science, engineering
and health studies

Research Article

Science, Engineering and Health Studies
https://li01.tci-thaijo.org/index.php/sehs
ISSN (Online): 2630-0087

Effect of soil composition in copper (II), lead (II), and zinc (II) ion adsorption capacity

Wei-Hsiang Tan[1*], *Noumie Surugau*[1], *Awang Bono*[2], *Mohd Hardyianto Vai Bahrun*[3], *Rubia Idris*[1], *Siti Aishah Mohd Ali*[1], *Rohana Tair*[1] *and Sahibin Abd Rahim*[1]

[1] Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Kota Kinabalu, Sabah 88400, Malaysia
[2] GRISM Innovative Solutions, Kota Kinabalu, Sabah 88400, Malaysia
[3] Faculty of Engineering, Universiti Teknologi Malaysia, UTM Johor Bahru, Johor 81310, Malaysia

***Corresponding author**:*
Wei-Hsiang Tan
tanwh@ums.edu.my

***Received**: 7 December 2022*
***Revised**: 11 May 2023*
***Accepted**: 22 May 2023*
***Published**: 24 July 2023*

***Citation**:*
Tan, W., Surugau, N., Bono, A., Bahrun, M. H. V., Idris, R., Ali, S. A. M., Tair, R., and Rahim, S. A. (2023). Effect of soil composition in copper (II), lead (II), and zinc (II) ion adsorption capacity. Science, Engineering and Health Studies, 17, 23020001.

ABSTRACT

The ability of soil to bind with heavy metals is related to soil adsorption capacity. Different soil compositions have different adsorption capabilities for heavy metal ions. In this study, the excess adsorption isotherm of binary adsorption by individual heavy metals (Cu^{2+}, Pb^{2+}, and Zn^{2+}) onto different clay–sand ratios was investigated. Five different ratios were examined (1:0, 9:1, 7:3, 1:1, and 0:1). The excess adsorption isotherm was measured using a typical batch adsorption approach, and the experimental data were interpreted using the pseudo-ideal monolayer adsorption model. The adsorption capacities ranged from 0.003 to 1.83×10^{-3} mg/g (Cu^{2+}), 0.007 to 1.62×10^{-2} mg/g (Pb^{2+}), and 2.0 to 1.71×10^{-5} mg/g (Zn^{2+}). The results revealed that increasing the clay composition in the admixture increased the selectivity of Pb^{2+} more than Cu^{2+} and Zn^{2+}. The sequence of adsorption capacity in the non-competitive adsorption of different compositions of clay and sand showed the following heavy metal adsorption pattern: $Pb^{2+} > Cu^{2+} > Zn^{2+}$.

Keywords: excess adsorption isotherm; pseudo-ideal monolayer adsorption model; Pb^{2+}; Cu^{2+}; Zn^{2+}

1. INTRODUCTION

The anthropogenic sources of heavy metals are primarily from industrial, pharmaceutical, mining, and smelting discharge; domestic disposal; and improper management of industrial waste or agricultural activities (Bagul et al., 2015; Sankhla et al., 2016; Yahya et al., 2018). These heavy metals can be disposed of through treatment, filtration, or immediate release into rivers, oceans, lakes, or land. Some industries haphazardly release heavy metals into the environment due to a lack of adequately equipped plants, improper environmental management, and operations outside of appropriate standards, particularly in developing countries (Anyanwu et al., 2018). The lack of environmental technologies and regional law enforcement in developing nations also contributes to the increased rate of heavy metal contamination in the environment (Hu et al., 2014; Ding, 2019). As heavy metals are non-biodegradable, non-thermodegradable, persistent, and cannot be chemically degraded (Oluyemi and Olabanji, 2011; Taghipour et al., 2013), they tend to accumulate in very small amounts and remain in soil or water. An increase in heavy metal concentration accumulation over time will significantly affect environmental quality.

