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Selangor Science &Technology Review
Special Issue: Applied Science & Mathematics
Vol. 6, No. 2, (2022)

Removal of Copper Ion From Aqueous Solution Using Biosorbent Derived from Banana Pseudo Stem

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Abstract: This study investigated the potential of banana pseudo stem to remove copper ion from aqueous solution. The raw banana pseudo stem was washed, cut, dried and ground into powder to convert it into biosorbent. Batch copper adsorption experiments were performed in order to determine the optimum condition of the parameter. The influence of copper ion adsorption parameters including initial copper ion solution concentration (100 - 350 mg/L), adsorbent dosage (0.1 g - 0.6 g), pH (2 - 10), contact time (60 - 270 min) and temperature (30 – 60 °C) were evaluated. According to the batch experiment, the optimum value was found as initial copper ion concentration at 300 mg/L, adsorbent dosage at 0.1 g, solution pH at 8, contact time at 210 min and temperature of 55 °C. The removal efficiency of copper ion using banana pseudo stem was achieved more than 99 % at optimized conditions of influential parameters. Therefore, banana pseudo stems are potentially to be utilized as a new biosorbent material in the removal of copper from water due to high adsorption efficiency and low cost.

Keywords: Adsorption, banana pseudo stem, copper removal, influential parameters.

1. Introduction

Copper is known to be one of the most toxic of heavy metals which can spread easily through living organisms and mostly spread in the environment (Nebagha et al., 2015). Multiple industries such as textiles, electroplating, mining, metallurgy and battery production are the major source of copper pollution in water resources (Xie, Wen, Zhan, & Jin, 2018). For this reason, the pollution of copper in water has become one of the big concerns today worldwide. It is very necessary to develop a new method that is more efficient to maintain heavy metal ion pollution even at a relatively low concentration.

There are many common methods for heavy metal removal from an aqueous solution such as precipitation, solvent extraction, evaporation, cementation, membrane filtration and ion exchange but most of these processes are costly to use (Bagali, Gowrishankar, & Roy, 2017). The adsorption process is one of the effective treatment methods, in the range of pollutants from moderate to low concentrations (Mnasri-Ghnimi & Frini-Srasra, 2019). Conventional adsorbents such as activated carbon, zeolite, silica gels have certain disadvantages including poor adsorption capacity, high cost and tend to oxidize (Wang et al., 2018). For this reason, attention has been given to the natural properties of other non-conventional solid materials proposed as low-cost, efficient and green adsorbents for the removal of inorganic pollutants.

Musa acuminata or known as banana is widely planted especially in tropical countries such as Malaysia. High demand for the production of banana fruit generates more banana pseudo stem residues. After the harvest, the stems are usually dumped in wet conditions or simply burned as waste without proper removal. Without proper management of the abundant banana stems waste, this situation will release high amounts of toxic gases such as carbon dioxide thus leading to environmental problems (Ahmad & Danish, 2018). The fact that these plant materials consist of cellulose which can adsorb heavy metal ions in an aqueous solution

(Seng, 2018). Most research on banana wastes such as leaves, fruits peels, stems, and roots had shown good potential and provide more advantages by their natural properties for the adsorption process compared to other adsorbent materials (Ali, Saeed & Mabood, 2016). This research is attempted to investigate the potential of the banana pseudo stem as biosorbent for the removal of copper ions from aqueous solution.

2. Materials and Methods

2.1 Materials and Chemicals

Banana pseudo stem of *Musa paradisiaca* (pisang berangan) sample was obtained from Ijok, Bestari Jaya. Copper (II) sulfate, $CuSO_4.5H_2O$, HCl and NaOH were purchased from HmbG Chemicals. All the chemicals were analytical reagent grade. Distilled water was used throughout the experiments.

2.2 Preparation of Copper Ion Solution

Copper (II) stock solution of 1000 mg/L was prepared by dissolving 3.93 g of $CuSO_4.5H_2O$ in 1000 mL of distilled water. This stock copper ion solution was then diluted with distilled water to require working initial concentration of copper ion solutions for the batch adsorption experiments [Kasa & Geremew, 2017]. All prepared working copper ion solutions were adjusted to the required pH by using 0.1 M HCl or 0.1 M NaOH.

