Adsorption Isotherms and Kinetics of Lead and Cadmium Ions: Comparative Studies Using Modified Melon (*Citrullus colocynthis*) Husk

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**ABSTRACT**

Growth in population has caused a corresponding increase in agricultural production which consequently led to an increase in agricultural wastes or byproducts. This is sometimes difficult to manage and may pose a menace to the society if not properly disposed. Hence, this research investigated the efficacy of utilizing agricultural byproduct (melon husk) in removing Pb2+ and Cd2+ from wastewaters so as to prevent their deleterious impact on ecosystem and public health. This was achieved by treating tannery effluents with melon husks modified with H2PO4, NaOH and CH3N2O among others. Results showed that, the Freundlich and Langmuir adsorption capacities on the modified melon husks ranged from 0.1403 – 1.551 mg/g and 0.1499 – 0.6013 mg/g, respectively. Also, the R² values for Pseudo 1st and 2nd order rate constants ranged from 0.0272 – 0.2391 and 0.9112 – 0.9958, respectively. Hence, it was concluded that the modified melon husks followed Freundlich isotherm model as well as Pseudo-2nd order kinetics and could be effectively used to remove Pb2+ and Cd2+ from wastewater.

**INTRODUCTION**

The impact of heavy metals in wastewaters or effluents has long been identified by various researchers. Hence, several conventional techniques of removing heavy metals from effluents have been developed in order to reduce or avoid its impacts. However, most of these techniques like chemical precipitation, ion exchange, membrane filtration as well as electrolytic recovery are all associated with both technical and economic constraints in developing countries thus, limiting their usages [1, 2]. Among the various heavy metals, Mercury (Hg), Lead (Pb) and Cadmium (Cd) are known to be highly toxic. This is because the United States Environmental Protection Agency (USEPA) established their maximum permissible limits to be very low compared to others as could be observed in Table 1. Hence, priority should be given to these metals in order to evade their lethal effects. Nevertheless, Lead ion (Pb2+) and Cadmium ion (Cd2+) have been identified of having high concentrations in tannery effluents [3, 4].

Some researchers have worked on the use of agricultural byproducts like coconut shell, maize cob, orange peels, cassava peels, rice husk and banana peels in removing heavy metals from wastewaters [5–10]. However, very little has been done using melon (*Citrullus colocynthis*) husk. Besides, *Citrullus colocynthis* (Figure 1a) is highly demanding in West-African countries (developing countries) especially Nigeria since the seeds (Figure 1b) are used in preparing a special delicacy known as “egusi soup” after threshing. This encourage commercial cultivation of *Citrullus colocynthis* in the mentioned countries. However, the husks or chaffs left after threshing the seeds (Figure 1c) are often considered as waste. Moreover, numerous studies have reported that adsorbent capacity on metal ions could be boosted by treating it with phosphoric acid (H3PO4), sodium hydroxide (NaOH) and urea (CH3N2O) among others [11–13]. Hence, it is important to investigate the efficacy of using the modified form of this abundant byproduct of *Citrullus colocynthis*, in adsorbing Pb2+ and Cd2+ in tannery effluents, which have been reported to have high concentrations of the said metals [3].

**MATERIALS AND METHOD**

**Preparation and modification of adsorbent**

Husks (chaffs) of *Citrullus colocynthis* seeds were obtained from marketers in Sabon Gari Market, Zaria-Nigeria (11°6’24.99”N, 7°43’30.83”E) thereafter, metallic objects in the husks were removed with the aid of a bare magnet. This was done in order to ensure that the husks were free from materials that may create extra metallic ions. Surface
Modification with phosphoric acid (H₃PO₄) was accomplished by soaking 2g of the milled, washed and dried husks of melon (Citrullus colocynthis) in 2 ml of 0.1M H₃PO₄ for a period of 12 hours in a crucible. Thereafter, the crucible and its content were heated at 500°C in a muffle furnace for 15 minutes. This was followed by washing it with 0.5M sodium bicarbonate (NaHCO₃) until the pH of the liquor was fairly neutral within the range of 6-7. It was further pulverized and sieved through 250μm mesh after rinsed with distilled water and oven dried at 105°C for 12 hours.

