

**CAFEi 2012-99**

**ADSORPTION OF CADMIUM (II) IONS FROM AQUEOUS SOLUTION USING  
PALM OIL FLY ASH (POFA)**

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**ABSTRACT**

The aim of this study is to conduct comprehensive studies of Cd (II) ions removal using a low-cost locally available adsorbent which is from agricultural waste. Batch adsorption experiments were conducted for the adsorption of Cd (II) ions from aqueous solution using palm oil fly ash (POFA). The parameters studied include contact time, pH, adsorbent dosage and adsorbate initial concentration. The results showed that the adsorption of Cd (II) ions was very fast initially and equilibration time was achieved after 210 min of contact time. The optimum pH was obtained at pH 9.0. High pH ( $\geq 9.0$ ) favours the adsorption and removal of Cd (II) ions from aqueous solution. As the adsorbent dosage increased, the removal of Cd increased, whereas the adsorption capacity decreased. Higher initial concentration led to lower removal percentages but higher adsorption capacity. The adsorption behavior of Cd (II) ions fitted Langmuir and Freundlich isotherms well, but followed Langmuir isotherm more precisely, with a maximum adsorption capacity and  $R^2$  value of 15.823 mg/g and 1.0 respectively. The applicability of Langmuir isotherm suggested the formation of monolayer coverage of Cd (II) ions at the outer surface of the adsorbent. Therefore, this study demonstrated that POFA could be used successfully for adsorption of Cd (II) ions from aqueous solution.

**Keywords:** *Adsorption, palm oil fly ash, cadmium, aqueous solution, isotherm*

**INTRODUCTION**

Nowadays, heavy metals are amongst the most serious pollutants that becoming a severe public health problem [1]. The increasing use of heavy metals over the past few decades has inevitably led to an increased flux of metallic substances in the environment [2]. Apparently, increasing concentration of heavy metals can cause severe health hazard due to their toxicity, cannot be readily degraded and persistent in nature particularly when it exceeds the permissible limits [3]. Non-essential heavy metals such as cadmium, lead and copper are dangerous for living organisms because they tend to bio-accumulate and in time they cause serious effects to the human health [4]. Cadmium (Cd) is considered to be an extremely toxic metal without known biological function. Cd has been recognized as one of toxic metals and toxicological studies have shown that in long-term effects from cd poisoning includes kidney damage and changes to the constitution of the bone, liver, and blood. Short-term effects include nausea, vomiting, diarrhea, and cramps [3, 5].

Presently, different treatment technologies are available to remove heavy metals from aqueous solution. Several conventional methods such as chemical precipitation, coagulation, reverse osmosis, ion exchange, membrane filtration, oxidation, air stripping, and adsorption have been applied for various wastewater treatment [3, 6]. Apparently, among numerous clean-up techniques for contaminated water, sorption techniques have been proposed as a promising technique used for the removal of diverse contaminants, simple, easy to operate, and is highly effective in removing heavy metals from effluents either with high solute loadings or dilute concentrations [2, 7]. Adsorption of heavy metals using conventional adsorbents such as commercialized activated carbon has been used widely in many applications as an effective adsorbent. However, the high cost of the activation process limits its use in wastewater treatment applications [8-10]. Therefore by using agricultural wastes as low cost adsorbents, are seen as an innovative solution that is both efficient and economical.

The use of by products derived from agricultural wastes as low cost adsorbents to remove organic or inorganic contaminants would be most ideal since these materials are available in abundance in many countries [9, 11]. Malaysia is one of the main palm oil producers in the world that annually produces more than 18 million tons of palm oil production [12]. With the growth of palm oil production in Malaysia, the amount of residues

generated also shows a corresponding increase. Palm oil fly ash (POFA) is produced after combustion of oil palm fiber and shell as boiler fuel to produce steam for palm oil mill consumption [12-13]. POFA is enriched with porous materials that contain large surface area and pore volume which has excellent adsorption properties. Chemical composition of POFA has shown that it contains high amounts of aluminosilicates compounds and presence of calcium oxide as it can assist in providing adequate negatively charged sites for cation exchange reaction to take place with toxic heavy metals present in aqueous wastewater during treatment. Moreover, the alkaline nature of fly ash makes it a good neutralising agent [1, 14-15].

As an alternative way to utilize its function, the application of these biomasses for value-added purposes such as in the removal of various heavy metals has to be explored and needs further investigation. In order to enhance the value of this material, POFA could be transformed into a low cost absorbent for the removal of heavy metals in wastewater treatment industry [12, 13, 16]. Apart from that, the abundance and cheap supply of the biomass materials will justify their use as potential adsorbents for the removal of different pollutants [17]. Therefore, the objective of this research was to conduct a series of batch adsorption experiments to investigate and explore the feasibility of palm oil fly ash (POFA) as a low cost adsorbent for removal of Cd (II) ions from aqueous solutions. In the present studies, the adsorption characteristics of Cd (II) ions onto POFA were investigated under varying experimental conditions, such as contact time, pH value, dosage level and initial concentration.

