relationship (Figure 3). The Freundlich activation adsorbent isotherm model resulted in the equation y = -0.0047x-1.412 with R^2 = 0.967, which also showed a very strong correlation. The R^2 value of the non-activated sludge adsorbent was higher than that of the activated sludge adsorbent.

This result shows that activation of the sludge adsorbent does not have a significant effect on the effectiveness of Cu (II) absorption in solution. The Langmuir isotherm model for activated and non-activated sludge adsorbents showed different values. The Langmuir isotherm correlation coefficient on non-activated adsorbent obtained the equation y = 25.126x - 0.0001 with an R^2= 1 value, which shows a very strong correlation relationship (Figure 4). While on the activated adsorbent, the Langmuir isotherm model produces the equation y = 25.358x - 0.0005 with R^2 = 1, which shows a very strong correlation relationship. This result shows that a sludge adsorbent has good sorption ability towards Cu(II). Freundlich and Langmuir adsorption constants were obtained from the slope of the linear equation of the isotherm model (Table 4).

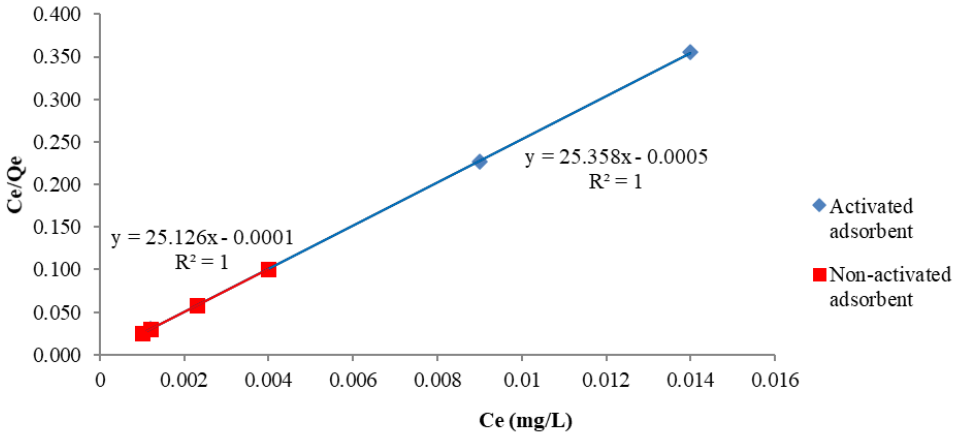

Figure 3. Freundlich isotherm of Cu(II) adsorption

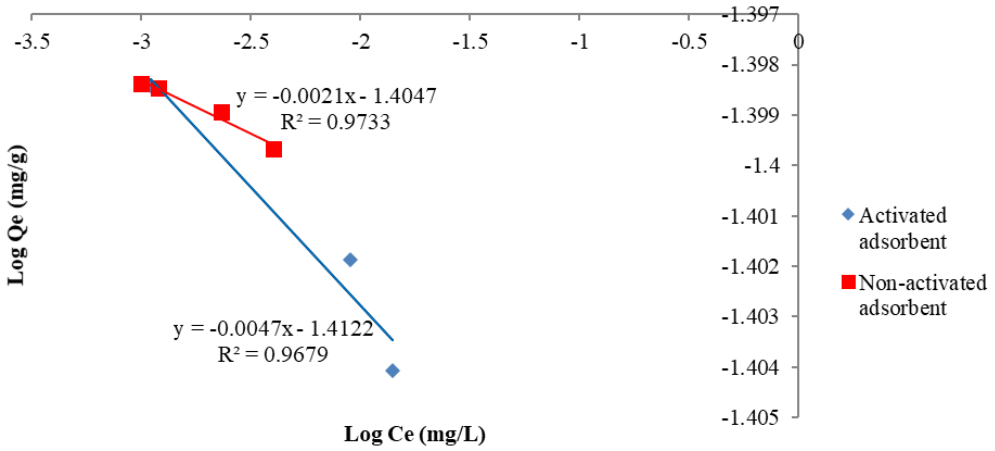

Figure 4. Langmuir isotherm of Cu(II) adsorption

Table 4. Freundlich dan Langmuir constant

Freundlich	Non-aktivasi	Aktivasi
Adsorption capacity, Kf	0.995	0.989
Typical adsorpsi, 1/n	-0.002	-0.005
Intensity of adsorption, n	-476.19	-212.766
R^2	0.973	0.967
Langmuir	Non-aktivasi	Aktivasi
Adsorption capacity, q_m	0.040	0.079
Equilibrium adsorption constant, K_L	$3.97.10^6$	$1.97.10^5$
Langmuir constant, RL	0.999	0.999
R^2	1	1

Adsorption Kinetics Study

Adsorption kinetics shows the rate at which the adsorbent absorbs the adsorbate. The ability of absorption could be seen from the rate of adsorption. The adsorption rate was described by the reaction order, namely pseudo-first-order (Figure 5) and pseudo-second-order (Figure 6). The constant kinetics of pseudo-first-order on activated and non-activated adsorbents were low R^2 values of 0.042 and 0.05. While the R^2 value of pseudo-second-order in activated adsorbent was 0.999 and non-activated adsorbent was 1 (Table 5). These results indicate the adsorption process in this study followed pseudo-second-order mechanism.