The ground treated husk was dried for a period of one week in an airtight container for utilization. However, modification with phosphoric acid (H₃PO₄) was accomplished by soaking 2g of the milled, washed and dried husks of melon (Citrullus colocynthis) in 2 ml of 0.1M H₃PO₄ for a period of 12 hours in a crucible. Thereafter, the crucible and its content were heated at 500°C in a muffle furnace for 15 minutes. This was followed by washing it with 0.5M sodium bicarbonate (NaHCO₃) until the pH of the liquor was fairly neutral within the range of 6-7. It was further pulverized and sieved through 250μm mesh after rinsed with distilled water and oven dried at 105°C for 24 hours. The 250μm sieved particles were stored in an airtight container as melon husk modified with H₃PO₄. Similarly, modification with sodium hydroxide (NaOH) was attained by oven heating 500g of the ground melon husk continuously in 0.5M NaOH for a period of 6 hours and then, filtered and washed thoroughly with distilled water until the supernatant became clear. Afterward, it was soaked in 1% formaldehyde (CH₂O) at 50°C for a period of 4 hours to prevent any further colour interference during activation [15]. Excess CH₂O was removed by rinsing with distilled water, drained and oven dried for 24 hours at 80°C. The ground treated husk was further pulverized and 250μm sieve particles were collected and stored in an airtight container. However, modification with urea (CH₂N₂O) was accomplished by soaking 100g of the ground melon husks in 10% CH₃N₂O solution for 24 hours. It was filtered and sun-dried for a period of one week for 6 hours on daily basis thereafter, further milling (grinding) was done and 250μm sieve particles were collected and stored in an airtight container for utilization.

**Collection of adsorbates**

The adsorbate used in this research was tannery effluents obtained in sample bottles at the Nigerian Institute of Leather and Science Technology, Zaria (11°9'26.65"N, 7°39'24.81"E). However, filtration of the tannery effluents was done before collection into the sample bottles in order to remove suspended particles. Samples were labeled and transported in a cooler containing ice to the laboratory thereafter, they were stored in a refrigerator until analysis. This was done in order to prevent bacterial proliferation which could alter the result [16]. Prior to sampling, the sample bottles were washed with 10% nitric acid (HNO₃), thoroughly rinsed with distilled water and allowed to dry. Notwithstanding, the bottles were further rinsed with the sample been sampled [17].

**Adsorbate (effluent) treatment**

The adsorbates (tannery effluents) were taken out from the refrigerator and allowed to attain room temperature (20-25°C) thereafter, it was thoroughly agitated and 250ml was poured into a conical flask. A weighing balance (FAJA series, made by HANNA LTD, England) was used in measuring 3g of the adsorbent into the conical flask and it was again agitated for proper mixing of both adsorbate and adsorbent. A set of 11 conical flasks of capacity 100ml (labelled as 0, 10, 20, 30, ..., 100) were arranged and 20ml of the mixture were measured into each of the conical flasks arranged. The first 20ml sample labelled ‘0’ was quickly filtered at zero (0) minute interval

### TABLE 1. Permissible limits for most toxic heavy metals

| Heavy metal | Impact | USEPA limit (mg/l) |
|-------------|--------|--------------------|
| Arsenic (As) | Skin manifestations, visceral cancers, vascular disease | 0.05 |
| Cadmium (Cd) | Kidney damage, renal disorder, human carcinogen | 0.01* |
| Chromium (Cr) | Headache, diarrhea, nausea, vomiting, carcinogen | 0.05 |
| Copper (Cu) | Liver damage, Wilson disease, insomnia | 0.25 |
| Nickel (Ni) | Dermatitis, nausea, chronic asthma, coughing, human carcinogen | 0.20 |
| Zinc (Zn) | Depression, lethargy, neurological signs and nervous system | 0.80 |
| Lead (Pb) | Damage the fetal brain, diseases of the kidneys, circulatory system and nervous system | 0.006* |
| Mercury (Hg) | Rheumatoid arthritis, diseases of the kidneys, circulatory system and nervous system | 0.00003* |

* = extremely toxic compared to others [14]

**Figure 1.** Plate (a). Citrullus colocynthis fruits, plate (b). Citrullus colocynthis seeds, plate (c) Citrullus colocynthis seed husks
using filter paper (whatman). This was done in order to serve as control for the sake of determining initial concentration of adsorbate (i.e. at time t = 0). Adsorption of metals in adsorbate by adsorbent have been reported to be affected by duration of stirring the mixture [15]. Hence, the remaining 20ml samples were stirred simultaneously in different magnetic stirrers at different duration as 10, 20, 30, …, 100 min, respectively.