In nature, heavy metals exist in several complex or compound forms, including oxides, phosphates, sulfates, hydroxides, sulfides, nitrates, silicates, and organic matter (Masindi and Muedi, 2018). These also posess various oxidation states. Consequently, oxidation properties also affect the behavior of heavy metals. Likewise, the oxidation state of numerous heavy metals in the environment, particularly in soil components, determines their toxicity. The level of oxidation state can affect the determination of heavy metals in both natural and artificial geochemical barriers. In contaminated soils, the oxidation state of heavy metals, such as arsenic, selenium, chromium, and antimony increases (Vodyanitskii, 2013). Heavy metals can become hazardous to the environment and other forms of life when their oxidation state increases or decreases due to their ability to form free radicals. This causes DNA damage, alters sulfhydryl homeostasis, and leads to lipid peroxidation. For instance, chromium (III) is an essential trace element for human health, whereas chromium (VI) is carcinogenic and the most dangerous form of chromium. Meanwhile, due to its high solubility, arsenic (III) is more hazardous than arsenic (V) at a lower oxidation state. Moreover, it has been discovered that the mobility of heavy metals, particularly in soil, is closely related to their oxidation levels. The mobility of arsenic, chromium, and vanadium is greater in lower oxidation states, whereas antimony's mobility improves in higher oxidation states.

In general, soil is composed of different compositions, minerals, and particles, which result in soil properties that vary from one location to another. Common features of soil include clay, sand, and silt. Diverse soil constituents possess a variety of binding capacities with various contaminant forms that can be bound to the soil (Bhakta and Munekage, 2013). Soil has evolved into a natural adsorbent capable of accumulating contaminants like heavy metals from natural and anthropogenic sources. Heavy metals in soil might dissolve in the soil solution or occupy exchange sites in inorganic soil constituents. They may also be adsorbed in inorganic soil constituents, precipitated as pure or mixed solids, present in the structure of secondary minerals, or present in the structure of primary minerals (Kome et al., 2019; Draszawka-Bołzan, 2017). Among these interactions, adsorption plays the most significant role in the accumulation of heavy metals in soils. Nonetheless, it is necessary to comprehend the role of soil in determining whether it is a sink or source of heavy metals because each type of soil possesses different compartments that influence its adsorption capacity and retention time to retain heavy metals in soil. Even a small amount of clay can be separated into numerous types, including kaolinite, bentonite, chlorite, glauconite, and vermiculite (Adeyemo et al., 2017). This study examined the adsorption of selected heavy metals onto various soil components and determined their adsorption capacities. Due to the wide variety of soil types, the scope of this investigation was limited to sand and clay. The sand was river sand, while the clay was kaolin. In addition, adsorption through a composition containing varying proportions and types of clay or sand has not been performed or reported.

In previous studies, the measurement and models of conventional adsorption isotherm were directly interpreted from measured excess adsorption isotherm with the assumption that only single adsorption was involved in a binary system (Müllerová et al., 2003; Jiang et al., 2010; Budianta, 2011; Ghasemi-Fasaei et al., 2012; Arabzai and Honma, 2014). Only the solute component was involved in the adsorption system, whereas the components in the solvent (e.g., distilled water) were ignored or assumed to play no part in the adsorption process. Compared to the concentration of solute in the bulk solution, this assumption referred to a very dilute solute. Most of the literature was reported without further examination based on such assumptions. Contrary to the excess adsorption isotherm, which assumes that all system components participate in adsorption, this assumption is less accurate. In this study, the pseudo-ideal monolayer adsorption model was utilized for the analysis and interpretation of the adsorption isotherm, as well as to measure the excess isotherm. As all components dissolved in the solution participate in the adsorption process, this model describes binary and multiple adsorption. There is no presumption that only solute components participate in adsorption while solvent components do not (Bono et al., 2008; Bono et al., 2014; Bono et al., 2016).

2. MATERIALS AND METHODS

2.1 Materials

The chemicals used in this study were copper nitrate trihydrate ($Cu(NO_3)_2{\cdot}3H_2O$), lead (II) nitrate ($Pb(NO_3)_2$), and zinc (II) nitrate hexahydrate ($Zn(NO_3)_2{\cdot}6H_2O$). All were purchased from Sigma-Aldrich. The kaolin clay ($Al_2Si_2O_5(OH)_4$) was purchased from R&M Chemicals, and the river sand from a local sand supplier.

2.2 Adsorption study

The experimental measurement of excess adsorption isotherms with some modifications has been explained in detail by Tan et al. (2018, 2021). Individual adsorbate solutions (Cu^{2+}/Pb^{2+}/Zn^{2+}) with concentrations ranging from 10 to 1,000 mg/kg were prepared. The weight ratio between the adsorbent and the adsorbate solution was fixed at 1:50. The soil's clay–sand ratio was examined at 1:0, 9:1, 7:3, 1:1, and 0:1. All samples were prepared in triplicate. Each sample was placed in a 250 mL sealed conical flask in an incubator shaker for 24 h at 30 °C and at 100 rpm to achieve equilibrium. The samples were then centrifuged, and the concentrations of the solutions before and after adsorption were determined using inductively coupled plasma-optical emission spectrometry.