2.3 Preparation of Banana Pseudo Stem Biosorbent (BSB)

The stem or trunk was cleaned, rinsed, chopped and left to air dried overnight. It was then dried in the oven, 105 °C for 24 hours and reached constant weight [Bagali, Gowrishankar & Roy, 2017]. After that, the dried raw sample was ground using a commercial grinder and continued with sieving for homogenization of particle size using kitchen meshes. Finally, the powder of banana pseudo stem biosorbent (BSB) was kept in an air-closed container and placed in a desiccator for further application [Bagali, Gowrishankar & Roy, 2017].

2.4 Batch Adsorption Study

Adsorption experiments were carried out in batch mode at room temperature to evaluate the removal efficiency of copper ion from aqueous solution using the prepared BSB. Various influential parameters; initial copper ion concentration (100 mg/L – 350 mg/L), adsorbent dosage (0.1 g – 0.6 g), solution pH (2 – 10), contact time (60 min – 270 min) and temperature (30 °C – 60 °C) were investigated for the removal of copper from aqueous solution onto BSB. Batch experiments were carried out using a set of 100 mL of Erlenmeyer flask with 100 mL of appropriate initial concentration of copper ion solution and mixed with a required amount of BSB. Using a shaking incubator (Protech SI 1000D, Malaysia), the mixtures were agitated at a stirring speed of 120 rpm for different time intervals. Then the flasks were withdrawn and the mixtures were filtered using the Whatman 42 filter paper. The residual concentration of copper ion after adsorption was measured by determining the absorbance at the wavelength of 665 nm using a UV-VIS Spectrophotometer (Genesys 20 4001/4 California). Previously, the calibration curve was prepared by diluting the copper ion stock solution into a series of different concentrations of copper ion solutions and the absorbance of each solution was measured at 664 nm. The standard curve of copper ion solution was created by plotting the measured absorbance versus the prepared concentration of the solution. All the experiments were performed in triplicates and standard deviation was presented. The percentage removal of the copper ion was calculated by Eq. (1) as follow:

$$\%R = \frac{(C_0 - C_e)}{C_0} \times 100 \quad (1)$$

where, C_0 and C_e are the initial and final concentrations of copper ion in the solution.

3. Results and Discussion

3.1 Effect of Influential Adsorption Parameters

3.1.1 Initial Concentration

The effect of initial copper ion concentration (ranging from 100 mg/L to 350 mg/L) on the percentage removal was determined by adding 0.10 g of BSB in the working solution at its natural pH (6.8), stirring speed 120 rpm and 24 hours contact time, as shown in Figure 1 (a). Obviously, the percentage removal of copper ions increased with an increasing initial concentration of the metal, which is due to the presence of copper ions to bind onto the active site of BSB (Benzoui, Selatna & Djabali, 2018). However, an equal removal was observed at the initial concentration of copper ion of 300 and 350 mg/L, which confirmed that the adsorption has reached its saturation, as a limited number of available active sites on the BSB surface. At these concentrations, it is predicted that the process of intramolecular diffusion of copper ions took place with little influence of H^+ ions as it was conducted at non-adjusted pH (Kalak, Cierpiszewski & Ulewicz, 2021). Therefore, an initial concentration of copper ion at 300 mg/L was chosen for subsequent optimization study.

3.1.2 Adsorbent Dosage

Figure 1 (b) illustrates the effect adsorbent dosage of BSB with an initial concentration of 300 mg/L in the range from 0.1 g to 0.6 g at natural pH, 120 rpm of stirring speed for 24 hours was studied. From the analysis, an interesting finding was observed, that the lowest dosage showed higher copper ion removal. As a logic, higher adsorbent dosage offers more active sites which help in the removal of metal ions. Similar findings by Buema, Trifas and Harja (2021) explained the higher removal of copper achieved at lower adsorbent dosage as the reduction of the adsorbent surface available to Cu^{2+} ions occurred due to the aggregation or accumulation of binding sites. Findings from Sreedhar and Sakethram Reddy (2019) and Akpomie and Adebowale (2015) also proved that higher metal removal did not reflect good performance in the adsorption capacity. It gives the advantage of being cost-effective as the adsorption can be performed in a low dosage of adsorbent. Therefore, for subsequent analysis, the 0.1 g adsorbent dosage was selected.