Adsorbent dosages were varied at 0.2, 0.4, 0.6, 0.8 and 1.0g at constant adsorbate concentration and stirring duration (contact time). Likewise, concentrations of the adsorbate (effluent) were varied (using distilled water) at constant dose of adsorbent and stirring duration. The concentrations of Pb$^{2+}$ and Cd$^{2+}$ in all the experimental conditions for the treated adsorbate (effluents) were determined through atomic adsorption spectrometer (model number: AAS 500, made by Fredon Ltd, USA).

**Adsorption isotherm studies**

Freundlich and Langmuir models are known to be the most commonly used isotherms models on activated carbon in water and wastewater treatment [18, 19]. Hence, this research considered the said models on the adsorption isotherm studies. The amount of metallic ions adsorbed on the various modified adsorbents ($q_i$) was determined through Equation (1) as stated below:

$$q_i = \frac{V}{M} (C_0 - C_i)$$  \hspace{1cm} (1)

In equation (1), $V$ is the volume of adsorbate in litres, $M$ is the mass of adsorbent in gram, $C_0$ is the initial concentration of metallic ions in adsorbate in mg/l and $C_i$ is the concentration of metallic ions remaining in adsorbate at a given time $t$ in mg/l. In addition, the concentrations of adsorbate observed not have to change with time in the various adsorption processes were recorded as equilibrium concentrations ($C_e$). The adsorption isotherm governing the removal of both metallic ions (Pb$^{2+}$ and Cd$^{2+}$) from the adsorbate by the various modified adsorbents was known by plotting graphs of log $q_i$ against log $C_e$ (for Freundlich model) and $\frac{1}{q_i}$ against $\frac{1}{C_e}$ (for Langmuir model). Thereafter, the best-fitted equations of the plots were compared with the linearized forms of Freundlich and Langmuir isotherm models, which lead to the determination of adsorption capacities. The model that gave higher values of coefficient of determination ($R^2$) was recorded as the adsorption isotherm governing the adsorption process. The linearized form of Freundlich isotherm model is given in Equation (2) as follows:

$$\log q_i = \frac{1}{n} \log C_e + \log k_f$$  \hspace{1cm} (2)

where: $q_i$ is the amount of ions adsorbed on adsorbent in (mg/g), $C_e$ is the equilibrium concentration (mg/l), $k_f$ is the Freundlich constant, which indicate adsorption capacity of adsorbent (mg/g), $n$ is the Freundlich constant which indicate adsorption intensity (g/L). On the other hand, the linearized form of Langmuir isotherm model is given in Equation (3) below:

$$\frac{1}{q_i} = \frac{1}{q_m k} \left( \frac{1}{C_e} \right) + \frac{1}{q_m}$$  \hspace{1cm} (3)

In Equation (3), $q_i$ is the amount of ions adsorbed on adsorbent in (mg/g), $C_e$ is the equilibrium concentration (mg/l), $q_m$ is the monolayer adsorption capacity at equilibrium (mg/g) and $k$ is the Langmuir equilibrium constant (l/mg).

**Adsorption kinetics studies**

The amount of ions adsorbed at equilibrium (mg/g) at different contact time $t$ were determined and recorded as $q_e$ through Equation (4) stated below:

$$q_e = \frac{V}{M} (C_0 - C_e)$$  \hspace{1cm} (4)

All symbols in Equation (4) remain the same as previously explained. Graphs were plotted based on the linearized forms of Pseudo 1st and 2nd order kinetics. The rate constants of adsorption were determined by comparing the equation of the best-fitted plots with the linearized forms of Pseudo 1st and 2nd order kinetics given in Equations (5) and (6), respectively.

$$\log(q_e - q_i) = -k_1 t + \log q_e$$  \hspace{1cm} (5)

$$\frac{1}{q_i} = \frac{1}{q_e} (t) + \frac{1}{k_2 q_e^2}$$  \hspace{1cm} (6)

In Equations (5) and (6), $k_1$ and $k_2$ are the rate constants of Pseudo 1st and 2nd order adsorption in min$^{-1}$ and g.mg$^{-1}$.min$^{-1}$, respectively; while, other symbols remain the same as previously explained. The order of kinetics that governs the adsorption process was identified through the coefficient of determination ($R^2$) values associated with the equation of best-fitted plots.

