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## **Kinetic biosorption study of cadmium onto coconut copra meal as biosorbent**

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**Abstract:** The sorption of cadmium ions on an agricultural by-product, coconut copra meal, was investigated. A batch sorption model, based on the assumption of the pseudo-second-order mechanism, was applied to predict the rate constant of sorption, the equilibrium sorption capacity and the initial sorption rate with the effect of initial cadmium concentration and temperature. Activation energy of sorption was determined based on the pseudo-second-order rate constants. In addition, the experimental results were analysed by pseudo-Langmuir, pseudo-Freundlich and pseudo-Redlich-Peterson isotherms based on pseudo-second order kinetic expression constant. Both pseudo-Langmuir and pseudo-Redlich-Peterson isotherms were found to represent the measured sorption data well. According to the evaluation using the pseudo-Langmuir equation, the monolayer sorption capacity was obtained to be 2.59 mg/g.

**Keywords:** copra meal; cadmium ions; pseudo-second-order; kinetics.

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Yuh-Shan Ho obtained his PhD (1995) at the University of Birmingham, United Kingdom. He has published 110 SCI journal papers (which have

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## 1 Introduction

A low-cost sorbent is defined as one which is abundant in nature, or is a by-product or waste material from another industry (Bailey et al., 1999). The use of these low-cost materials could be an alternative to the more costly processes. The potential of biological materials as an alternative to treat low metal-bearing wastewaters has been investigated. Some of the biowastes reported to effectively sequester heavy metals include waste tea, exhausted coffee, exhausted coffee, nut and walnut shells (Orhan and Büyükgüngör, 1993), rice husk (Khalid et al., 1998), etc.

A number of biosorption processes for pollutants have been studied in an attempt to find a suitable explanation of the mechanism and the kinetics. In recent years, biosorption mechanisms involving kinetics-based models have been reported. Numerous kinetic models have described the reaction order of sorption systems based on solution concentration. These include first-order (Saiers et al., 1994) and second-order (McCoy and Liapis, 1991) reversible ones, first-order (Mohan et al., 2002) and second-order (Chu and Hashim, 2003) irreversible ones and pseudo-first-order (O'Shannessy and Winzor, 1996) and pseudo-second-order ones (Zaror, 1997) based on the solution concentration. On the other hand, reaction orders based on the capacity of the adsorbent, such as Lagergren's first-order equation (Lagergren, 1898), Zeldowitsch's model (Zeldowitsch, 1934) and Ho's pseudo-second-order expression (Ho, 1995; Ho and McKay, 1998a, 1999, 2000), have also been presented. In addition, the pseudo-second-order expression has been successfully applied to the sorption of metal ions, dyes, herbicides, oils and organic substances from aqueous solutions (Ho, 2004a; Zheng et al., 2005).

Copra meal produced in large amount has very little application apart from its use as animal feed owing to its high protein and fibre content. There is no information in the literature on the use of coconut copra as biosorbent. In this work, the kinetics of biosorption for the use of copra meal as biosorbent for cadmium ion removal from solution is investigated. In addition, pseudo-isotherms were also presented for the biosorption system.

## 2 Materials and methods

### 2.1 Materials

Coconut was obtained from the open market in Benin City. The fruits were dehusked, split and sun dried until the meat (endosperm) reached a moisture content of 5%.

The copra was blandered in a food-processing blender and the oil extracted with hot water. The copra meal was then washed several times with hot water to remove excess oil, sun dried and sieved to obtain a size less than 250  $\mu\text{m}$ . The sieved copra meal was soaked in 0.02 mol/dm<sup>3</sup> HCl overnight. The acid solution was filtered off, and the copra meal was washed with distilled water until the pH of the wash became neutral. The copra meal was dried at 373 K for 24 hours and stored in an air-tight container. The stock solution of cadmium(II) (1000 mg/dm<sup>3</sup>) was prepared in distilled water using cadmium nitrate salt (BDH); all working solutions were prepared by diluting the stock solution with distilled water.