2.3 Pseudo-ideal monolayer adsorption model

In accordance with Bono et al. (2014), six equations were used to apply the pseudo-ideal monolayer adsorption model. Equation 1, was used to determine the numerical value of excess adsorption isotherm of adsorbate:

$$\Gamma_1 = \frac{W_0(x_0 - x_1)}{W_s} \qquad (1)$$

Where x_0 is the initial concentration of adsorbate, x_1 is the concentration of adsorbate in equilibrium, W_0 is the weight of solution, and W_s is the weight of adsorbent.

Equation 2 was applied to calculate the conformity of pseudo-ideal:

$$\frac{x_1 x_2}{\Gamma_1} = \frac{1}{N_s}\left[x_1 + \frac{1}{K-1}\right] \qquad (2)$$

Where K is the equilibrium constant, N_s is the total mole of adsorbed phase (adsorption saturation value), and x_2 is the equilibrium concentration.

Equations 3 and 4 determined the concentration of components 1 and 2 of adsorbed phase (mole fraction), while Eequations 5 and 6 identified the number of moles of components 1 and 2 of adsorbed phase (mol/g):

$$x_1^s = \frac{Kx_1}{1+(K-1)x_1} \tag{3}$$

$$x_2^s = 1 - x_1^s \tag{4}$$

$$n_1^s = N_s \frac{Kx_1}{1+(K-1)x_1} \tag{5}$$

$$n_2^s = N_s - n_1^s \tag{6}$$

Where x_1^s and x_2^s are the respective concentrations of components 1 and 2 in the adsorbed phase, and n_1^s and n_2^s are the respective moles of components 1 and 2 adsorbed.

3. RESULTS AND DISCUSSION

Figure 1 shows the excess adsorption isotherm of binary adsorption of individual Cu^{2+}, Pb^{2+}, and Zn^{2+} ions at different clay–sand ratios. The pseudo-ideal monolayer adsorption model revealed that the excess isotherm obtained from all individual adsorptions of Cu^{2+}, Pb^{2+}, and Zn^{2+} exhibited the same U-shaped pattern, either monolayer type or Langmuir monolayer type (Kippling, 1965). U-shaped isotherms are more favorable for one component according to composite isotherm (monolayer type) classification. In this case, it refers to the solute, which is the heavy metal ion used. An S-shaped isotherm is preferred for different particular components at different particular concentrations (Song et al., 2013). Therefore, there may be a solute component preference at low solute concentrations and a solvent component preference at high solute concentrations (i.e., low solvent concentration). Consequently, only Cu^{2+}, Pb^{2+}, and Zn^{2+} were adsorbed during each adsorption. The excess adsorption curve formed earlier as the sand composition increased (Figure 1). The formation of the curve indicates a decreasing rate of adsorption and selectivity for the heavy metal involved. As the number of adsorption sites decreased, the adsorption surface period became saturated, and the curve quickly formed. Due to the larger surface area of the clay, the increase in clay composition delayed the formation of the excess adsorption curve (related to the adsorption rate). Excess adsorption of heavy metals on 100% clay was higher than for other mixed compositions. Based on these non-competitive excess adsorption isotherms, the clay–sand ratio in soil and sand has a major impact on the number of adsorption sites on the surface area and the adsorption capacity of metal ions.