**RESULTS AND DISCUSSION**

**Freundlich adsorption isotherm**

The adsorption capacity ($k_f$) and intensity ($n$) of the various adsorbent used were determined by plotting log $q_i$ (amount of ions adsorbed on adsorbent in mg/g) against log $C_e$ (equilibrium concentration in mg/l) for the various adsorbent applied. This is demonstrated in Figure 2 by considering Pb$^{2+}$ adsorbed by melon husk modified with phosphoric acid (H$_3$PO$_4$).

By comparing the equation displayed in Figure 2 and the standard Freundlich isotherm model given in Equation (2), implies that the gradient ($\frac{(1)}{n}$) of Equation (2) is equivalent to 0.5681 in Figure 2. That is; $\frac{(1)}{n} = 0.5681$ and $n = 1.76$.
Similarly, the intercept \((\log k_f)\) of Equation (2) is equivalent to the intercept of the equation displayed in Figure 2. That is; 
\[
\log k_f = -0.2209 \implies k_f = 10^{-0.2209} = 0.6
\]
In other words, the adsorption capacity \((k_f)\) of melon husk modified with phosphoric acid \((H_3PO_4)\) on Pb\(^{2+}\) is 0.6 mg/g while the intensity \((n)\) is 1.76 g/L. The Freundlich constants \(k_f\) and \(n\) for the other adsorbents were calculated in the same way and their values are summarized in Table 2.

**Langmuir adsorption isotherm**

The Langmuir monolayer adsorption capacity \((q_m)\) and the equilibrium constant \((k)\) of the adsorbents were obtained by plotting the reciprocals of the amount of ions adsorbed \((\frac{1}{q_e})\) against the reciprocals of equilibrium concentration \((\frac{1}{c_e})\). This is illustrated in Figure 3 by considering the case of Pb\(^{2+}\) adsorbed by melon husk modified with phosphoric acid \((H_3PO_4)\).

Comparing the equation displayed in Figure 3 and the standard Langmuir isotherm model given in Equation (3), it could be inferred that the intercept; \(\frac{1}{q_m} = 4.1929 \implies q_m = 0.2385\)

Also, the gradient; \(\frac{1}{34.9992k} = 34.9992 = \implies k = \frac{1}{34.9992q_m} = \frac{1}{34.9992(0.2385)} = 0.1198\)

In other words, the Langmuir monolayer adsorption capacity \((q_m)\) and equilibrium constant \((k)\) for Pb\(^{2+}\) adsorbed by melon husk modified with urea \((H_3PO_4)\) are 0.2835 mg/g and 0.1198 l/mg, respectively. The Langmuir constants \((q_m\) and \(k)\) of all the adsorbents considered were determined in the same way and their values are shown in Table 3.

By comparing Figures 2 and 3, it is conspicuous that the data points fit more into the Freundlich model than Langmuir model. This observation was also noted for the other experimental conditions. Thus, buttressing the reason why higher values of coefficient of determination \((R^2)\) were recorded in Table 2 compared to Table 3. In other words, the reason why the data points in Figure 3 (Langmuir model) did not fit into the regression line is because the adsorption process followed Freundlich isotherm model not Langmuir isotherm model. This is in line with previous research [20]. Hence, the adsorption of Pb\(^{2+}\) and Cd\(^{2+}\) occurred on heterogeneous surfaces not homogenous monolayer. Furthermore, the adsorption capacities for both Freundlich \((k_f)\) and Langmuir \((q_m)\) models were higher in Pb\(^{2+}\) than Cd\(^{2+}\) under the same condition thus, suggesting that Pb\(^{2+}\) were more easily adsorbed by the different modified melon husks. This affirmed the assertions of some earlier related studies [21, 22].

