International Journal of Advanced Engineering and Management Research

Vol. 10, No. 02; 2025

ISSN: 2456-3676

Adsorption of Lead from Synthetic Solution Using Adsorbent Developed from Drinking Water Treatment Plant's Sludge

Mardwita Mardwita, Robiah Robiah, Husnul Khotimah
Department of Chemical Engineering, Engineering Faculty
Universitas Muhammadiyah Palembang,
Jenderal Ahmad Yani Street, 13 Ulu, Palembang 30263, Indonesia

doi.org/10.51505/ijaemr.2025.1111 URL: http://dx.doi.org/10.51505/ijaemr.2025.1111

Received: Mar 24, 2025 Accepted: Apr 03, 2025 Online Published: Apr 16, 2025

Abstract

Human activity increases along with advances in technology and industry in Indonesia. Environmental pollution seems to be worsening with time. Hazardous metal which is released to the environment from industry activities, such as chromium can cause poisoning and serious impact on living organisms including humans. Adsorption is widely used in separation process and it is considered as an efficient method. In this research, adsorbent from sludge obtained from drinking water treatment plant in Palembang were prepared. The adsorbent was used to adsorb lead in synthetic solution. The sludge was activated using sodium hydroxide and the experiment was conducted on mass of 2.5 – 5.0 grams of adsorbent, pH 5 – 9 and contact time varied between 30 to 150 minutes. The adsorption results were analyzed using Atomic Absorption Spectrophotometry (AAS) to measure lead content after adsorption. Fourier Transform Infrared Spectroscopy (FTIR) was conducted for functional group analysis and X-Ray Fluorescence (XRF) analysis for element identification. The results showed that the highest adsorption of lead was obtained at pH 9, adsorbent mass 5 grams, and contact time 120 minutes with efficiency results of 99.8%.

Keywords: adsorbent, lead, hazardous, sludge, water treatment plant

1. Introduction

Water is a necessity that must be clean and free from hazardous waste. Industrial wastewater that is discharged into rivers without prior treatment generally contains heavy metals such as chromium (Cr), iron (Fe), manganese (Mn), cadmium (Cd), zinc (Zn), copper (Cu), nickel (Ni), lead (Pb), mercury (Hg), etc (Cherifi et al., 2022). These metals are dangerous for living things and the environment. Heavy metals are chemical elements with a density of more than 5 gr/cm^3. This element is a significant source of pollution because of its toxicity which can disrupt life processes (Chaiwong et al., 2024). A heavy metal, such as lead and chromium, is naturally present in small amounts in the environment due to processes such as rock weathering and soil runoff (Kazak, 2021). However, human activities, such as household waste disposal, industry (fabric industry, etc) and other activities can increase the lead concentrations in waters through discarded waste. Chromium trivalent (III) and chromium hexavalent (VI) are heavy metals known for their carcinogenic potential, which can cause cancer of the kidneys and liver (Yang et al., 2022; Astuti et al., 2022).

Various methods have been used to reduce the amount of heavy metal in the environment, such as ion exchange, osmosis, chemical precipitation, membrane filtration, and adsorption (Chakraborty et al., 2022). The adsorption process was commonly used due to its low cost, environmentally friendly, and easy application. Adsorption is a method of separating components in a fluid, where the adsorbent absorbs the adsorbate component (Mouratib et al., 2024).

Drinking Water Company is a drinking water treatment plant that provides clean water for households. However, the process in this water treatment plant will produce sewage sludge as a by-product. The sludge is watery material produced from this plant and contains many chemicals such as aluminum oxide (Al_2O_3), silicon dioxide (SiO_2), and iron oxide (Fe_2O_3) (Cardoso et al., 2019). These materials usually have a large surface area and high reactivity; therefore, it is suitable for adsorbing and offer many benefits as an alternative adsorbent such as their affordable cost, simple process, and high efficiency (Zhang et al., 2019).