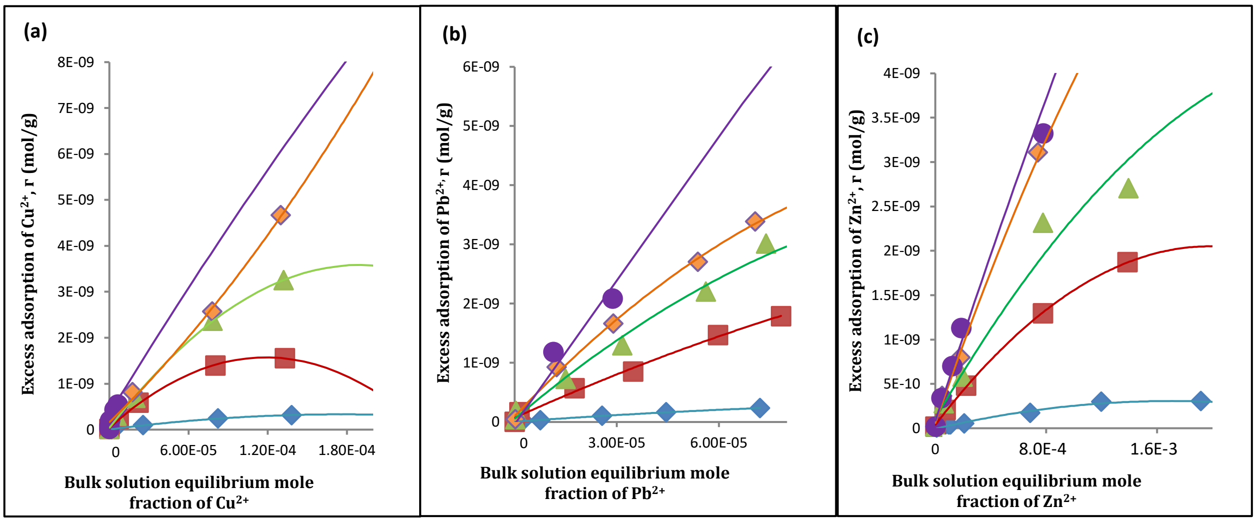

Figure 1. Excess adsorption isotherm of heavy metal ions (a) Cu^{2+}, (b) Pb^{2+}, and (c) Zn^{2+} onto different compositions of clay and sand at 30 °C. (Note: ◆ sand, 🟥 1:1 (clay:sand), ▲ 7:3 (clay:sand), ◆ 9:1 (clay:sand), and ● clay)

The equilibrium constant (*K*) and adsorption capacity (N_s) yielded from the slope and intercept of the plot for different compositions of clay and sand were obtained using linear regression of the pseudo-ideal monolayer adsorption model (Equation 2). All data of individual adsorption of Cu^{2+}, Pb^{2+}, and Zn^{2+} onto mixed compositions of clay and sand satisfactorily obtained a Langmuir relationship, and the correlation coefficient (R^2) was shown to have a strong or moderate linear relationship (Table 1). R^2 for Cu^{2+} adsorption was above 0.82, in all ratios except 9:1, which was 0.70. The R^2 for Pb^{2+} adsorption was above 0.76, except in 100% sand, which showed a moderate linear relationship of 0.69. Zn^{2+} showed a strong positive linear relationship with an R^2 above 0.74 for all respective compositions. This confirms that the individual non-competitive adsorption of Cu^{2+}, Pb^{2+}, and Zn^{2+} onto different compositions of clay and sand are of monolayer type and conform the pseudo-ideal monolayer adsorption model. The obtained adsorption capacity values were negligible because all the aqueous speciation in the solution was considered when calculating the concentration. Heavy metal ions, anions, and water molecules were included in calculating the concentration and the mole fraction involved in the adsorption system (Equation 2). Meanwhile, in the conventional adsorption isotherm, only the solute component is assumed to be involved in adsorption. Other present speciation and water molecules from aqueous solution are ignored. The assumption might be valid for a very dilute aqueous solution, or a very low solubility solute in the solution, but it is not applicable in a completely miscible solution. Thus, it is reasonable to include all of the aqueous speciation and water molecules when calculating the concentration in the adsorption system.

The capacity to absorb heavy metals in soil decreased as sand content increased or clay decreased. As the clay–sand ratio changed from 9:1 to 1:1, the adsorption capacity for Cu^{2+} decreased from 4.4×10^{-4} to 2.1×10^{-4} mg/g. In contrast, the Pb^{2+} adsorption capacity increased significantly as the ratio decreased from 1.02×10^{-3} mg/g (9:1), to 9.32×10^{-4} mg/g (7:3) and 5.28×10^{-4} mg/g (1:1). However, the Zn^{2+} adsorption capacity continued to increase as the ratio increased from 1.58×10^{-4} mg/g (1:1), to 3.48×10^{-4} mg/g (7:3) and 7.09×10^{-1} mg/g (9:1). The difference in adsorption capacity is proportional to the surface area and cation exchangeable adsorbent. Clay has a specific surface area of 16.60 m^2/g and a pore volume of 0.10 cm^3/g, while sand has a specific surface area of 0.57 m^2/g and a pore volume of 0.003 cm^3/g (Mustapha et al., 2019). These results demonstrate that the number of adsorption sites on the surface of clay is significantly greater than that of sand. Thus, adsorption capacity in soil increases with a higher clay–sand ratio. In addition, cation exchange occurs only on the surface of clay.