## 2.2 Methods

### *Effect of initial concentration*

A range of cadmium concentrations (10.5–201 mg/dm<sup>3</sup>) (adjusted to pH 6) were used, and the flasks agitated for 100 minutes. A 2.0 -g sample of copra meal was added to each 100 ml volume of cadmium solution and agitated at 150 rpm and the temperature was set at 24°C for all experiments. Samples (2.0 ml) were withdrawn at suitable time interval and the filtrate analysed by atomic absorption spectrophotometry (AAS).

### *Effect of temperature*

Two gram of copra meal was added to a 500-ml flask containing 100 ml of 201 mg/dm<sup>3</sup> of cadmium (pH 6) stirred at 150 rpm and at temperature 297 K. Samples (2.0 ml) were withdrawn at suitable time intervals and the filtrate analysed by Atomic Absorption Spectrophotometer (AAS). The experiment was repeated at 311, 323 and 333 K.

## 3 Results and discussion

The sorption of cadmium by copra meal was very rapid, regardless of the metal concentration (Figure 1). It may be further noted that most of the metal uptake by biosorbents occurred during the first few minutes, as in the case of sorption of lead onto tree fern (Ho et al., 2004). As the cadmium concentration is increased, the sorption capacity progressively decreased from 0.330 mg/g in 10.5 mg/dm<sup>3</sup> to 2.35 mg/g in 201 mg/dm<sup>3</sup> solution. Higher cadmium sorption at higher cadmium solution concentration may be because of the higher metal to sorbent ratio, which increases as the copra meal quantity is decreased. As the solution concentration was increased at a given quantity of sorbent, the cadmium/copra meal ratio increased, which in turn was reflected in an increased cadmium uptake per biosorbent. Fourest and Roux (1992) have explained it to be owing to the net cadmium ion availability around the microenvironment of the sorbent, and the electrostatic interaction between them at non-limiting sorption sites on copra meal.

The sorption may be represented by the pseudo-second-order kinetics (Ho and McKay, 1999, 2000) given by

$$\frac{dq_t}{dt} = k(q_e - q_t)^2 \quad (1)$$

where  $k$  is the pseudo-second-order rate constant. For boundary conditions  $t = 0$  to  $t = t$  and  $q_t = q_t$ , the integrated form of the equation is

$$\frac{1}{q_e - q_t} = \frac{1}{q_e} + kt \quad (2)$$

which can also be written as

$$q_t = \frac{1}{kq_e^2} + \frac{t}{q_e} \quad (3)$$

or, in the linear form,

$$\frac{t}{q_t} = \frac{1}{h} + \frac{1}{q_e} t \quad (4)$$

where  $h = kq_e^2$  can be regarded as the initial sorption rate as  $t$  approaches 0. If the pseudo-second-order kinetics is applicable, the plot of  $t/q_t$  vs.  $t$  gives a linear relationship, which allows computation of  $q_e$ ,  $k$ , and  $h$  without having to know any parameter before hand.

**Figure 1** Effect of initial concentration on the sorption of cadmium ions onto copra meal

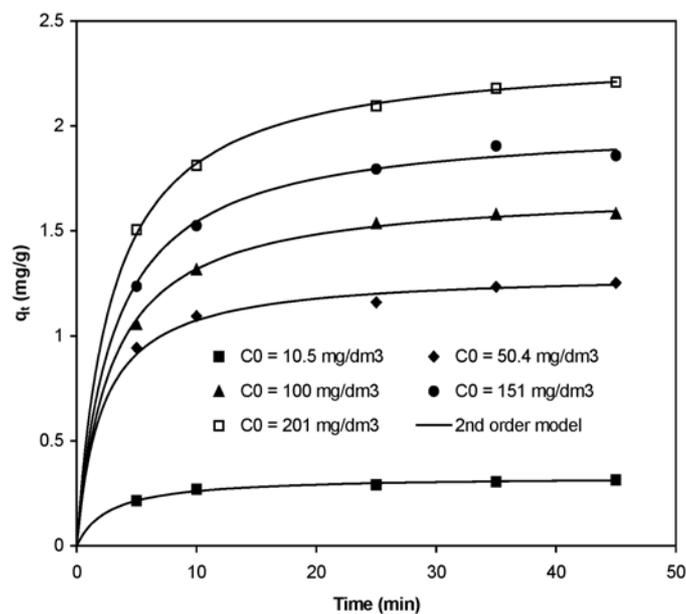


Figure 1 shows a plot of the experimental data points for the sorption of cadmium by copra meal as a function of time. These plots show that, for all initial cadmium concentrations, the amount of cadmium sorbed increases rapidly with time at the beginning and becomes very slow towards the end of the process. The plots also demonstrated that the sorption increased for lower initial cadmium concentrations at any specific time. Furthermore, a large fraction of the total amount of cadmium was removed within a short period of time.