Some research has been conducted using adsorbent from sludge to adsorb heavy metals, such as red mud that is used to adsorb lead (Pb^{2+}), copper (Cu^{2+}), and cadmium (Cd^{2+}) (Gutub & Soliman, 2017). Their results showed that the dosage of red mud will affect the ability of adsorption, the increasing dosage will increase the number of active adsorption sites. On the other hand, the internal energy of molecular motion will increase in higher temperature; this will lead to attraction of heavy metals to the surface of red mud. Rajakaruna, R.M.A.S.D et al. reviewed some removal of heavy metals from wastewater using sludge-based materials. They describe that the chemical and physical activation methods have been widely utilized for sludge-based adsorption (Rajakaruna et al., 2023). S.A. Abo-El-Enein et al. have studied the efficiency of sludge as an adsorbent to remove Pb(II), Cd(II), and Ni(II) from wastewater and investigated the effect of firing temperature, pH, contact time, adsorbent dose and initial metal ions concentration. They found that the increasing pH value of the solution will increase the metal ions removal percentage, while the firing temperature has no significant effect on the adsorptive capacity towards Pb(II) (Abo-El-Enein et al., 2017).

Other factor such as the chemical activation process in the process of making activated sludge can affect the pore structure, functional groups, and metal adsorption ability (Dahhou et al., 2016). Chemically activated sludge generally has better surface area and adsorption efficiency compared to biologically activated sludge. In contrast to biologically activated sludge, which is obtained through biological processes, chemically activated sludge is produced by chemical precipitation of wastewater using coagulants (Astuti et al., 2022; Soliman et al., 2023).

ISSN: 2456-3676

Based on the description above, in this study a series of adsorbent from sludge to adsorb lead from synthetic solution were prepared. The main objectives of this study were to study the feasibility of applying sludge from drinking water treatment plant as an adsorbent for the adsorption of lead; and to investigate the effects of pH, contact time, and mass of adsorbent on the adsorption process.

2. Method

The preparation of adsorbent from sludge is as follows:

2.1 Sludge preparation

Sludge waste from Drinking Water Company is collected and washed using distilled water. The sludge is then dried in an oven at a temperature of 110°C, after drying the sludge is crushed and sifted using a 250-mesh sieve. The sifted dried sludge is ready to be used for the next stage.

2.2 Sludge activation

A total of 150 gr of sifted dried sludge was then put into a beaker glass and 2 M NaOH solution was added (ratio 1:2). The mixture was stirred for 3 hrs, then filtered, the solid was washed using distilled water until pH 7. The filtered solid was then dried in the oven at 120°C. After the drying process, the activated solid is crushed using a mortar and it is ready to be use as an adsorbent.

2.3 Adsorbent characterization

The adsorbent is then characterized using X-Ray Fluorescence (XRF) analysis to identify the elements contained in the adsorbent and Fourier Transform Infrared Spectroscopy (FTIR) analysis for functional group analysis.

2.4 Determination of optimum conditions for adsorption of Pb ions

The parameters were used to determine the best conditions in the adsorption process. The parameters were pH variations (5 and 9), mass variations (2.5 and 5 gr) and contact time variations (30, 60, 90, 120, 150 min). A 500 mL of Pb solution was prepared with a concentration of 300 mg/L in an Erlenmeyer. The pH of the solution is adjusted to 5 or 9 by adding 0.1 M HNO_3 solution for acidic pH or 0.1 M NaOH solution for basic pH. Next, 2.5 or 5 gr of adsorbent was added into the Erlenmeyer flask containing Pb solution. The mixture was stirred at 120 rpm for 30 min, and then the mixture was filtered using a filter paper. The same procedure was also applied for a mass of 5 gr adsorbent pH 9 and a contact time of 30-150 min. The filtration results were analysed using Atomic Absorption Spectrophotometry (AAS). The adsorption efficiency (%E) of Pb ions is calculated using the following formula (Cheng et al., 2021; Soliman et al., 2023)

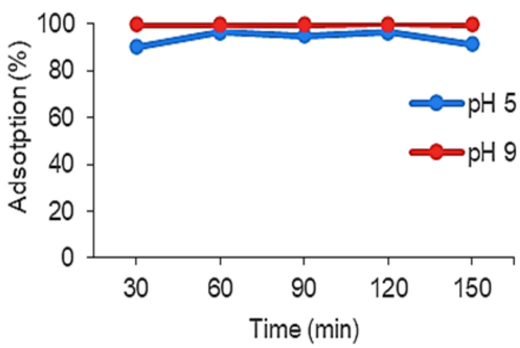
$$\%E = [(Co-Ce)/Ce] \times 100 \qquad (1)$$

%E = Adsorption efficiency,
Co = Initial ion concentration (Pb) (mg/mL),
Ce = Concentration (Pb) at equilibrium (mg/mL).