**Pseudo-1st order adsorption kinetics**

The rate constant \((k_1)\) of Equation (5) was determined by plotting \(\log(q_e - q_t)\) against contact time \(t\) and the gradient obtained was equal to \(-k_1\). This is illustrated in Figure 4 by considering Pb\(^{2+}\) adsorbed by melon husk modified with phosphoric acid \((H_3PO_4)\). The comparison between the standard linearized model for Pseudo-1st order kinetics given in Equation (5) and the equation displayed in Figure 4 revealed that; \(-k_1 = -0.0128\) i.e. \(k_1 = 0.0128\)

Hence, the rate constant \((k_1)\) of Pseudo-1st order kinetics for Pb\(^{2+}\) adsorbed by melon husk modified with phosphoric acid \((H_3PO_4)\) is 0.0128 min\(^{-1}\). The same method was employed in all the adsorbents for both metal ions \((Pb^{2+}\) and \(Cd^{2+})\) and their rate constants \((k_1)\) as well as coefficients of determination \((R^2)\) are shown in Table 4. However, the data

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**TABLE 2. Freundlich adsorption constants for melon husks modified with H3PO4, NaOH and CH3N2O**

|                  | Lead ions (Pb\(^{2+}\)) | Cadmium ions (Cd\(^{2+}\)) |
|------------------|--------------------------|----------------------------|
|                  | \(k_f\) (mg/g) | \(n\) (g/l) | \(R^2\) | \(k_f\) (mg/g) | \(n\) (g/l) | \(R^2\) |
| \(H_3PO_4\)      | 0.6013       | 1.7603       | 0.8984   | 0.4417       | 1.6111       | 0.7604   |
| \(NaOH\)         | 0.4644       | 1.4914       | 0.8433   | 1.2650       | 1.1527       | 0.4709   |
| \(CH_3N_2O\)     | 0.3809       | 1.3305       | 0.9713   | 0.3169       | 1.0204       | 0.7028   |

**TABLE 3. Langmuir adsorption constants for melon husks modified with H3PO4, NaOH and CH3N2O**

|                  | Lead ions (Pb\(^{2+}\)) | Cadmium ions (Cd\(^{2+}\)) |
|------------------|--------------------------|----------------------------|
|                  | \(q_m\) (mg/g) | \(k\) (l/mg) | \(R^2\) | \(q_m\) (mg/g) | \(k\) (l/mg) | \(R^2\) |
| \(H_3PO_4\)      | 0.2385       | 0.1198       | 0.4871   | 0.1962       | 0.1131       | 0.5733   |
| \(NaOH\)         | 0.1874       | 0.1129       | 0.3426   | 0.1551       | 0.1086       | 0.6892   |
| \(CH_3N_2O\)     | 0.1499       | 0.1106       | 0.6612   | 0.1403       | 0.1002       | 0.5545   |
points in all the cases involving Pseudo-1st order kinetics, did not fit into their various regression lines as could be seen in Figure 4. This made the associated R² values shown in Table 4 to be very small. Since the data points did not fit into the regression line, it suggests that the adsorption process did not follow Pseudo-1st order kinetics.

**Pseudo-2nd order adsorption kinetics**

The gradient and intercept of Equation (6) were determined through the plot shown in Figure 5. The comparison between the standard linearized model for Pseudo-2nd order kinetics given in Equation (6) and the equation displayed in Figure 5, inform that the gradient: \( k_2 = \frac{1}{q_e} = 13.698 \) and \( q_e = 0.073 \)

Similarly, the intercept: \( \frac{1}{k_2q_e^2} = 50.087 \Rightarrow \frac{1}{k_2(0.0730^2)} = 50.087 ; k_2 = \frac{1}{50.087} = 3.7465 \)

In other words, the Pseudo-2nd order rate constant \( k_2 \) for the adsorption of Pb²⁺ by melon husk modified with phosphoric acid (H₃PO₄) is 3.7465 g.mg⁻¹.min⁻¹. The Pseudo-2nd order rate constants for the remaining adsorbents were determined in likewise manner and their values are summarized in Table 5. Unlike Figure 4 (Pseudo-1st order kinetics), the data points in Figure 5 (Pseudo-2nd order kinetics) fitted well in the regression line. Consequently, it explains the reason why the associated R² value in Figure 5 is high. This observation was also noted in the remaining adsorbent as could be seen in Table 5. In other words, the fitness of the data points in the regression line for cases involving Pseudo-2nd order kinetics simply implies that the adsorption process in the various adsorbent obeyed Pseudo-2nd order rate expression, which is in consonance with previous observations [20–23].