Table 1 lists the rate constant,  $k$ , the equilibrium sorption,  $q_e$ , the initial sorption rate,  $h$  and the coefficients of determination,  $r^2$ , of sorption at various initial concentrations of cadmium; these were calculated from the intercept and slope of the straight line plots of  $t/q_t$  vs.  $t$  according to equation (4). The initial sorption rate increased with an increase in the initial concentration of cadmium ions in solution. Thus, the initial sorption rate varied from 0.123 mg/g min to 0.805 mg/g min as the initial concentration of cadmium ions was varied from 10.5 mg/dm<sup>3</sup> to 201 mg/dm<sup>3</sup>. The values of rate constants decreased from 1.12 g/mg min to 0.145 g/mg min with an increase in the initial concentration of cadmium from 10.5 mg/dm<sup>3</sup> to 201 mg/dm<sup>3</sup>. The observed dependence of the rate on the initial concentration of cadmium indicates that removal of cadmium from dilute aqueous solution should be achieved much easily, since sorption relative to the initial concentration of cadmium is more rapid in dilute solution, i.e., a greater fraction of the cadmium present will be sorbed in a given period of time (Weber and Morris, 1963).

**Table 1** Parameters for the effect of initial cadmium concentration

$C_0$ , mg/dm <sup>3</sup>	$q_e$ , mg/g	$k$ , g/mg min	$h$ , mg/g min	$R^2$
10.5	0.330	1.12	0.123	0.999
50.4	1.30	0.358	0.609	0.999
100	1.70	0.206	0.593	1.000
151	2.02	0.163	0.660	0.999
201	2.35	0.145	0.805	1.000

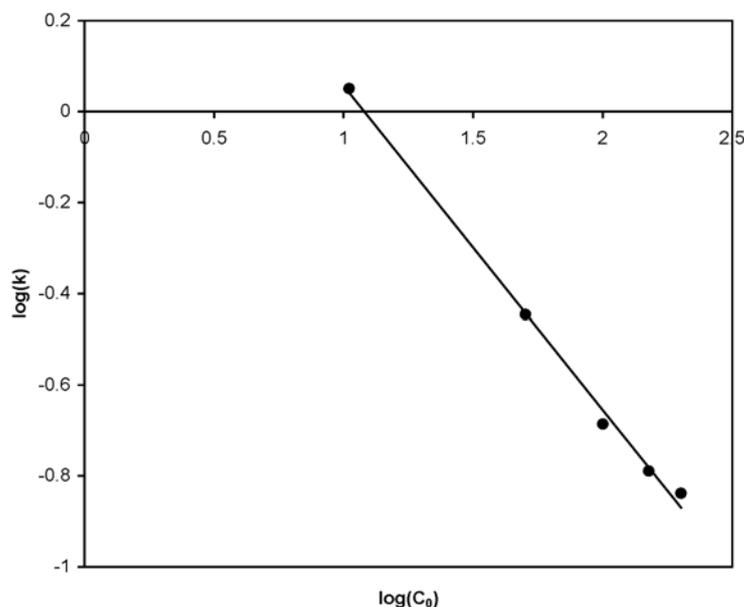
A correlation has been made empirically of the pseudo-second-order rate constant,  $k$ , as a function of the initial concentration of lead as follows:

$$k = mC_0^n. \quad (5)$$

McKay et al. (1983) reported that, in the case of sorption of Acid Blue 25 using chitin,  $n$  centres around the 0.5 values, confirming that intraparticle diffusion was a prominent factor in the sorption process. In the cases of sorption of larger molecular dyes, the sorption rate was slower, and intraparticle diffusion was the rate-limiting step (Jadhav and Vanjara, 2004; Sun and Yang, 2003). Conversely, in the cases of sorption of metal ions, the sorption rate was faster generally and was not concerted by intraparticle diffusion (Prasad and Saxena, 2004; Ho et al., 2004). The results from this study shown in Figure 2 suggest that the relationship between the pseudo-second-order rate constant,  $k$ , and the initial cadmium concentration follows equation (5) with a coefficient of determination of 0.996 as shown in the following equation:

$$k = 5.86C_0^{-0.71}. \quad (6)$$

The value of  $n$  value ( $-0.71$ ) is different from 0.5, based on intraparticle diffusion. This indicates that the kinetics of cadmium sorption using coconut copra meal was described by the pseudo-second-order expression rather than by the intraparticle diffusion, and intraparticle diffusion was not the rate-limiting step. In addition, the negative  $n$  value was also found as in the case of sorption of lead onto peat (Ho and McKay, 1998b).

**Figure 2** Logarithmic relationship between  $k$  and  $C_0$ 

### 3.1 Pseudo-isotherms

Pseudo-isotherms could be obtained using a pseudo-second order kinetic expression constant (Ho, 2004b). Sorption of cadmium onto coconut copra meal was tested by applying the pseudo-Langmuir, pseudo-Freundlich and pseudo-Redlich-Peterson isotherms. The amount of cadmium sorbed at equilibrium,  $q_e$ , can be obtained from pseudo-second-order equation, and the equilibrium cadmium concentration can be calculated from the equation below (Ho, 2004b; Ho and Wang, 2004):

$$C_{ep} = C_0 - \frac{q_e m_s}{V}. \quad (7)$$

$C_{ep}$  is the equilibrium cadmium concentration, mg/dm<sup>3</sup>;  $C_0$  is the initial cadmium concentration, mg/dm<sup>3</sup>;  $q_e$  is the equilibrium sorption capacity obtained from pseudo-second order rate equation, mg/g;  $V$  is solution volume, dm<sup>3</sup> and  $m_s$  is mass of mixed sorbent, g.

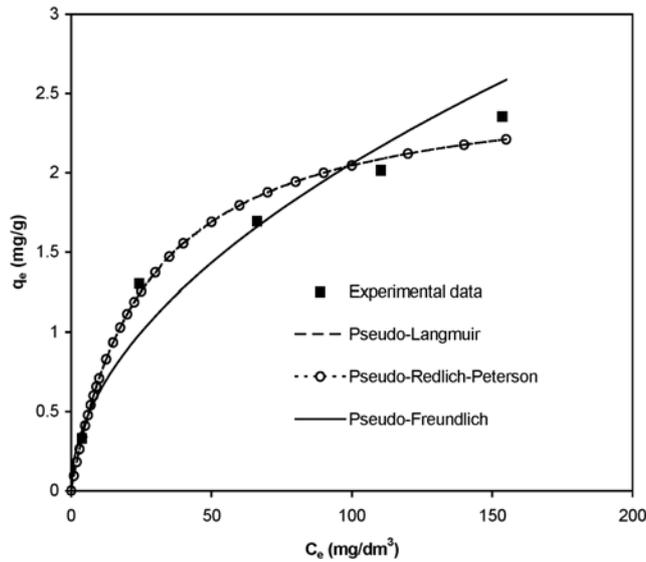
The isotherms and their respective linear forms are shown in Table 2. The coefficient of determination,  $r^2$ , has been used to determine the relationship between the experimental data and the isotherms in most studies. The coefficients of determination were found to be 0.999 for pseudo-Langmuir, 0.996 for pseudo-Redlich-Peterson, and 0.955 for pseudo-Freundlich isotherm, respectively. Figure 3 shows the better-fitting isotherms were pseudo-Langmuir and pseudo-Redlich-Peterson isotherms that were overlapped. The sorption behaviour of the cadmium onto coconut copra meal was examined by using the least squares linear regression analysis. The values of the pseudo-Langmuir isotherm constants were obtained from the slope and intercept of the straight line (Table 2). The saturated monolayer sorption capacity,  $q_m$ , and sorption equilibrium constant,  $K_a$ , were 2.59 mg/g and 0.0375 dm<sup>3</sup>/mg for pseudo-Langmuir