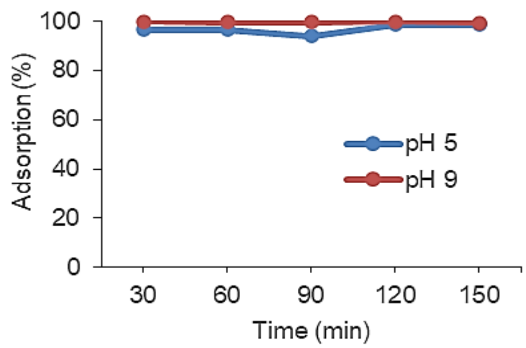
3. Results and Discussion

3.1 Effect of pH and mass on adsorption efficiency

The results of AAS analysis of samples with variations in pH 5 and 9 on the adsorption efficiency (%) of Pb ions at various contact times with an adsorbent mass of 2.5 gr and 5 gr can be seen in Figure 1a and b below.



a



b

Figure 1a. Effect of pH on adsorption (%) of Pb ions at varying contact times using 2.5 gr mass of adsorbent; 1b. Effect of pH on adsorption (%) of Pb ions at varying contact times using 5 gr mass of adsorbent

Based on Figure 1a at pH 5 with an adsorbent mass of 2.5 gr, the adsorption efficiency of Pb ions was 90% at a contact time of 30 min. As the contact time increased, the adsorption efficiency increased from 90.06% to 96% at a contact time of 60 min, but there was a small decrease at a contact time of 90, the adsorption efficiency slightly increased again at contact time 120 min (96.20%), however it decreased again at a contact time of 150 min from 96.20% to 91%. At pH 9, as can be seen in Figure 1a, with an adsorbent mass of 2.5 gr, the adsorption efficiency of Pb ions at a contact time of 30 min reached 99.5%, this percentage is higher than pH 5 at the same contact time. By increasing the contact time from 30 to 150 min, there are no significant changes in adsorption efficiency. The highest adsorption efficiency is 99.7% at 120 min; meanwhile it only slightly decreases at 150 min where the adsorption efficiency of Pb ions is 99.2%.

The results of AAS analysis of the samples with variations in pH 5 and 9 on the adsorption efficiency (%) of Pb ions at various contact times with an adsorbent mass of 5 gr can be seen in Figure 1b. Figure 1b shows that at pH 5 with an adsorbent mass of 5 gr, the adsorption efficiency of Pb ions was 96.5% for contact time 30 min. As the contact time increased from 30 to 150 min, the adsorption efficiency increased from 96.5% to 98.2%, but it decreased at the contact time of

90 min (adsorption efficiency was 93.8%). The AAS analysis at pH 9 with an adsorbent mass of 5 gr was also presented in Figure 1b. The adsorption efficiency with a contact time of 30 min reached 99.6% and there are no significant changes in the adsorption percentage with the increasing of contact time, although the highest adsorption was at 120 min (99.8%). As comparison of adsorption efficiency at contact time 120 min over 5 gr adsorbent, the maximum adsorption was equal to 99.8% at pH 9 and adsorption efficiency was 99.7% at pH 5.

Increasing the contact time between adsorbent and Pb allows the molecules to diffuse and adsorb more effectively, but once the active sites on the adsorbent are saturated, the adsorption efficiency will decrease due to desorption. In addition, increasing the amount of adsorbent increases the adsorption efficiency because more active sites are available for adsorption (Fat'Hi & Ali, 2022).

3.2 X-Ray Fluorescence (XRF) analysis

The element in the adsorbent was analysed by X-Ray Fluorescence (XRF). The results are presented in Table 1, which contains data regarding the content of chemical elements in the adsorbent.