Table 1. Equilibrium constant (*K*) and adsorption capacity (N_s) of different proportions of clay and sand toward the heavy metal ions Cu^{2+}, Pb^{2+}, and Zn^{2+}

	Adsorbent Ratio (%)		***K* g/mol**	**N_s mg/g**	**R^2**
	Clay	**Sand**			
Cu^{2+}	0	100	11,210	0.00003	0.96
	50	50	26,065	0.00021	0.94
	70	30	10,829	0.00033	0.82
	90	10	10,767	0.00044	0.70
	100	0	4,113	0.00183	0.95
Pb^{2+}	0	100	20,100	0.00007	0.69
	50	50	21,700	0.00053	0.76
	70	30	22,900	0.00093	0.78
	90	10	23,600	0.00102	0.81
	100	0	1,110	0.01620	0.82
Zn^{2+}	0	100	11,000	0.000025	0.84
	50	50	16,600	0.000158	0.74
	70	30	10,100	0.000348	0.76
	90	10	6,880	0.000709	0.79
	100	0	2,490	0.001710	0.89

Due to its smaller hydrated ionic size, Pb^{2+} has a greater adsorption capacity than Cu^{2+} and Zn^{2+}, making it more absorbable by clay–sand mixtures. Heavy metal ions are known to become hydrated in aqueous solutions. Pb^{2+} has a radius of 4.01 Å, while Cu^{2+} and Zn^{2+} have radii of 4.19 Å and 4.01 Å, respectively. Consequently, selecting the surface-active sites (hydroxyl group) and the pore size of admixtures with heavy metal ions depends on their hydrated ion radii (Al-Essa and Khalili, 2018). In addition, the ability of Pb^{2+} and Cu^{2+} surface species to form hydrolyzed complexes on surface-active admixtures increases their adsorption capacity, whereas Zn^{2+} only interacts with the adsorption sites of admixtures as divalent ions (Srivastava et al., 2005). Based on the results obtained, the ascending series of non-competitive adsorption onto various mixed clay and sand compositions can be demonstrated as $Pb^{2+} > Cu^{2+} > Zn^{2+}$.

Figure 2 depicts the concentrations of Cu^{2+}, Pb^{2+}, and Zn^{2+} in the adsorbed phase. The selectivity toward Cu^{2+}, Pb^{2+}, and Zn^{2+} was exceptionally high at relatively low solution concentrations. At low concentrations, heavy metals were predominantly adsorbed onto the adsorption sites of clay and sand, whereas at higher concentrations, clay and sand lost their ability to bind to heavy metals. The degree of selectivity of Cu^{2+} and Zn^{2+} was greatest at a 1:1 clay-sand composition ratio. The degree of selectivity of Pb^{2+} was not markedly different. However, as the composition ratio of clay increased, selectivity gradually decreased. Clay had the lowest selectivity of the three heavy metals. The large surface area increased the number of adsorption sites and decreased the selectivity of the adsorbent. Consequently, the large surface area increased the equilibrium mole fraction during the adsorption phase.

4. CONCLUSION

Pseudo-ideal monolayer adsorption theory is applicable in the adsorption of heavy metals Cu^{2+}, Pb^{2+}, and Zn^{2+} onto mixed compositions of clay and sand. The performance of high and moderately high R^2 in the linear form indicated that the obtained data were satisfactorily created a Langmuir relationship. Adsorption capacity increased as the component of clay increased in the clay–sand admixture. The difference in adsorption capacity was related to the higher surface area and cation-exchangeable clay. This study's descending adsorption capacity of heavy metals in different clay and sand compositions is $Pb^{2+} > Cu^{2+} > Zn^{2+}$.