## **MATERIALS AND METHODS**

### **Preparation of adsorbent and synthetic wastewater**

Palm oil fly ash was provided by the Faculty of Environmental Studies, Universiti Putra Malaysia. Before prior to usage, the palm oil fly ash (POFA) were dried at 105 °C for 24 hours. The entire chemicals utilized in the study were of analytical grade. Stock solution of Cd (II) ions with a concentration of 1000 mg/L was prepared by dissolving cadmium nitrate tetrahydrate  $\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$  (analytical reagent grade) in deionized water. The desired range of concentration of the metal components prepared from stock solution was varied between 10 and 200 mg/L by making fresh dilutions for each sorption experiment prior to usage.

### **Batch adsorption studies**

All adsorption experiments were performed on an orbital shaker at 200 rpm for agitation purpose in order to keep the media in suspension. Series of adsorption experiments were carried out at room temperature ( $31 \pm 2^\circ\text{C}$ ). The first experiment was to investigate the effect of adsorbent equilibrium contact time. Cd (II) solution (50 mL, 150 mg/L) and 0.5 g of POFA were added into the flasks and then agitated at 200 rpm at different interval contact times ranging from 30 and 300 minutes.

The second experiment was to study the effect of pH values throughout the adsorption process. The pH values of Cd (II) solutions were adjusted to 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 11.0 and 12.0 respectively with the aid of  $\text{HNO}_3$  (0.1 M) or  $\text{NaOH}$  (0.1 M) solutions. Then (50 mL, 150 mg/L) of Cd (II) solutions and 0.5 g of POFA were added into the flasks and then agitated at 200 rpm at pre-determined equilibrium contact time based on the first experiment. The third experiment was to investigate the effect of different adsorbent dosage. Different dosage of POFA ranging from 0.1, 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, and 5.0 grams respectively, are added into the flasks containing Cd (II) solution (50 mL, 150 mg/L) and then agitated at 200 rpm at pre-determined contact time and optimum pH value.

The fourth experiment was to study the isotherm and the effect of initial Cd (II) concentration. Solutions of Cd (II) at different concentration of 10, 50, 100, 150 and 200 mg/L were prepared and then treated as the procedure in the previous experiment. All solution samples were separated from the adsorbent using a syringe and filtered using 0.45  $\mu\text{m}$  nylon syringe filter, then 10 ml of reactant were extracted from the conical flasks prior for Cd (II) analysis using Inductively Coupled Plasma Mass Spectrometry (Perkin-Elmer, ICP-MS ELAN DRC-e). All methods were adapted from the standard methods for the examination of water and wastewater [18]. All tests were conducted in triplicate prior to every experiment to obtain a more accurate and consistent results.

### Percentage of removal and adsorption capacity

The removal percentage (A %), the amount of adsorbate adsorbed per unit mass of adsorbent at time t ( $q_t$ , mg/g), and the amount of adsorbate adsorbed per unit mass of adsorbent at equilibrium ( $q_e$ , mg/g), were calculated from the following equations:

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

$$q_t = V \times \frac{C_0 - C_t}{ms} \quad (2)$$

$$q_e = V \times \frac{C_0 - C_e}{ms} \quad (3)$$

where  $C_0$  and  $C_e$  (mg/L) are the initial and the final concentrations of adsorbates in flasks, respectively,  $C_t$  (mg/L) is the concentrations of adsorbates at time t. V is the volume of the solution (L) and ms is the mass of dry adsorbent used (g).

### Adsorption isotherm models

The adsorption equilibrium data of Cd (II) on POFA were analyzed in terms of Langmuir and Freundlich isotherm models. The linear form of Langmuir's isotherm model is given by the following equation:

$$\frac{C_e}{q_e} = \frac{1}{q_m b} + \frac{C_e}{q_m} \quad (4)$$

Here,  $q_e$  is the amount of equilibrium uptake (mg/g),  $C_e$  is the equilibrium cation concentration in solution (mg/L),  $q_m$  is the maximum monolayer adsorption capacity of the adsorbent (mg/g), and  $b$  is the Langmuir adsorption constant (L/mg) related to the rate of adsorption.

The Freundlich isotherm equation can be written in the linear form as given below:

$$\log q_e = \log k + \frac{1}{n} \log C_e \quad (5)$$

Whereas  $k$  is constant related to overall adsorption capacity (mg/g) and  $n$  are the Freundlich constants that are related to the adsorption capacity and intensity, respectively. The Freundlich constants  $k$  and  $n$  can be calculated from the slope and intercept of the linear plot, with  $\log q_e$  versus  $\log C_e$ .