Table 1. XRF characterization analysis of sludge

No	Element	Concentration (%)	Geological Components
1	Si	41.03	SiO_2
2	Al	25.10	Al_2O_3
3	Fe	6.37	Fe_2O_3

Based on Table 1, sludge contains several elements, both in single form and as oxides. Silica (Si) and alumina (Al) are the dominant elements in sludge with silica present as silicon oxide (SiO_2, 41.03%) and alumina oxide (Al_2O_3, 25.10%). Other elements were detected in low quantities such as Fe (6.37 %). The presence of Si and Al play an important role in the absorption process due to their effectiveness in binding Pb metal ions (Qi et al., 2020).

Silica (Si) is known as a natural absorbent material because of its ability to adsorb heavy metals through the active group's siloxane (Si-O-Si) and Silanol (Si-OH). Siloxane acts as a ligand that provides free electrons to interact with heavy metal cations (Shumiye et al., 2024). On the other hand, alumina (Al) is also considered as a potential adsorbent because it has several advantages, including high adsorption efficiency, mechanical strength, and large specific surface area. Alumina has a porous structure which is suitable for the adsorption process and can effectively bind various substances (Mouratib et al., 2024).

3.3 Fourier Transform Infrared (FTIR) Analysis

The FTIR spectrums of the adsorbent before and after adsorption of Pb are shown in Figure 2 and Figure 3, respectively. Figure 2 shows the adsorption band with the first wave peak at

Vol. 10, No. 02; 2025

ISSN: 2456-3676

frequencies 3649.34 cm^{-1}, which indicates the presence of stretched O-H bond (Cheng et al., 2021). The adsorption band at 1558.57 cm^{-1} indicates Si-O vibrations, while the adsorption band at 998.40 cm^{-1} indicates Al-O bending vibrations, and the frequency 776.77 cm^{-1} indicates Si-OH bending vibrations. These adsorption bands indicate the presence of silica and alumina groups in the sludge. Silica and alumina compounds are important compounds in adsorption process.