3.1.3 Effect of pH

The effect of pH on the adsorption of copper ions was substantial due to the low dosage of BSB which was 0.1 g to 0.6 g (Figure 1 (c)). This can be explained by the fact that at low values of the initial pH, the surface of the biosorbent would be surrounded by the ions H^+ inducing repulsive forces and hence decreasing the interaction of the ions of the copper with the sites of the biosorbent. Thus, insignificant in the adsorption rate at a low pH value can be due to the high concentration and the mobility of the ions H^+. Conversely, at high pH, the concentration of H^+ was decreased and the total surface area of the biosorbent became negatively charged, enhancing the sorption of the copper ion, by means of electrostatic interaction. As a result, the highest percentage removal of copper ions was at pH 8 with approximately 25%. This finding is comparable to that reported by Zamri et al. (2019), even though they studied the removal of methylene blue instead. In accordance with Zafar et al. (2015), the pH of the biosorption process is very crucial as it affects the adsorption efficiency, the surface chemistry of the biosorbent, and metal ion specification. These authors mentioned that the pH radically influences the site dissociation of the biomass surface and the chemistry of the toxic metals in the solution, hydrolysis, complexation by organic or inorganic ligands, precipitation and biosorption availability of the toxic metals, the degree of ionization and the activity of the functional groups in the biomass mainly the carboxylic group.