### Scanning electron microscope (SEM) and Energy-dispersive X-ray spectrometry (EDS) analysis

In the experiment, scanning electron microscopy examination was performed by using (SEM, Hitachi model S-3400N) to obtain the surface morphologies of POFA and to identify the presence of porosity. Fig. 1 shows the SEM micrographs of POFA morphological structure and indicates that the surface was porous in nature. SEM shows there is presence of pore on the surface of the adsorbent. Pore size distribution also affects the efficiency and selectivity of the adsorption process. Prior to the experiment, the composition of POFA used in the experiment was determined by an energy-dispersive X-ray spectrometry (EDS) detector that is attached along with the scanning electron microscope. Table 1 show the chemical composition and characteristics of POFA used for the adsorption studies. Higher carbon content can be observed that indicate the raw POFA structure itself is consist of porous carbon. The oil palm ash was found to contain amount of silica, potassium, and alumina that can be utilized to synthesize active compounds that are responsible for adsorption of various pollutants on the surface of adsorbents [12, 19].

Table 1: Chemical composition and characteristics of POFA used for adsorption studies.

| Chemical properties |                     |
|---------------------|---------------------|
| Element component   | Percent by weight % |
| C                   | 59.82               |
| O                   | 31.38               |
| Mg                  | 0.74                |
| Al                  | 2.34                |
| Si                  | 1.98                |
| P                   | 0.28                |
| Cl                  | 0.74                |
| K                   | 2.72                |
| Total               | 100.00              |

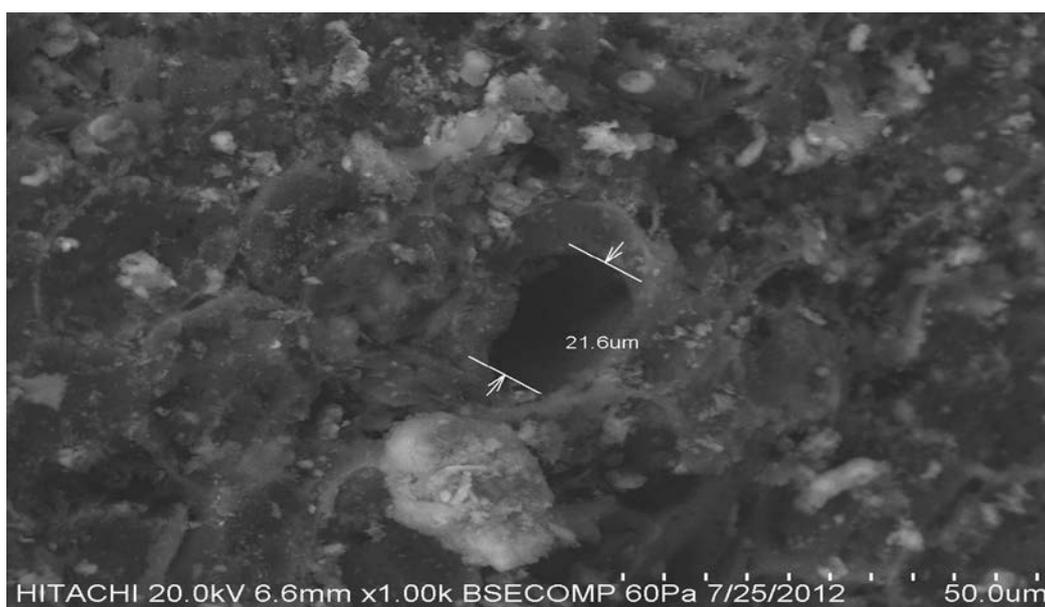


Fig. 1: Scanning electron micrographs (SEM) of POFA morphological structure.

## RESULTS AND DISCUSSIONS

### Effect of contact time

In the first experiment, the effect of different contact time was evaluated in order to identify the efficacy and feasibility of the adsorbent for its use in removal of Cd (II) ions. This is due to the development of charge on the surface of adsorbent is also governed by the contact time [20]. Apart from that, contact time was also considered as one of the major parameters that influence the adsorption capacity. Fig. 2 illustrates the effect of equilibrium contact time on the adsorption capacity and rate of Cd (II) ions uptake onto POFA.

The removal of Cd (II) ions increase rapidly during the first 30 min of the experiment. Afterwards, the removal adsorption rate was at a slower pace corresponding to contact time before reaching a plateau value at minutes 210 and can be considered to be remained constant from that point onwards. It is readily apparent from the figure that significant removals of the adsorbent occurred in minutes 210 and no appreciable changes in terms of removal were noticed afterwards. Thus, equilibration time was considered to be 210 min, which was considered as sufficient for the removal of Cd (II) ions using POFA. The concentration of Cd (II) ions was reduced from 150 mg/L to 7.332 mg/L after a 210 min contact time. Meanwhile, the amount of adsorbed Cd (II) ions by POFA from an initial concentration of 150 mg/L after a 210 min of equilibration time was 13.3721 mg/g.