isotherm; the pseudo-Freundlich sorption isotherm constant  $K_F$  was 0.178 and  $1/n$  was 0.521 and the pseudo-Redlich-Peterson isotherm constant  $A$  was 0.975,  $B$  was 1.82 and  $g$  was 1.000. Under the basic condition of this sorption system, it was estimated to be more likely to be approaching the Langmuir form where it can be seen from the data where the value of  $g$  was unity. Langmuir isotherm is a special case of Redlich-Peterson isotherm when constant  $g$  was unity.

**Table 2** Isotherms and their linear forms

Isotherm	Isotherm	Linear form
Langmuir	$q_e = \frac{q_m K_a C_e}{1 + K_a C_e}$	$\frac{1}{q_e} = \frac{1}{K_a q_m} + \frac{1}{C_e}$
Freundlich	$q_e = K_F C_e^{1/n}$	$\log(q_e) = \log(K_F) + 1/n \log(C_e)$
Redlich-Peterson	$q_e = \frac{A C_e}{1 + B C_e^g}$	$\ln \left( \frac{A C_e}{q_e} - 1 \right) = g \ln(C_e) + \ln(B)$

**Figure 3** Theoretical isotherms and experimental data

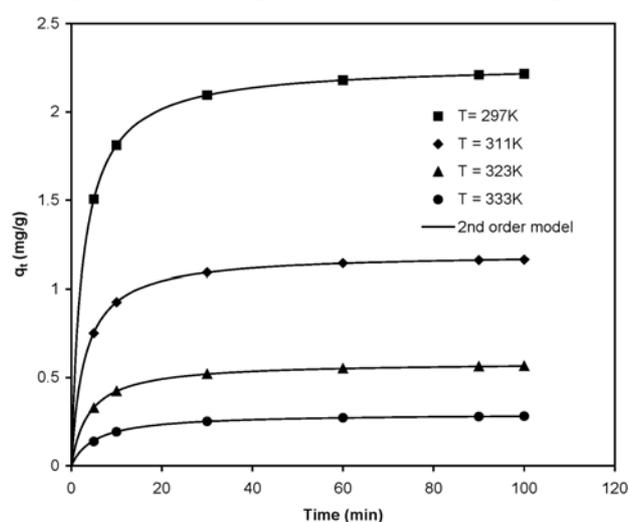


### 3.2 Effect of temperature

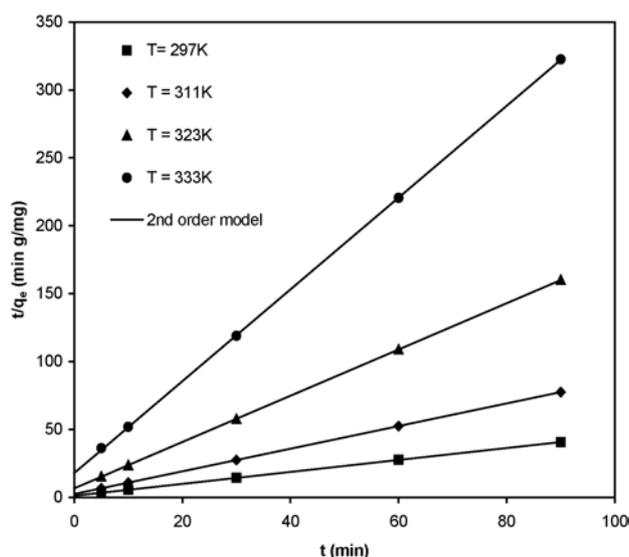
The effect of increasing temperature on the uptake of cadmium on copra meal is shown in Figure 4. Figure 5 shows excellent agreement between the experimental data and theoretical curves through the use of equation (4); this suggests that the sorption system follows a pseudo-second-order rate model. Table 3 shows that the pseudo-second-order rate constants for the cadmium/copra meal system increased steadily from 0.173 to 0.640 g/mg min for temperature increase from 297 K to 333 K. The sorption capacity decreased from 2.27 mg/g to 0.296 mg/g, and the initial sorption rate decreased from 0.895 mg/g min to 0.0559 mg/g min, when the temperature was increased from 297 K to 333 K. The increase in the equilibrium sorption of cadmium with temperature indicates