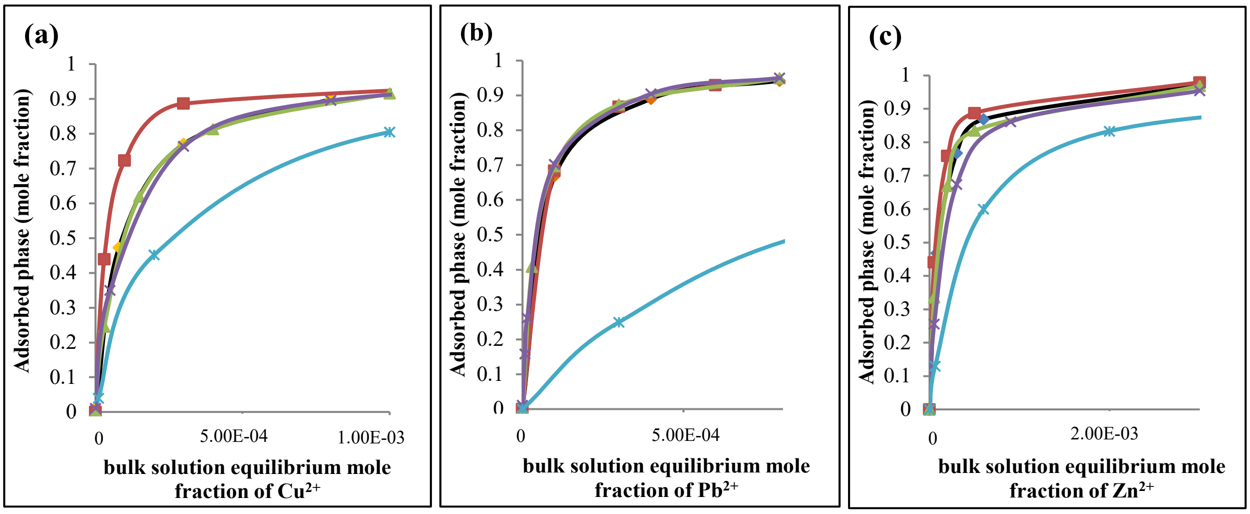

Figure 2. Selectivity of metal ions (a) Cu^{2+}, (b) Pb^{2+}, and (c) Zn^{2+} onto different compositions of clay-to-sand ratio at 30 °C
Note: ◆sand, ■1:1 (clay:sand), ▲ 7:3 (clay:sand), ✕ 9:1 (clay:sand), and ✳clay

ACKNOWLEDGMENT

The authors would like to acknowledge the financial support of Universiti Malaysia Sabah under the Skim Penyelidikan Bidang Keutamaan grant (SBK0486-2021).

REFERENCES

Adeyemo, A. A., Adeoye, I. O., and Bello, O. S. (2017). Adsorption of dyes using different types of clay: a review. *Applied of Water Science*, 7, 543-568.

Al-Essa, K., and Khalili, F. (2018). Heavy metals adsorption from aqueous solutions onto unmodified and modified Jordanian kaolinite clay: batch and column techniques. *American Journal of Applied Chemistry*, 6(1), 25-34.

Anyanwu, B. O., Ezejiofor, A. N., Igweze, Z. N., and Orisakwe, O. E. (2018). Heavy metal mixture exposure and effects in developing nations: an update. *Toxics*, 6(4), 65.

Arabzai, A., and Honma, S. (2014). Adsorption and transport of heavy metal ions in saturated soils. *Proceedings of the School of Engineering*, *Tokai University*, 39, 27-32.

Bagul, V. R., Shinde, D. N., Chavan R. P., Patil, C. L., and Pawar, R. K. (2015). New perspective on heavy metal pollution of water. *Journal of Chemical and Pharmaceutical Research,* 7(12), 700-705.

Bhakta, J. N., and Munekage Y. (2013). Identification of potential soil adsorbent for the removal of hazardous metals from aqueous phase. *International Journal of Environmental Science and Technology*, 10, 315-324.

Bono, A., Ramlan, N. A., Anisuzzaman, S. M., Chu, C. M., and Farm, Y. Y. (2016). Adsorption isotherm of non-azeotropic solution onto porous adsorbents. *Earth and Environmental Science*, 36, 012021.

Bono, A., Ramlan, N. A., Krishnaiah, D., Yadin, N., Chu, C. M., and Farm, Y. Y. (2014). Interpretation of adsorption isotherm of non-azeotropic mixture onto porous adsorbents. *Journal of Applied Sciences,* 14(23), 3300-3305.

Bono, A., Sarbatly, R., Krishnaiah, D., San, P. M., and Yan F. Y. (2008). Effect of ultrasound on liquid phase adsorption of azeotropic and non-azeotropic mixture. *Catalysis Today*, 131(1-4), 472-476.