From the observation, adsorptions rates were initially high at the beginning of the experiment due to high number of sites available for the sorption process. The changes in the rate of removal are due to the availability of vacant sites on the adsorbent. Consequently the adsorption of Cd (II) ions on the binding site of the adsorbent will result in the vacant site to be occupied thus significantly decreased the removal rate towards the end of the experiments. These indicate a possible monolayer of pollutant ions on the outer surface and pores of both adsorbent. Apart from that, continuous agitation results in pore diffusion onto the inner surface of adsorbent particles through the monolayer film. Therefore the contact time was set to 210 min in the following experiments to ensure adsorption equilibrium.

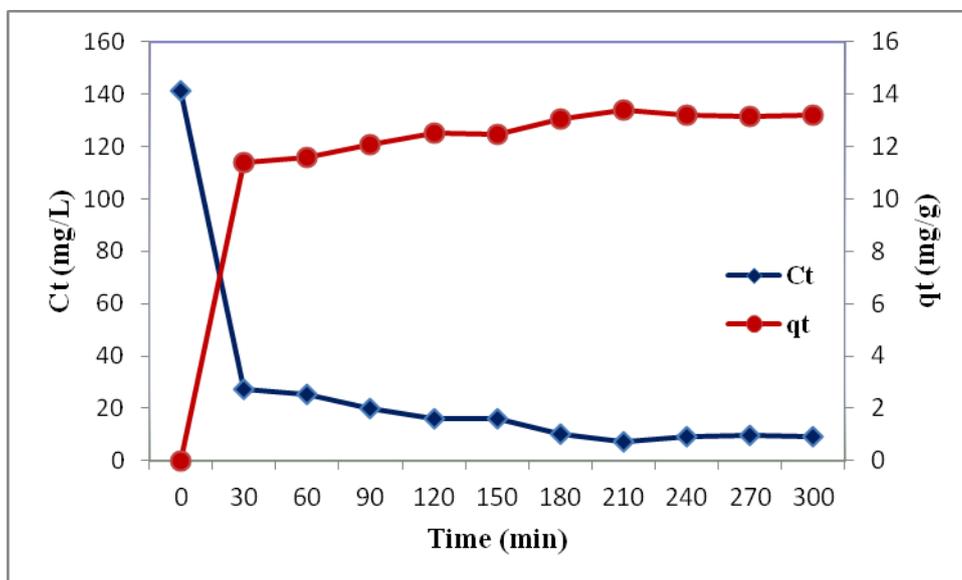


Fig. 2: Effect of contact time on adsorption of Cd (II) ions using POFA.

### Effect of pH

The pH value plays an important role in the whole adsorption process and particularly on the adsorption rate. Fig. 3 shows the effect of pH on the adsorption of Cd (II) ions using POFA. The adsorption capacity of POFA increased slowly from pH 3 and achieved its optimum rate at pH value of 9. The result shows that the residual of Cd (II) ions ( $C_e$ ) and the adsorption capacity ( $q_e$ ) obtained were 5.864 mg/L and 14.413 mg/g respectively at pH 9. Mainly the adsorption of Cd (II) ions was low at acidic condition. This was due to the acidity medium could affect the metal uptake of the adsorbent due to higher presence of  $H^+$  that compete with Cd (II) ions for active binding sites onto the adsorbent surface [15]. From the observation, at higher pH (> 9.0), the adsorption of Cd (II) ions was nearly constant and no significant change can be observed.

Apparently, when pH value was < 5.0, a significant electrostatic repulsion exists between the positively charged surface and the cationic Cd (II) ions, which inhibits the adsorption of Cd (II). This phenomenon can be explained due to higher concentration of  $H^+$  in the solution competes with Cd (II) ions for binding sites on the surface of POFA, resulting in the reduced uptake [22]. The increase in adsorption corresponding to pH can be attributed to the fact that the positively charged metal cations are repulsed less by the oxide surfaces at higher pH values. As the pH of the medium increases, the number of positively charged sites decreases and the number of negatively charged sites increases on the surface of adsorbents. Obviously, a negatively charged surface site favours the adsorption of cationic Cd (II) ions due to electrostatic attraction [2]. Therefore, it can be stated that the optimum pH for the removal of Cd (II) ions using POFA was obtained at pH 9 and was used in the following experiments in order to obtain optimum removal efficiency.