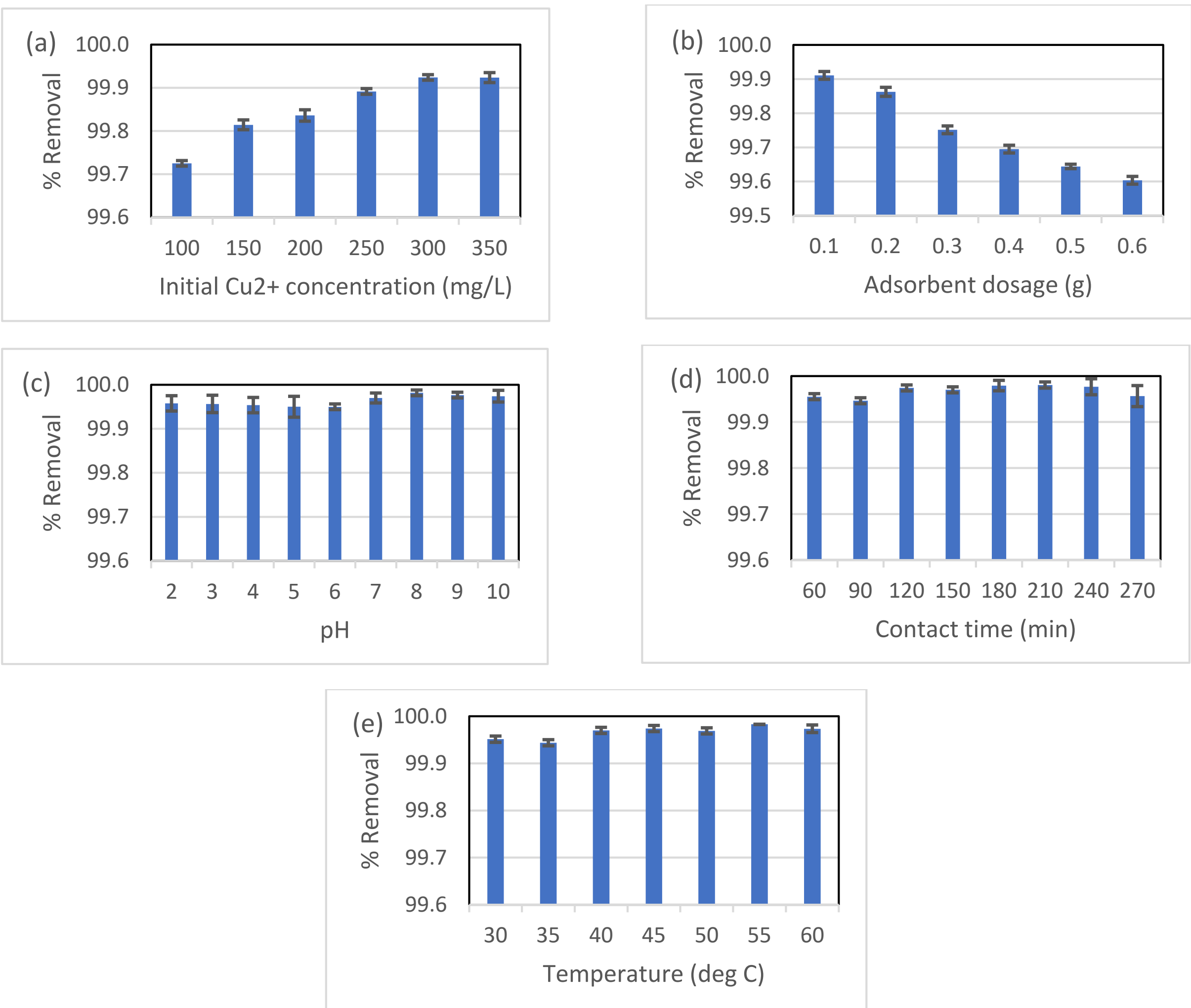

Figure 1. Percentage removal of copper ion from aqueous solution at different influential parameters; (a) initial copper ion concentration (b) adsorbent dosage (c) pH (d) contact time (e) temperature.

3.1.4 Effect of Contact Time

The effect of contact time was investigated at the predetermined optimum parameters of initial concentration at 300 mg/L by using 0.1 g of adsorbent dosage and solution pH of 8. The stirring speed and contact time were set at 120 rpm and 24 hours, respectively. It can be seen in Figure 1 (d) that by increasing the contact time from 60 min to 210 min the percentage removal of copper ions increases. After that, the percentage removal was decreased from 210 min to 270 min. This can be attributed to the availability of sites for the sorbate. In addition, a very high adsorption driving force at the beginning resulted in a higher adsorption rate. After the initial period, slower adsorption may be attributed to the slower diffusion of molecules into the interior pores of the biosorbent, and the molecules subsequently occupy positions within the adsorbent framework. This finding is comparable to the findings reported by Birhanu, Leta and Adam (2020), in which they studied the removal of chromium from synthetic wastewater by adsorption. They observed that the removal of chromium ions was increased from 60 min to 180 min. Then, the removal of chromium ions was decreased as the contact time increased from 180 min to 240 min. This implies that the removal of metal ions will increase as the contact time increases from 1 hour to 3 hours, and will start to decrease beyond 3 hours.

3.1.5 Effect of Temperature

As shown in Figure 1 (e), the effect of temperature on the copper ion adsorption was investigated from 30 °C to 60 °C. The findings show that the removal percentage is gradually increasing from 30 °C to 40 °C which could be the result of acquired energy in the system. This proves that the interaction of ions with the active sites surface of biosorbent is an endothermic process. The endothermic process is also considered as a chemical adsorption process. Later, the temperature is constant from 40 °C to 60 °C.

3.2 Comparison of Removal Efficiency with Various Adsorbents

Comparative analysis on the removal efficiency of copper using biosorbent derived from other agricultural wastes with this study is represented in Table 1. It is noticeable that the utilization of banana pseudo stem biosorbent achieved the highest removal efficiency of copper as compared with other adsorbents. However, the percentage removal was greatly influenced by the characteristic of the adsorbent and different adsorption parameters.

Table 1. Comparison of Cu removal efficiency with various types of adsorbent at different variables.

Adsorbent	Initial concentration (mg/L)	Dosage (g)	pH	Contact time (min)	Temperature (°C)	Removal efficiency (%)	Ref
Banana pseudo stem	300	0.1	8	210	55	99.97	Present
Fir tree sawdust	38	5	4.6	240	23	75.00	Nagy et al., 2016
Rice husk	10	2	6	100	-	98.79	Kasa & Geremew, 2017
Rambutan wood	6	1	6	60	-	65.00	Sidek, Draman & Mohd, 2017
Leucaena Leucocephala pods	50	0.75	8	25	25	97.60	Razak, Zulkepli & Idris, 2020

4. Conclusion

In the present study, the potential of banana pseudo stem as a natural adsorbent (without any treatment) for the removal of copper ions from aqueous solution was successfully carried out. The findings show that the maximum removal efficiency towards the adsorption of copper ions from the aqueous solution is 99.97%. This value is achievable by using the optimized parameters including 300 mg/L of initial concentration, adsorbent dosage at 0.1 g, pH 8, contact time at 210 min and temperature of 55 °C. In conclusion, the usage of raw banana pseudo stem without any treatment is highly recommended in removing copper ions from the aqueous solution.

5. Acknowledgements

The authors would like to express gratitude to the Selangor State Government and Universiti Selangor for providing financial supports through the *Geran Penyelidikan Negeri Selangor* (GPNS/18/01-UNISEL033).

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