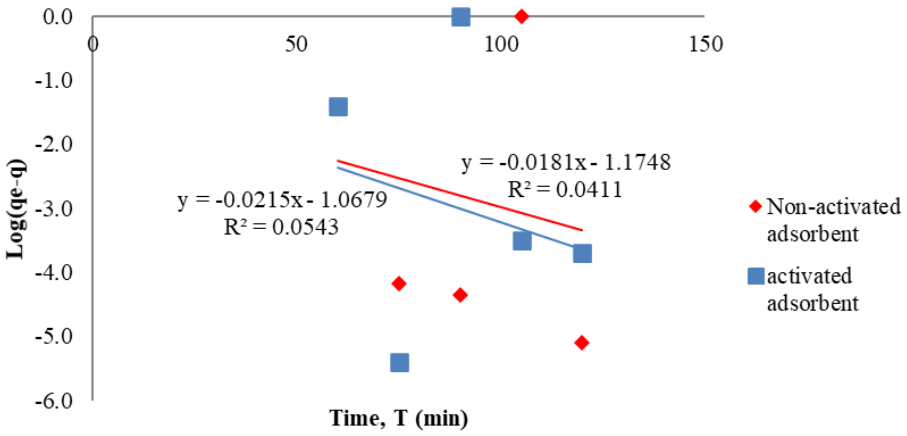

Figure 5. Pseudo first-order of Cu(II) adsorption

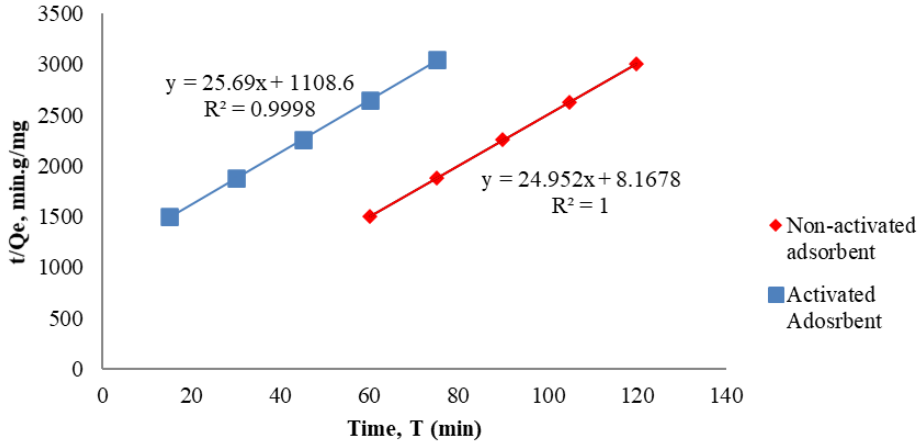

Figure 6. Pseudo second-order of Cu(II) adsorption

Table 5. Kinetic parameters of Cu(II) adsorption

Adsorbent	Pseudo first-order			Pseudo second-order		
	K_1 g/min.mg	Qe mg/g	R^2	K_2 g/min.g	Qe mg/g	R^2
Non-activated	-0.042	14.928	0.041	24.95	0.122	1
Aktivated	-0.050	11.692	0.054	25.69	0.001	0.99

DISCUSSION

In this study, the removal of Cu(II) by water treatment sludge adsorbents obtained excellent results for both types of activated and non-activated sludge adsorbents. The removal efficiency in adsorbent doses of 1.5, 2, 2.5, 3, and 3.5 g resulted from high removal rate for both types of adsorbents of 96.9–99.9%. The results show that the lowest adsorbent dose of 1.5 g has obtained high removal results. The removal of activated adsorbent at a dose of 1.5 g obtained higher efficiency than non-activated adsorbent. The addition of dose did not have a significant effect on the removal of Cu(II). However, when viewed from the adsorption capacity, the maximum adsorption value occurred at the lowest dose of 1.5 g on both adsorbents. The adsorption capacity decreased with the addition of a dose. This can be caused by the increasing dose of adsorbent causing imperfect interaction in the stirring process and overlapping adsorption sites due to the density of adsorbent particles so metal absorption is not optimal (Onundi et al., 2010). Similar results were also reported in (Al-Malack & Basaleh, 2016) where the adsorption capacity decreases with increasing adsorbent dose.

Contact time is one of the important parameters that affect the adsorption process (Hallajiqomi & Eisazadeh, 2017). The effect of contact time on Cu(II) adsorption was observed at 60, 75, 90, 105, and 120 minutes. The removal of both types of adsorbents obtained high-efficiency values of 98.6-99.9%. The adsorption capacity of the activated adsorbent reached equilibrium faster at 60-90 min and decreased at 105 and 120 min. While the adsorption equilibrium in non-activated adsorbent was achieved at a longer contact time than activation, at 90-120 minutes. Inactivated