that a low temperature favours cadmium removal by sorption on copra meal because an elevation in temperature increases the escaping tendency of cadmium from an interface (Pandey et al., 1984). This effect suggests that an explanation of the sorption mechanism associated with the removal of cadmium onto copra meal involves a physical process. Similar decreases in cadmium capacity with temperature was also observed by using biosorbents such as *Chlorella vulgaris* (Aksu, 2001) and dead *Sargassum* sp. (Cruz et al., 2004) as well as hematite (Singh et al., 1998) and cadmium on chitin (Benguella and Benaissa, 2002). This indicates that the biosorption process of cadmium onto coconut copra meal is exothermic.

**Figure 4** Effect of temperature on the sorption of cadmium ions onto copra meal



**Figure 5** Pseudo-second-order sorption kinetics of cadmium ions onto copra meal at various temperatures



**Table 3** The effect of changing temperature on cadmium adsorption at 201 mg/dm<sup>3</sup>

<i>T</i> , K	<i>q<sub>e</sub></i> , mg/g	<i>k</i> , g/mg min	<i>h</i> , mg/g min	<i>R</i> <sup>2</sup>
297	2.27	0.173	0.895	1.000
311	1.20	0.283	0.407	1.000
323	0.587	0.439	0.151	1.000
333	0.296	0.640	0.0559	1.000

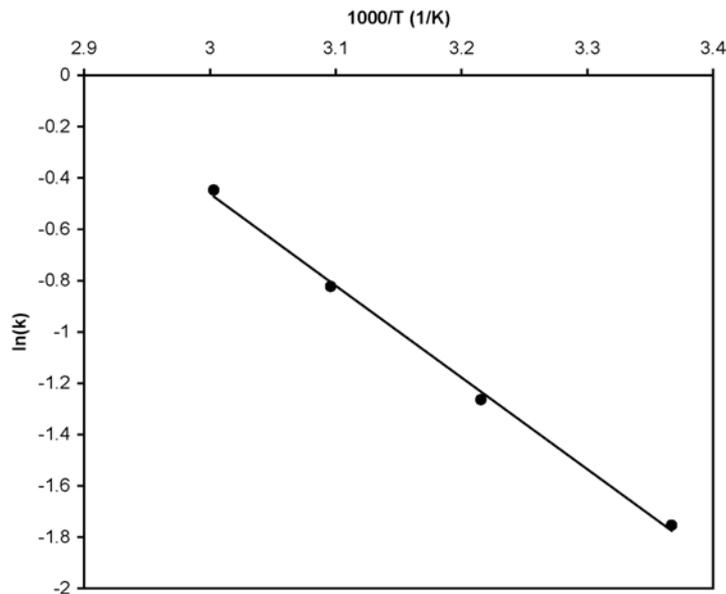
A linear relationship was found to exist between the pseudo-second-order rate constant, *k* and the reciprocal of the reaction temperature ( $r^2 = 0.997$ ). Therefore, the sorption rate constant may be expressed as a function of temperature by the following relationship:

$$k = k_0 \exp\left\{\frac{-E}{RT}\right\} \quad (8)$$

The relationship between *k* and *T* can be represented in an Arrhenius form as

$$k = 2.90 \times 10^4 \exp\left\{\frac{-29.8}{8.314T}\right\} \quad (9)$$

From the equation, the temperature-independent factor, *k*<sub>0</sub>, is  $2.90 \times 10^4$  g/mg min. Furthermore, the activation energy of sorption, *E*, is 29.8 kJ/mole for the sorption system of cadmium on copra meal (Figure 6). Singh et al. (1998) obtained activation energy of 42.2 kJ/mole for sorption of cadmium on hematite. Because the sorption of cadmium onto copra meal is an exothermic process, an increasing solution temperature would be expected to result in a decreased sorption capacity.