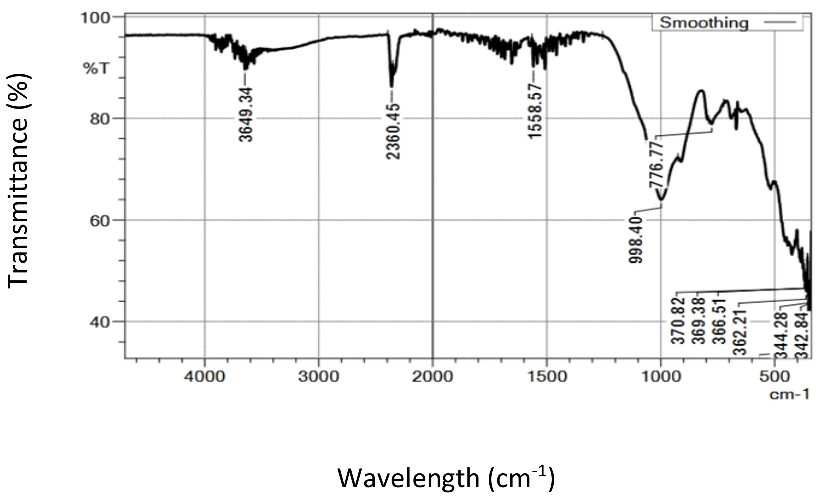


Figure 2. FTIR Spectra of adsorbent before adsorption

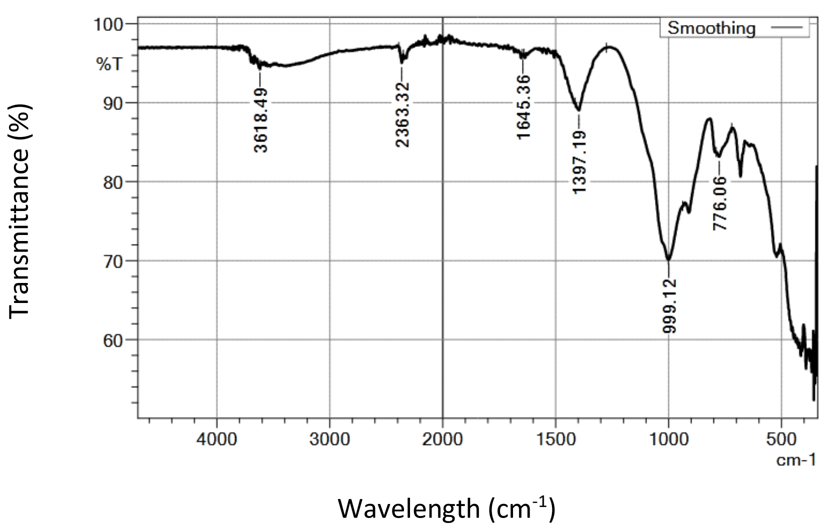


Figure 3. FTIR Spectra of adsorbent after adsorption

FTIR spectrum of adsorbent that has been used after adsorption of Pb at pH 9, contact time 120 min, mass of adsorbent 5 gr. The FTIR spectrum is shown in Figure 3. In Figure 3, the spectrum of the adsorbent shows a small broad peak at 3618.49 cm^{-1} which indicates the presence of an O-H functional group (Qi et al., 2020). Another intensity shift occurred at 1645.36 cm^{-1}, indicating the presence of the C=C. The new peak at a frequency of 1397.19 cm^{-1} shows the $-CH_2$ bonds which increases the adsorption capacity. The frequency at 999.12 cm^{-1} shows Si-O vibration and 776.06 cm^{-1} shows Si-OH bending vibration.

Conclusions

The drinking water treatment plant's sludge was successfully evaluated as an efficient adsorbent for Pb adsorption. The highest efficiency was 99.8% observed at pH 9, contact time 120 min and 5 gr adsorbent. The silica and alumina in adsorbent play an important role in adsorption of Pb. FTIR analysis shows the presence of hydroxyl groups (O-H), which increases the performance of the adsorbent in adsorbing Pb.

Acknowledgments

This research is funded by the grant from Universitas Muhammadiyah Palembang through the LPPM Universitas Muhammadiyah Palembang research grant 2024, contract number: 145.5/H-5/LPPM-UMP/VIII/2024.

References

Abo-El-Enein, S. A., Shebl, A., & Abo El-Dahab, S. A. (2017). Drinking water treatment sludge as an efficient adsorbent for heavy metals removal. *Applied Clay Science*, *146*(June), 343–349. https://doi.org/10.1016/j.clay.2017.06.027

Astuti, D. H., Adriyanti, A. L., Buditama, A., Nurmawati, A., & Indrati, L. (2022). Morphology characteristic study of adsorbent prepared from Sidoarjo hot mud. *Nusantara Science and Technology Proceedings*, *2022*, 247–253. https://doi.org/10.11594/nstp.2022.2736

Cardoso, C. M. M., Zavarize, D. G., Lago, P. de A., Pedroza, M. M., Brum, S. S., & Mendonça, A. R. V. (2019). Evaluating adsorbent properties of drinking water treatment plant sludge-based carbons activated by K_2CO_3/CH_3COOH: a low-cost material for metal ion remediation. *SN Applied Sciences*, *1*(7). https://doi.org/10.1007/s42452-019-0709-8

Chaiwong, C., Koottatep, T., Chirasuwannaphot, Y., Thanasrilungkul, C., Panchai, P., Chanamarn, W., Noophan, P., Kasahara, T., Wongkiew, S., & Polprasert, C. (2024). Novel multifunctional sewage sludge-based adsorbents for treatment of municipal wastewater. *Journal of Applied Science and Engineering*, *27*(9), 3127–3146. https://doi.org/10.6180/jase.202409_27(9).0010

Chakraborty, R., Asthana, A., Singh, A. K., Jain, B., & Susan, A. B. H. (2022). Adsorption of heavy metal ions by various low-cost adsorbents: a review. *International Journal of Environmental Analytical Chemistry*, *102*(2), 342–379.