**TABLE 5. Pseudo-2nd order rate constant for Pb²⁺ and Cd²⁺ sorption by modified melon husks**

| Lead ions (Pb²⁺) | \( k_2 (\text{g.mg}^{-1}.\text{min}^{-1}) \) | R² | Cadmium ions (Cd²⁺) | \( k_2 (\text{g.mg}^{-1}.\text{min}^{-1}) \) | R² |
|-----------------|-----------------------------|---|---------------------|-----------------------------|---|
| H₃PO₄           | 3.7465                      | 0.9319 |                      | 0.09431                    | 0.6224 |
| NaOH            | 0.8784                      | 0.9958 |                      | 11.1857                    | 0.7657 |
| CH₃N₂O         | 1.0136                      | 0.9112 |                      | 11.6174                    | 0.7043 |

**CONCLUSION**

On the basis of the analyzed data, it could be concluded that melon husk modified with either H₃PO₄, NaOH or CH₃N₂O could be effectively used in the removal of Pb²⁺ and Cd²⁺ from wastewater as their adsorption capacities were quite high. However, modification with H₃PO₄ performed best. The adsorption of Pb²⁺ and Cd²⁺ by melon husk modified with either H₃PO₄, NaOH or CH₃N₂O followed Freundlich isotherm model as well as Pseudo-2nd order adsorption kinetics. In addition, melon husks modified with either H₃PO₄, NaOH or CH₃N₂O adsorbed more lead ions (Pb²⁺) than cadmium ions (Cd²⁺) under the same experimental condition. Hence, it is recommended that whenever the need...
of using modified melon husk to adsorb metal ions from effluent arises, modification with H₂PO₄ should be considered first before NaOH and CH₃N₂O.