**Figure 6** Relationship between rate constant and temperature

#### 4 Conclusion

The removal of cadmium ions by coconut copra meal was a function of initial cadmium ion concentration and temperature. The sorption capacity of cadmium ions from solution increased with increasing initial cadmium concentration and decreasing reaction temperature. The kinetics of cadmium ion sorption onto copra meal was based on the assumption of the pseudo-second-order explanation. An activation energy of sorption has been obtained based on the pseudo-second-order rate constants. The Redlich-Peterson and the Langmuir isotherms have higher coefficients of determination than the Freundlich isotherm for the sorption of cadmium onto coconut copra meal. Langmuir isotherm is a special case of Redlich-Peterson isotherm when constant  $g$  was unity.

#### References

- Aksu, Z. (2001) 'Equilibrium and kinetic modelling of cadmium(II) biosorption by *C. Vulgaris* in a batch system: effect of temperature', *Separation and Purification Technology*, Vol. 21, No. 3, pp.285–294.
- Bailey, S.E., Olin, T.J., Bricka, R.M. and Adrian, D.D. (1999) 'A review of potentially low-cost sorbents for heavy metals', *Water Research*, Vol. 33, No. 11, pp.2469–2479.
- Benguella, B. and Benaissa, H. (2002) 'Cadmium removal from aqueous solutions by chitin: kinetic and equilibrium studies', *Water Research*, Vol. 36, No. 10, pp.2463–2474.
- Chu, K. and Hashim, M. (2003) 'Modeling batch equilibrium and kinetics of copper removal by crab shell', *Separation Science and Technology*, Vol. 38, No. 16, pp.3927–3950.
- Cruz, C.C.V., da Costa, A.C.A., Henriques, C.A. and Luna, A.S. (2004) 'Kinetic modeling and equilibrium studies during cadmium biosorption by dead *Sargassum* sp. biomass', *Bioresource Technology*, Vol. 91, No. 3, pp.249–257.
- Fourest, E. and Roux, J.C. (1992) 'Heavy-metal biosorption by fungal mycelial by-products: mechanisms and influence of pH', *Applied Microbiology and Biotechnology*, Vol. 37, No. 3, pp.399–403.
- Ho, Y.S. (1995) *Adsorption of Heavy Metals from Waste Streams by Peat*, PhD Thesis, Faculty of Engineering, University of Birmingham, UK.
- Ho, Y.S. (2004a) 'Comment on 'Removal of copper from aqueous solution by aminated and protonated mesoporous aluminas: kinetics and equilibrium'', in Rengaraj, S., Kim, Y., Joo, C.K. and Yi, J. (Eds.): *Journal of Colloid and Interface Science*, Vol. 276, No. 1, pp.255–258.
- Ho, Y.S. (2004b) 'Pseudo-isotherms using a second order kinetic expression constant', *Adsorption-Journal of the International Adsorption Society*, Vol. 10, No. 2, pp.151–158.
- Ho, Y.S. and McKay, G. (1998a) 'Sorption of dye from aqueous solution by peat', *Chemical Engineering Journal*, Vol. 70, No. 2, pp.115–124.
- Ho, Y.S. and McKay, G. (1998b) 'Kinetic model for lead(II) sorption on to peat', *Adsorption Science and Technology*, Vol. 16, No. 4, pp.243–255.
- Ho, Y.S. and McKay, G. (1999) 'Pseudo-second order model for sorption processes', *Process Biochemistry*, Vol. 34, No. 5, pp.451–465.
- Ho, Y.S. and McKay, G. (2000) 'The kinetics of sorption of divalent metal ions onto sphagnum moss peat', *Water Research*, Vol. 34, No. 3, pp.735–742.
- Ho, Y.S. and Wang, C.C. (2004) 'Pseudo-isotherms for the sorption of cadmium ion onto tree fern', *Process Biochemistry*, Vol. 39, No. 6, pp.759–763.
- Ho, Y.S., Chiu, W.T., Hsu, C.S. and Huang, C.T. (2004) 'Sorption of lead ions from aqueous solution using tree fern as a sorbent', *Hydrometallurgy*, Vol. 73, Nos. 1–2, pp.55–61.