https://doi.org/10.1080/03067319.2020.1722811

Cheng, H., Liu, Y., & Li, X. (2021). Adsorption performance and mechanism of iron-loaded biochar to methyl orange in the presence of Cr^{6+} from dye wastewater. *Journal of Hazardous Materials*, *415*(March), 125749. https://doi.org/10.1016/j.jhazmat.2021.125749

Cherifi, M., Mecibah, W., Bouasla, S., Laefer, D. F., & Hazourli, S. (2022). Wastewater sludge as a low-cost effective adsorbent of hexavalent chromium: equilibrium, kinetics, and thermodynamic studies. *Desalination and Water Treatment*, *278*, 102–116. https://doi.org/10.5004/dwt.2022.29052

Dahhou, M., El Moussaouiti, M., Benlalla, A., El Hamidi, A., Taibi, M., & Arshad, M. A. (2016). Structural aspects and thermal degradation kinetics of water treatment plant sludge of moroccan capital. *Waste and Biomass Valorization*, *7*(5), 1177–1187. https://doi.org/10.1007/s12649-016-9513-5

Fat'Hi, A. M., & Ali, A. H. (2022). Effect of adsorption conditions on the removal of lead (II) using sewage sludge as adsorbent material. *Journal of Engineering and Sustainable Development*, *26*(3), 1–9. https://doi.org/10.31272/jeasd.26.3.1

Gutub, S. A., & Soliman, M. F. A. (2017). *Removal of Fe^{++} from Wastewater Using Sludge-polymer Hybrid Adsorbents*. *January 2016*.

Kazak, O. (2021). Fabrication of in situ magnetic activated carbon by co-pyrolysis of sucrose with waste red mud for removal of Cr(VI) from waters. *Environmental Technology and Innovation*, *24*, 101856. https://doi.org/10.1016/j.eti.2021.101856

Mouratib, R., Nechchadi, B., Naribi, Z., Alami Younssi, S., Bouhria, M., El Krati, M., & Tahiri, S. (2024). Efficiency of dry drinking water treatment sludge as adsorbent for methylene blue and acid red 97 removal from aqueous solutions. *Desalination and Water Treatment*, *318*(March), 100372. https://doi.org/10.1016/j.dwt.2024.100372

Qi, X., Wang, H., Zhang, L., Xu, B., Shi, Q., & Li, F. (2020). Removal of Cr (III) from aqueous solution by using bauxite residue (red mud): Identification of active components and column tests. *Chemosphere*, *245*, 125560. https://doi.org/10.1016/j.chemosphere.2019.125560

Rajakaruna, R. M. A. S. D., Sewwandi, B. G. N., Najim, M. M. M., Baig, M. B., Alotaibi, B. A., & Traore, A. (2023). Sustainable Approaches for Wastewater Treatment: An Analysis of Sludge-Based Materials for Heavy Metal Removal from Wastewater by Adsorption. *Sustainability (Switzerland)*, *15*(20). https://doi.org/10.3390/su152014937

Shumiye, E., Nadew, T. T., Tedla, T. S., Getiye, B., Mengie, D. A., & Ayalew, A. G. (2024). Preparation of an activated adsorbent from water treatment plant sludge for phosphate removal from wastewater: optimization, characterization, isotherm, and kinetics studies. *Journal of Water Sanitation and Hygiene for Development*, *14*(2), 122–143. https://doi.org/10.2166/washdev.2024.278

Yang, D., Chu, Z., Feng, X., Ge, Q., Wang, R., Zhang, J., Li, S., Zheng, R., Wei, W., Yi, S., & Chen, H. (2022). Dual ions neutralized and stabilized red mud for chromium(VI) polluted soil remediation. *ACS ES and T Engineering*, *2*(5), 913–923. https://doi.org/10.1021/acsestengg.1c00420

Zhang, L., Pan, J., Liu, L., Song, K., & Wang, Q. (2019). Combined physical and chemical activation of sludge-based adsorbent enhances Cr(IV) removal from wastewater. *Journal of Cleaner Production*, *238*, 117904. https://doi.org/10.1016/j.jclepro.2019.117904