REFERENCES

1. Yahaya, I.E. and Akinlabi, A.K., 2016. Equilibrium sorption of Lead (II) in aqueous solution onto EDTA-modified Cocoa (Theobroma cacao) Pod husk residue. Iranian (Iranica) Journal of Energy and Environment, 7(1): 58-63.
2. Yunus, Z.M., Othman, N., Hamdan, R. and Ruslan, N.N., 2017. Honeydew Rind Activated Carbon as an Adsorbent for Zn (II) and Cr (III) Removal from Aqueous Solution: An Optimization Study. Pertanika Journal of Science & Technology, 25(10): 155-162.
3. Parveen, S., Bharose, R. and Singh, D., 2017. Assessment of physico-chemical properties of tannery waste water and its impact on fresh water quality. International Journal of Current Microbiology and Applied Sciences, 6(4): 1879-1887.
4. Joel, M.A.L., Syed, S.A. and Dey, T.K., 2017. Assessment of Kinetic Coefficients for Chrome Tannery Wastewater Treatment by Activated Sludge System. Iranian (Iranica) Journal of Energy and Environment, 8(1): 56-60.
5. Gogda, A.A., Patidar, R. and Reba, S., 2015. Adsorption of Sr²⁺ from saline sources by coconut shell charcoal. Journal of Dispersion Science and Technology, 36(8): 1162-1167.
6. Malthang, J.M., Simate, G.S. and de Beer, M., 2018. Adsorption of Ma⁺ from the Acid Mine Drainage using banana peel. International Journal of Water and Wastewater Treatment, 4(1): 153-159.
7. Duru, C.E. and Duru, L.A., 2017. Adsorption capacity of maize biomass parts in the remediation of Cu²⁺ ion polluted water. World News of Natural Sciences, 12: 51-62.
8. Adebayo, G.B., Mohammed, A.A. and Sokoya, S.O., 2016. Biosorption of Fe (II) and Cd (II) ions from aqueous solution using a low cost adsorbent from orange peels. Journal of Applied Sciences and Environmental Management, 20(3): 702-714.
9. Schwantes, D., Gonzalves, A.C., Coelho, G.F., Campagnolo, M.A., Dragunski, D.C., Tarley, C.R.T., Miola, A.J. and Leismano, E.A.V., 2016. Chemical modifications of cassava peels as an adsorbent for various heavy metals. Journal of Chemistry, 2016: 1-15.
10. Vieira, M.G.A., de Almeida Neto, A.F., Da Silva, M.G.C., Carneiro, C.N. and Melo Filho, A.A., 2014. Adsorption of lead and copper ions from aqueous effluents on rice husk ash in a dynamic system. Brazilian Journal of Chemical Engineering, 31(2): 519-529.
11. Mohammad, N.K., Ghaemi, A. and Tahvildari, K., 2019. Hydroxide modified activated alumina as an adsorbent for CO₂ adsorption: experimental and modeling. International Journal of Greenhouse Gas Control, 88: 24-37.
12. Delghani, M.H., Tajik, S., Panahi, A., Khezri, M., Zarei, A., Heidarinejad, Z. and Yousefi, M., 2018. Adsorptive removal of nosium acuid from aqueous solutions using poly urea-formaldehyde: a novel polymer adsorbent. MethodsX, 5: 1148-1155.
13. Wu, L., Wan, W., Shang, Z., Gao, X., Kobayashi, N., Luo, G. and Li, Z., 2018. Surface modification of phosphoric acid activated carbon by using non-thermal plasma for enhancement of Cu (II) adsorption from aqueous solutions. Separation and Purification Technology, 197: 156-169.
14. USEPA, 2018. Drinking Water Standards and Advisory Tables. United State Environmental Protection Agency, Washington, D.C., USA.
15. Bouilla-Petriciolet, A., Mendoza-Castillo, D.I. and Reynel-Avila, H.E., 2017. Adsorption processes for water treatment and purification. Cham (Switzerland): Springer.
16. APHA. 2012. Standard Methods for Examination of Water and Wastewater (25th Edition). American Public Health Association, Washington, D.C., USA.
17. Ogbozige, F.J., Ibrahim, F.B. and Adie, D.B., 2018. Drinable Water Stored in Hot Climates: Interactions among Water Quality Parameters. Arid Zone Journal of Engineering, Technology and Environment, 14(3): 389-390.
18. Sirajo, L., Musa, L. and Ndanna, I.A., 2018. Determination of Adsorption Kinetics of Coconut Husk Adsorbent for Heavy Metals Removal Using Langmuir and Freundlich Isotherm Expressions. International Journal of Research – Granthaalaya, 6(10): 87-94.
19. Bagheri, M., Nasiri, M., Talaiekhozani, A. and Abedi, L., 2018. Equilibrium Isotherms of Formaldehyde Elimination from the Aqueous Solutions Containing Natural Adsorbents of Rice Bran and the Resulting Ashes. Journal of Human, Environment and Health Promotion, 4(2): 87-93.
20. Suyamboo, B.K. and Perumal, R.S., 2012. Equilibrium, thermodynamic and kinetic studies on adsorption of a basic dye by Citrullus lanatus rind. Iranian (Iranica) Journal of Energy & Environment, 3(1): 23-34.
21. Liu, X., Xu, X., Dong, X. and Park, J., 2020. Competitive adsorption of heavy metal ions from aqueous solutions onto activated carbon and agricultural waste materials. Polish Journal of Environmental Studies, 29: 749-761.
22. Li, W., Liao, X., Wang, L. and Huang, Z., 2019. Adsorption of cadmium and lead in wastewater by four kinds of biomass xanthates. Water Science and Technology, 79(6): 1222-1230.
23. Banerjee, K., Ramesh, T., Gandhimathi, R., Nidheesh, P.V. and Bharathi, K.S., 2012. A novel agricultural waste adsorbent, watermelon rind. Journal of Human, Environment and Health Promotion, 4(105): 155-159.
24. Heidarinejad, Z. and Yousefi, M., 2018. Adsorptive removal of noxious and harmful dyes from aqueous solutions using palm waste. Journal of Applied Sciences and Environmental Management, 22(9): 1199-1204.
25. Li, X., Xu, X., Dong, X. and Park, J., 2020. Competitive adsorption of heavy metal ions from aqueous solutions onto activated carbon and agricultural waste materials. Polish Journal of Environmental Studies, 29: 749-761.
26. Li, W., Liao, X., Wang, L. and Huang, Z., 2019. Adsorption of cadmium and lead in wastewater by four kinds of biomass xanthates. Water Science and Technology, 79(6): 1222-1230.
27. Banerjee, K., Ramesh, T., Gandhimathi, R., Nidheesh, P.V. and Bharathi, K.S., 2012. A novel agricultural waste adsorbent, watermelon rind. Journal of Human, Environment and Health Promotion, 4(105): 155-159.
28. Heidarinejad, Z. and Yousefi, M., 2018. Adsorptive removal of noxious and harmful dyes from aqueous solutions using palm waste. Journal of Applied Sciences and Environmental Management, 22(9): 1199-1204.
29. Li, X., Xu, X., Dong, X. and Park, J., 2020. Competitive adsorption of heavy metal ions from aqueous solutions onto activated carbon and agricultural waste materials. Polish Journal of Environmental Studies, 29: 749-761.