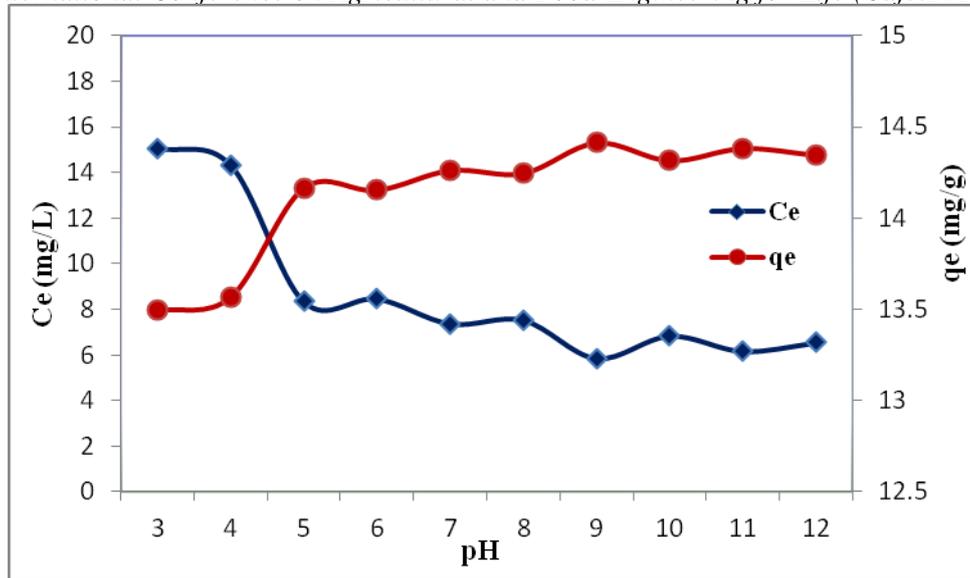


Fig. 3: Effect of pH on adsorption of Cd (II) ions using POFA.

### Effect of adsorbent dosage

The effect of variation of adsorbent dosage was also examined for cadmium solutions of 150 mg/L concentration at fixed equilibration time of 210 min and optimum pH values of 9. Fig. 4 shows the effect of adsorbent dosage variation on the removal and adsorption of Cd (II) ions using POFA. A trend of increment in the removal percentage (A%) corresponding to adsorbent dosage was observed. As the adsorbent dosage increase so does the A% until it reach a certain dosage where the A% become constant or a plateau value was obtained.

The A% increased from 0.1 to 3.0 g of dosage, but a slower removal pace was observe as the adsorbent dosage increase > 3.0 g. It is plausible to suggest that with higher dosage of adsorbent there would be greater availability of exchangeable sites for the adsorbate [8]. Nevertheless, at adsorbent dosage > 3.0 g, the incremental Cd (II) ion removal becomes very low as the surface metal ions concentration and the solution metal ions concentration come to equilibrium with each other [2-3] resulting a slower uptake onto POFA. Meanwhile, the decrease in  $q_e$  with increase in the adsorbent dosage is mainly due to the unsaturation of adsorption sites through the adsorption reaction. Another reason may be due to the particle interactions, such as aggregation, resulting from high sorbent concentration. Such aggregation would lead to a decrease in the total surface area of the adsorbent [2, 22].

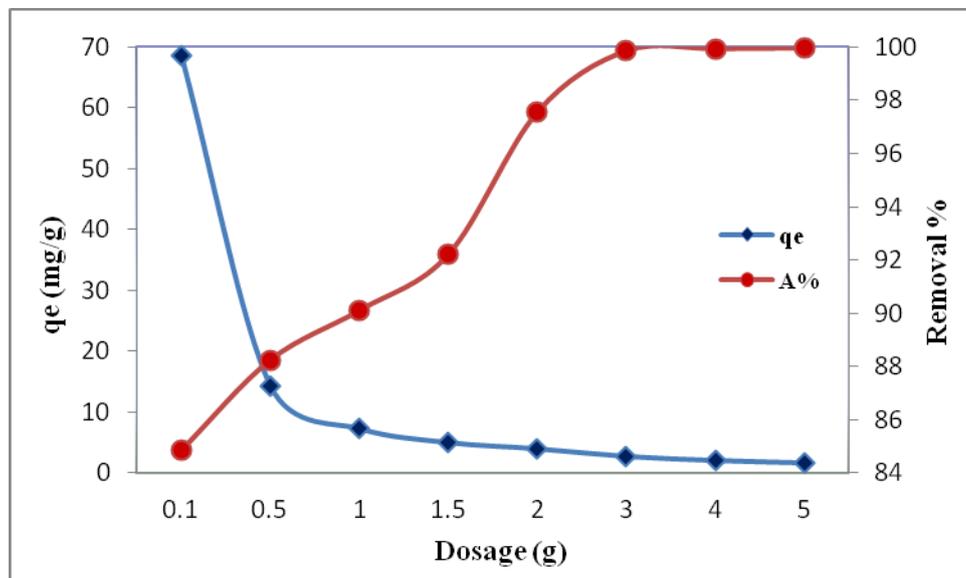


Fig. 4: Effect of adsorbent dosage variation on the removal and adsorption of Cd (II) ions using POFA.