Budianta, W. (2011). Adsorption of heavy metal by natural clayey soil. *Journal of Southeast Asian Applied Geology*, 3(1), 72-75.

Ding, Y. Z. (2019). Heavy metal pollution and transboundary issues in ASEAN countries. *Water Policy*, 21(5), 1096-1106.

Draszawka-Bołzan, B. (2017). Effect of pH and soil environment. *World News of Natural Sciences,* 8, 50-60.

Ghasemi-Fasaei, R., Gafari-Haghighi, M., Mousavi, S. M., and Dehghan, M. (2012). Sorption characteristics of heavy metals onto natural zeolite of clinoptilolite type. *International Research Journal of Applied and Basic Sciences*, 3(10), 2079-2084.

Hu, H., Jin, Q., and Kavan, P. (2014). A study of heavy metal pollution in China: current status, pollution-control policies and countermeasures. *Sustainability*, 6(9), 5820-5838.

Jiang, M. Q., Jin, X. Y., Lu, X. Q., and Chen, Z. L. (2010). Adsorption of Pb(II), Cd(II), Ni(II) and Cu(II) onto natural kaolinite clay. *Desalination*, 252(1-3), 33-39.

Kippling, J. J. (1965). *Adsorption from solutions of non-electrolytes*, London: Academic Press, pp. 32-62.

Kome, G. K, Enang, R. K., Tabi, F. O., and Yerima, B. P. K. (2019). Influence of clay minerals on some soil fertility attributes: a review. *Open Journal of Soil Science*, 9(9), 155-188.

Masindi, V., and Muedi, K. L. (2018). Environmental contamination by heavy metals. In *Heavy Metals* (Saleh, H. M., and Aglan, R. F., Eds.), pp. 115-133, London: IntechOpen.

Mustapha, S., Ndamitso, M. M., Abdulkareem, A. S., Tijani, J. O., Mohammed, A. K., and Shuaib, D. T. (2019). Potential of using kaolin as a natural adsorbent for the removal of pollutants from tannery wastewater. *Heliyon*, 5, e029232.

Müllerová, H., Kruml, O., Vybíhal, K., Zeman, J., and Müller, P. (2003). Adsorption of copper and cadmium from aqueous solution by various types of sediments under static and dynamic conditions. *Bulletin of Geosciences*, 78(3), 169-178.

Oluyemi, E. A., and Olabanji, I. O. (2011). Heavy metals determination in some species of frozen fish sold at Ile-

Ife main market, Southwest Nigeria. *Ife Journal of Science*, 13(2), 355-362.

Sankhla, S. M., Kumari, M., Nandan, M., Kumar, R., and Agrawal, P. (2016). Heavy metals contamination in water and their hazardous effect on human health-a review. *International Journal of Current Microbiology and Applied Sciences,* 5(10), 759-766.

Song, X., Zhang, Y., Yan, C., Jiang, W., and Chang, C. (2013). The Langmuir monolayer adsorption model of organic matter into effective pores in activated carbon. *Journal of Colloid and Interface Science*, 389(1), 213-219.

Srivastava, P., Singh, B., and Angove, M. (2005). Competitive adsorption behavior of heavy metals on kaolinite. *Journal of Colloid and Interface Science,* 290(1), 28-38.

Taghipour, H., Mosaferi, M., Armanfar, F., and Gaemmagami, S. J. (2013). Heavy metals pollution in the soils of suburban areas in big cities: a case study. *International Journal of Environmental Science and Technology*, 10, 243-250.

Tan, W. H., Surugau, N., and Bono, A. (2018). Heavy metal retention on agricultural soil. *ASM Science Journal,* 11(2), 149-155.

Tan, W. H., Surugau, N., Bahrun, M. H. V., and Bono, A. (2021). Heavy metal Cu(II) and Pb(II) retention on clay soil. In *Proceedings of the Seminar on Science and Technology 2021*, pp. 42-44, Sabah, Malaysia.

Vodyanitskii, Y. N. (2013). Determination of the oxidation states of metals and metalloids: an analytical review. *Eurasian Soil Science*, 46(12), 1139-1149.

Yahya, Al. N., Mohamed, S. K., and Mohamed, A. G. (2018). Environmental pollution by heavy metals in the aquatic ecosystems of Egypt. *Open Access Journal of Toxicology*, 3(1), 555603.