adsorbents, adsorption reaching equilibrium in the first 60 minutes can be related to the availability of surface area and active sites on the adsorbent surface, where metal ions are rapidly adsorbed to more active sites (Al-Malack & Basaleh, 2016). After the available surface is filled, the adsorption process becomes slower at 105 minutes until it reaches saturation. Based on the results, the equilibrium time of the activated adsorbent is 60-90 minutes, where the molecules adsorbed by metal ions are equal to the desorbed ions. At this equilibrium time, the removal efficiency of Cu(II) reached a maximum value of 99.8%. Similar findings were also reported that contact time affects the removal of Cd^{2+} and Pb^{2+} metals (Kobya et al., 2015). The increase in contact time allows the release of adsorbate that has been adsorbed on the adsorbent site, causing a decrease in adsorption capacity which is seen at 105 and 120 minutes on the activated adsorbent. The length of the stirring process also causes mass transfer resistance between adsorbent and adsorbate (Suzaki et al., 2017).

Adsorption isotherms aim to determine the mechanism of absorption that occurs during the adsorption process running at equilibrium and constant temperature. Adsorption isotherms also explain the equilibrium concentration of adsorbent and adsorbate proportional to the absorption rate (Rajabi et al., 2016; Sankaran et al., 2020). The Langmuir model describes the formation of a single layer on the adsorbent surface, while the Freundlich model describes the formation of multi-layer adsorption process on the adsorbent surface (Daradmare et al., 2021; Javadian et al., 2015). The correlation coefficient (R^2) estimated from the Langmuir model has a higher value than the Freundlich model. In non-activated adsorbent, the R^2 value of the Langmuir model is 1, higher than Freundlich 0.973. In the activated adsorbent, the R^2 value of Langmuir is 1, while the R^2 value of Freundlich is 0.967. Thus, the Langmuir model is more suitable to describe the adsorption process of Cu(II) by activated and non-activated sludge adsorbent where the adsorption process occurs in a single-layer on a homogeneous surface.