### Effect of initial concentration

The effect of initial concentration on the adsorption of Cd (II) ions by POFA was investigated with varying solution concentrations (10, 50, 100, 150 and 200 mg/L) using 0.5 g adsorbent dosage. As expected, based on Fig. 5 the amount of Cd (II) ions adsorbed at equilibration time and optimum pH shows that with increasing of solution concentration,  $q_e$  increased, whereas A% decreased. The rate at which cadmium ions pass from the bulk solution to the particle surface is proportional to the increasing of mass transfer driving force. Similar results were reported for adsorption of Cd from aqueous solution [2, 23-24]. The Cd uptake mechanism is particularly dependent on the initial concentration; at low initial solution concentration, the surface area and the availability of adsorption binding sites were relatively high, thus the Cd (II) ions were easily adsorbed and removed. Meanwhile, at higher initial solution concentration, the total available active sites are limited, thus resulting in a decrease in A% of Cd (II) ions [2]. The increased in  $q_e$  at higher initial concentration can be attributed from the enhancement of driving force.

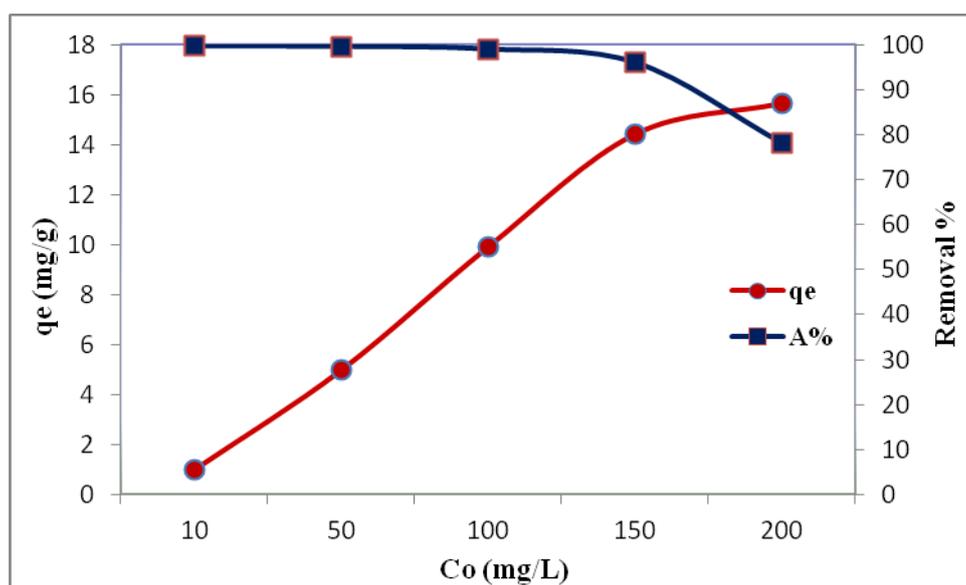


Fig. 5: Effect of initial concentration on the removal and adsorption of Cd (II) ions using POFA.

### Adsorption isotherms

The adsorption studies were conducted at a fixed adsorption contact time (210 min), optimum pH of 9, and 0.5 g of adsorbent dosage by varying the solution concentration. The equilibrium data were analyzed using Langmuir and Freundlich (Eqs. 4 and 5) in order to obtain the best fitting isotherm. The isotherms for adsorption using POFA were shown graphically in Fig. 6. Meanwhile the isotherm parameters for both isotherms were listed in Table 2. All the plots showed a straight line, indicating that the adsorption of Cd (II) ions follows both isotherms well. Comparison of coefficients indicates that the Langmuir isotherm fitted more precisely ( $R^2=1$ ) than the Freundlich isotherm ( $R^2=0.8184$ ) for adsorption using POFA. The basic assumption of Langmuir adsorption isotherm is based on monolayer coverage of the adsorbate on the surface of adsorbent [25-26], which is an indication of the fact that the adsorption of Cd (II) ions onto POFA generates monolayer formation.

Table 2: Langmuir and Freundlich isotherm constants and correlation coefficients

| POFA         | Langmuir isotherm coefficients |            |       | Freundlich isotherm coefficients |       |       |
|--------------|--------------------------------|------------|-------|----------------------------------|-------|-------|
|              | $q_0$ (mg/g)                   | $b$ (L/mg) | $R^2$ | $K$                              | $1/n$ | $R^2$ |
| Cadmium (Cd) | 15.823                         | 1.780      | 1     | 2.187                            | 0.372 | 0.818 |