- Jadhav, D.N. and Vanjara, A.K. (2004) 'Adsorption kinetics study: removal of dyestuff effluent using sawdust, polymerized sawdust and sawdust carbon-II', *Indian Journal of Chemical Technology*, Vol. 11, No. 1, pp.42–50.
- Khalid, N., Rahman, A., Ahmad, S., Kiani, S.N. and Ahmed, J. (1998) 'Adsorption of cadmium from aqueous solutions on rice husk', *Radiochimica Acta*, Vol. 83, No. 3, pp.157–162.
- Lagergren, S. (1898) 'Zur theorie der sogenannten adsorption gelöster stoffe. *Kungliga svenska vetenskapsakademiens*', *Handlingar*, Vol. 24, No. 4, pp.1–39.
- McCoy, M.A. and Liapis, A.I. (1991) 'Evaluation of kinetic models for biospecific adsorption and its implications for finite bath and column performance', *Journal of Chromatography A*, Vol. 548, Nos. 1–2, pp.25–60.
- McKay, G., Blair, H.S. and Gardner, J.R. (1983) 'The adsorption of dyes in chitin. III. Intraparticle diffusion processes', *Journal of Applied Polymer Science*, Vol. 28, pp.1767–1778.
- Mohan, S.V., Rao, N.C. and Karthikeyan, J. (2002) 'Adsorptive removal of direct azo dye from aqueous phase onto coal based sorbents: A kinetic and mechanistic study', *Journal of Hazardous Materials*, Vol. 90, No. 2, pp.189–204.
- O'Shannessy, D.J. and Winzor, D.J. (1996) 'Interpretation of deviations from pseudo-first-order kinetic-behavior in the characterization of ligand binding by biosensor technology', *Analytical Biochemistry*, Vol. 236, No. 2, pp.275–283.
- Orhan, Y. and Büyükgüngör, H. (1993) 'The removal of heavy metals by using agricultural wastes', *Water Science and Technology*, Vol. 28, No. 2, pp.247–255.
- Panday, K.K., Prasad, G. and Singh, V.N. (1984) 'Removal of Cr(VI) from aqueous solution by adsorption on fly ash-wollastonite', *Journal of Chemical Technology and Biotechnology A-Chemical Technology*, Vol. 34, No. 7, pp.367–374.
- Prasad, M. and Saxena, S. (2004) 'Sorption mechanism of some divalent metal ions onto low-cost mineral adsorbent', *Industrial and Engineering Chemistry Research*, Vol. 43, No. 6, pp.1512–1522.
- Saiers, J.E., Hornberger, G.M. and Liang, L. (1994) 'First- and second-order kinetics approaches for modeling the transport of colloidal particles in porous media', *Water Resources Research*, Vol. 30, No. 9, pp.2499–2506.
- Singh, D.B., Rupainwar, D.C., Prasad, G. and Jayaprakas, K.C. (1998) 'Studies on the Cd(II) removal from water by adsorption', *Journal of Hazardous Materials*, Vol. 60, No. 1, pp.29–40.
- Sun, Q.Y. and Yang, L.Z. (2003) 'The adsorption of basic dyes from aqueous solution on modified peat-resin particle', *Water Research*, Vol. 37, No. 7, pp.1535–1544.
- Weber Jr., W.J. and Morris, J.C. (1963) 'Kinetics of adsorption on carbon from solution', *Journal of the Sanitary Engineering Division-ASCE*, Vol. 89, pp.31–59.
- Zaror, C.A. (1997) 'Enhanced oxidation of toxic effluents using simultaneous ozonation and activated carbon treatment', *Journal of Chemical Technology and Biotechnology*, Vol. 70, No. 1, pp.21–28.
- Zeldowitsch, J. (1934) 'Über den mechanismus der katalytischen oxydation von CO an  $MnO_2$ ', *Acta Physicochimica U.R.S.S.*, Vol. 1, Nos. 3–4, pp.449–464.
- Zheng, S.K., Yang, Z.F., Jo, D.H., Park, Y.H. and Ho, Y.S. (2005) 'Comment on 'Removal of chlorophenols from groundwater by chitosan sorption'', *Water Research*, Vol. 39, No. 1, pp.264–268.

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