Another important parameter in the Langmuir isotherm is seen from the RL value (adsorption quantity dimension). The adsorption process is favorable if the value is $0<RL<1$ which indicates the adsorption process is reversible. If RL = 0 then the adsorption process is irreversible, RL = 1 is linear and RL>1 is unfavorable adsorption (Zhang et al., 2022). Based on the experimental results, the RL value obtained on activated and non-activated sludge adsorbents is 0.999, so it is said that the adsorption process is favorable and reversible (desorption process can occur). The desorption process can occur due to the interaction that occurs between adsorbents to absorb Cu(II) in solution. Thus, the adsorption process tends to be physical adsorption, where there is an energy difference or electrically charged attractive force (Van der Walls force) that causes Cu(II) ions with weak interactions to be physically bonded to the sludge adsorbent molecules.

To determine the potential mechanism controlling the adsorption rate, the linear regression method was used with pseudo-first-order and pseudo-second-order kinetic models (Ahmed & Ahmaruzzaman, 2016; Wang et al., 2019b). The results showed that the correlation coefficient (R^2) value estimated from the pseudo-second-order was 1, significantly higher than the R^2 obtained from the pseudo-first-order on both activated and non-activated adsorbents (Figure 5 and Figure 6). The low R^2 value of the pseudo-first-order model indicates that the adsorption rate is not affected by changes in reactant concentration. Thus, increasing the concentration of the reagent will not affect the magnitude of the adsorption rate. The adsorption process follows a second-order pseudo model which indicates the adsorption rate depends on the equilibrium adsorption capacity but not the adsorbate

concentration (Rajabi et al., 2016; Sadegh et al., 2015). The pseudo-second-orderpseudo-second-order indicates the adsorption process is a chemisorption process involving ion exchange and valence strength (Daradmare et al., 2021; Zheng et al., 2019).

Similar studies have been carried out using activated adsorbents (activated carbon) from various agricultural waste biomasses and biological materials (Chai, Tan, et al., 2021; Leong et al., 2019), with metal removal efficiencies reaching 90–99% (Bobade & Eshtiagi, 2015; Chai, Cheun, et al., 2021). The adsorbent from water treatment sludge in this study has a high metal removal effectiveness that can compete with other types of biomass. Recycling sludge into adsorbents will reduce the volume of sludge as a by-product of water and wastewater treatment plants. The application of activated carbon can remove not only metals but also various pollutants, such as odor, color, taste, and organic substances, from water in domestic and industrial wastewater treatment. However, the adsorption process by activated carbon has some limitations, such as loss of adsorption efficiency after regeneration and secondary pollution as contaminants are separated from the adsorbent but not destroyed. Therefore, further studies are needed to overcome the formation of secondary pollution from the application of activated carbon in pollutant removal.

CONCLUSION

This study found the potential of recycling water treatment sludge as a low-cost and renewable adsorbent with high efficiency in Cu(II) removal. Activation of the adsorbent influenced Cu(II) absorption with a shorter contact time. Optimum Cu(II) sorption was achieved at a low adsorbent dose, but increasing the dose did not have a significant effect on Cu(II) adsorption. Overall, activated sludge adsorbents had better performance in Cu(II) removal than non-activated adsorbents. The adsorption isotherm in this study was described by the Langmuir model and the reaction rate followed the pseudo second-order. Further studies on sludge adsorbent as a selective and competitive material for the adsorption of various heavy metals at higher concentrations are needed. Development studies of practical and low-cost carbon-based adsorbents are needed on a large scale for industrial applications. However, the possibility of secondary pollution from the adsorbent material should be considered.

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