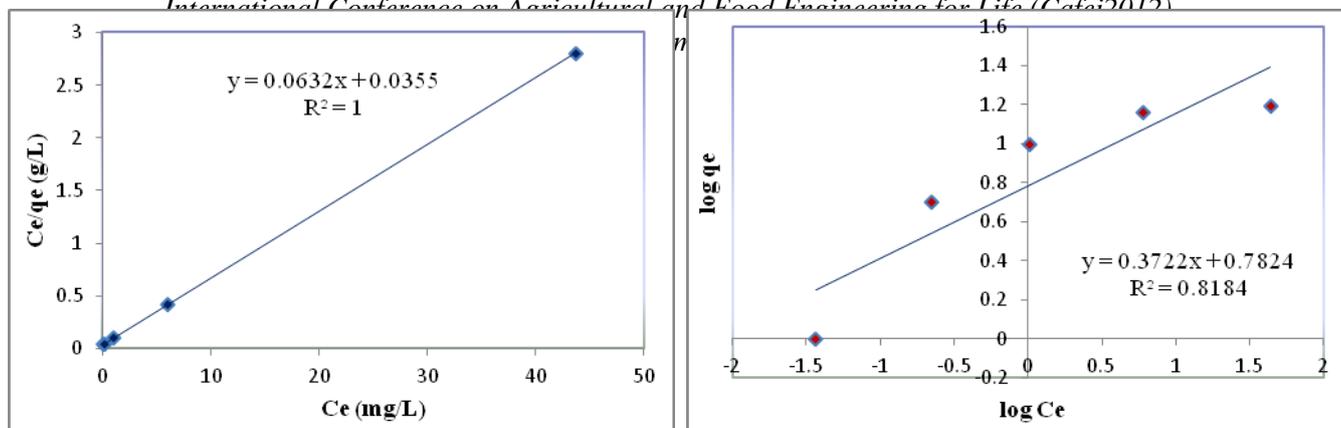


Fig. 6: Langmuir (a) and Freundlich (b) adsorption isotherms of Cd (II) ions using POFA.

## CONCLUSIONS

In this study, batch adsorption experiments for the adsorption of Cd (II) ions from aqueous solution have been carried out using POFA as low cost adsorbent. The adsorption characteristics have been examined at different contact times, pH values, adsorbent dosage levels and initial Cd (II) ion concentrations. The results obtained in this study clearly demonstrated that adsorption rate of Cd (II) ions was very fast initially in the first 30 min and more than 80% of total Cd (II) ions were removed within that period. Meanwhile, the adsorption capacity ( $q_e$ ) increased slowly corresponding to contact time before reaching a plateau value after the contact time of 210 min. Thus, equilibration time was considered to be 210 min, which was considered as sufficient for the removal of Cd (II) ions using POFA.

The optimum pH for the removal of Cd (II) ions using POFA was obtained at pH 9.0. Generally, the adsorption capacity of Cd (II) ions by POFA increased with an increase in the pH values of the adsorbate solution. Apparently an increase in dosage of adsorbent led to increase in Cd (II) ions removal but decrease in adsorption capacity ( $q_e$ ). With an increase in initial Cd (II) ion concentration, adsorption capacity of Cd (II) ions by POFA increased but the removal percentage (A%) of Cd (II) ions decreased. Langmuir adsorption model was better fitted for the adsorption of Cd (II) ions than Freundlich isotherms using POFA. The highest monolayer adsorption capacity obtained was 15.823 mg/g for adsorption of Cd (II) ions by POFA at equilibration time of 210 min and optimum pH of 9.0. In conclusion, studies on batch adsorption indicate that POFA has a excellent potential for the removal of Cd (II) ions from aqueous solution.

## ACKNOWLEDGEMENTS

This work was supported by the Faculty of Environmental Studies and Engineering of Universiti Putra Malaysia, Malaysia.

## REFERENCES

- [1] Bayat, B. (2002). Combined removal of Zinc (II) and Cadmium (II) from aqueous solution by adsorption by adsorption onto high-calcium Turkish fly ash. *Water, Air, and Soil Pollution*. **136**: 69-92.
- [2] Wang, F.Y., Wang, H. & Ma, J.W. (2010). Adsorption of cadmium (II) ions from aqueous solution by a new low-cost adsorbent - Bamboo charcoal. *Journal of Hazardous Materials*. **177**: 300-306.
- [3] Naiya, T. K., Bhattacharya, A. K. & Das, S. K. (2009). Adsorption of Cd (II) and Pb (II) from aqueous solutions on activated alumina. *Journal of Colloid and Interface Science*. **333**: 14-26.
- [4] St. Albanese, M.L., De Luca, B., De Vivo, A.M., & Lima, G. Grezzi. (2008). Relationships between heavy metal distribution and cancer mortality rates in the Campania Region, Italy, *Environ. Geochem.* ISBN: 9780444531599.
- [5] Bernard, A. (2008). Cadmium & its adverse effects on human health. *Indian J Med Res*. **128**: 557-564.
- [6] Salam, O.E.A., Reiad, N.A., & ElShafei, M.M. (2011). A study of the removal characteristics of heavy metals from wastewater by low-cost adsorbents. *Journal of Advanced Research*. **2**(4): 297-303.
- [7] Popuri, S.R., Vijaya, Y., Boddu, V.M., & Abburi, K. (2009). Adsorptive removal of copper and nickel ions from water using chitosan-coated PVC beads. *Bioresource Technology*. **100**: 194-199.
- [8] Babel, S., & Kurniawan, T.A. (2003). Low-cost adsorbents for heavy metals uptake from contaminated water: A review. *J. Hazard. Mater.* **B 97**: 219-243.

- [9] Demirbas, A. (2008). Heavy metal adsorption onto agro-based waste materials: A review. *Journal of Hazardous Materials*. **157**(2-3): 220-229.
- [10] Sud, D., Mahajan, G., & Kaur, M.P. (2008). Agricultural waste material as potential adsorbent for sequestering heavy metal ions from aqueous solutions -A review. *Bioresource Technology*. **99**: 6017-6027.
- [11] Chu, K.H., Hashim, M.A., Ng, P.C., & Chong, M.T. (2000). Palm oil fuel ash as an adsorbent for heavy metals. Proceedings of the Second Pacific Basin Conference Brisbane, May 14-18. Adsorption Science and Technology. pp. 154-158. doi: 10.1142/9789812793331\_0031.
- [12] Ahamd, T. Rafatullah, M., Ghazali, A., Sulaiman, O., & Hashim, R. (2011). Oil palm biomass-based Adsorbents for the removal of water pollutants - A Review. *Journal of Environmental Science and Health, Part C: Environmental Carcinogenesis and Ecotoxicology Reviews*. **29**(3): 177-222.
- [13] Chowdhury, Z.Z., Zain, S.M., & Rashid A.K. (2011). Equilibrium isotherm modelling, kinetics and thermodynamics study for removal of lead from waste water. *E-journal of Chemistry*. **8**(1): 333-339.
- [14] Ahmaruzzaman, M. (2010). A review on the utilization of fly ash. *Progress in Energy and Combustion Science*. **36**: 327-363.
- [15] Visa, M., Isac, L., & Duta, A. (2012). Fly ash adsorbents for multi-cation wastewater treatment. *Applied Surface Science*. **258**(17): 6345-6352.
- [16] Foo, K.Y., & Hameed, B.H. (2009). Value-added utilization of oil palm ash: A superior recycling of the industrial agricultural waste. *Journal of Hazardous Materials*. **172**: 523-531.
- [17] Salamatina, B, Kamaruddin, A.H., & Abdullah, A.Z. (2007). Removal of Zn and Cu from wastewater by sorption on oil palm tree-derived biomasses. *J Appl Sci*. **7**: 2020-2027.
- [18] APHA, AWWA, WEF. (2005). Standard methods for the examination of water and wastewater, 21<sup>st</sup> edition. American Public Health Association, Washington: DC.
- [19] Ghazali, A., Daud, W.R.W. & Law, K.N. (2006). Alkaline peroxide mechanical pulping (APMP) of oil palm lignocellulosics: Part 2. Empty Fruit Bunch (EFB) responses to pretreatments. *Appita J*. **59**: 65-70.
- [20] Sharma, Y.C., Umaa, Upadhyay, S.N. & Weng, C.H. (2008). Studies on an economically viable remediation of chromium rich waters and wastewaters by PTPS fly ash. *Colloids and Surfaces A: Physicochemical. Eng. Aspects*. **317**: 222-22.
- [21] Chu, K.H. & Hashim, M.A. (2002). Adsorption characteristics of trivalent chromium on palm oil fuel ash. *Clean Techn Environ Policy*. **4**: 8-15.
- [22] Rao, M.M., Rao, G.P., Seshaiiah, K., Choudary, N.V. & Wang, M.C. (2008). Activated carbon from Ceiba pentandra hulls, an agricultural waste, as an adsorbent in the removal of lead and zinc from aqueous solutions. *Waste Manage*. **28**: 849-858.
- [23] Papandreou, A., Stournaras, C.J. & Panias, D. (2007). Copper and cadmium adsorption on pellets made from fired coal fly ash. *J. Hazard Mater*. **148**: 538-47.
- [24] Srivastava, V.C., Mall, I.D. & Mishra, I.M. (2008). Removal of cadmium (II) and zinc (II) metal ions from binary aqueous solution by rice husk ash. *Colloids Surf A: Physicochem Eng Aspects*. **312**: 172-84.
- [25] Nadeem, M., Mahmood, A., Shahid, S.A., Shah, S.S., Khalid, A.M. & McKay, G. (2006). Sorption of lead from aqueous solution by chemically modified carbon adsorbents. *J. Hazard. Mater*. **B138**: 604613.
- [26] Singh, K.K., Singh, A.K. & Hasan, S.H. (2006). Low cost biosorbent wheat bran for the removal of cadmium from wastewater: kinetic and equilibrium studies. *Bioresour. Technol*. **97**: 994-1001.