

Second Order Kinetic Model for the Adsorption of Cobalt(II) Ions onto Two Cameroonian Clays: Kaolinite and Smectite

Horace Manga Ngomo*, Charles Fon Abi¹, Gaëlle Tatiana Ngnie Tuemgnie, Patrice Kenfack Tsobnang and Joseph Ketcha Mbadcam

Physical and Theoretical Chemistry Laboratory, Faculty of Science, University of Yaoundé 1
P.O. Box 812, Yaoundé, Cameroon

¹Department of Chemistry, Higher Teachers' Training College, University of Yaoundé 1
P.O. Box 47, Yaoundé, Cameroon

✉ ngomo43@yahoo.co.uk

Received July 8, 2010; revised and accepted May 15, 2012

Abstract: The removal of Co(II) ions by two Cameroon clays—kaolinite and smectite as adsorbents—was investigated in a batch system. The effect of Co(II) ions initial concentration, Co, pH and contact time, t , has been studied in terms of kinetic models. The experimental data fitted well the pseudo-second order kinetic model allowing the rate constant to be evaluated. This study shows that these clays could be used as important efficient adsorbent materials for the uptake of Co(II) ions from aqueous solution at low initial concentrations. This study is important for the treatment of Co(II) ions effluent where continuous removal can be achieved on a large scale.

Key words: Adsorption, cobalt(II) ions, kinetic models, kaolinite, smectite.

Introduction

The Lomié deposit in Cameroon, which will be exploited for the next 200 years, will make this country the main producer of cobalt and nickel in the world. The extraction of these metals will cause the pollution of ground water in these areas due to leaching of these metals from the top soils by rain water, erosion of the exploited sites and spillage of storage sites. These metals are stable and persistent in the environment because they cannot degrade or be destroyed (Kocaoba et al., 2008). The discharge of cobalt to surface water and their accumulation by aquatic organisms and sediments are drawing attention to the cycling and fate of this element in aquatic systems (Kim et al., 1995; Ebner et al., 2001; Misak et al., 1992; Boyle et al., 2002; Netzer and Hughes, 1984; Chiu and Wang, 2009; Kocaoba and Akyuz, 2005;

Baek and Yang, 2004; Yavuz et al., 2003; Kara et al., 2003). For a daily ingestion of 0.04 to 0.14 mg/kg, the health implication on humans includes pneumonia, fibroses and respiration irritation.

Considerable research has been carried-out in developing cost-effective metal removal techniques, among which are precipitation, ion exchange, electrochemical treatment, filtration, distillation, reverse osmosis, ultrafiltration and adsorption. The available conventional techniques are ineffective or extremely expensive, especially when the metals are dissolved in large volumes of solution yielding relatively low concentration (Kim et al., 1995; Ebner et al., 2001; Misak et al., 1992; Boyle et al., 2002; Netzer and Hughes, 1984; Chiu and Wang, 2009; Kocaoba and Akyuz, 2005; Baek and Yang, 2004; Yavuz et al., 2003; Kara et al., 2003).

Adsorption is frequently the most economical methods

*Corresponding Author

for this purpose, especially using low-cost naturally occurring adsorbents as clays (Chiu and Wang, 2009; Kocaoba and Akyuz, 2005; Baek and Yang, 2004; Yavuz et al., 2003; Kara et al., 2003). The attraction of adsorption to researchers is due to the simplicity of the adsorption process and equipment available. In addition, the adsorbents are of a wide variety and are abundant. For this reason, literature has recorded several research works on the elimination of toxic substances, particularly heavy metals from liquid solution. The adsorption of cobalt(II) ions onto solid surface has been investigated with adsorbents such as inorganic metal oxides (Kim et al., 1995; Ebner et al., 2001; Misak et al., 1992; Boyle et al., 2002), activated carbon (Netzer and Hughes, 1984) and clays (Chiu and Wang, 2009; Kocaoba and Akyuz, 2005; Baek and Yang, 2004; Yavuz et al., 2003; Kara et al., 2003).

The aim of the present report is to study the adsorption of Co(II) ions on two local clays obtained from two different regions in Cameroon. The effect of Co(II) ions initial concentrations, C_0 , pH and contact time, t , has been studied in terms of the kinetic models.

Experimental Section

Adsorbent Samples

The adsorption of Co(II) ions from aqueous solution by two local clays from Cameroon, kaolinite and smectite, has been carried out. The kaolinite comes from Mayoum, a region in the west of Cameroon and the smectite is obtained from Sabga, a region in the north-west of Cameroon. The characteristics of the kaolinite and smectite samples have been reported in an earlier work (Njoya et al., 2007; Tonle et al., 2003). Their physicochemical properties are respectively, $\text{pH}_{\text{SME}} (5.85) < \text{pH}_{\text{KAO}} (6.27)$. They are both gray in colour with their specific surface areas of $700 \text{ m}^2/\text{g}$ and $86 \text{ m}^2/\text{g}$ respectively. Their cation exchange capacities (CEC) in $\text{meq}/100 \text{ g}$ are respectively, 86×10^2 and 78×10^2 . The chemical composition of these clay samples are shown in Table 1. The adsorbents were first dried in air and then crushed in a china mortar, sieved at $180 \mu\text{m}$ particle sizes (mesh). They were then homogenised in a Retsh

shaker and dried in an Hereaus oven at 120°C for 24 hours to remove adsorbed water and volatile impurities. Initial concentrations of the Co(II) salt solutions ranged from $8.5 \times 10^{-3} \text{ M}$ to $3.5 \times 10^{-2} \text{ M}$. The residual concentrations were measured by using an *Aqualytic* UV Visible spectrophotometer at 519 nm .

Kinetic Batch Adsorption Experiments

The batch kinetic experiments of the adsorption studies were carried out at room temperature in a 150 mL conical flask. For each run, 1 g of the adsorbent was weighed and placed in the flask containing a solution of Co^{2+} ions at the desired concentration. Three concentrations of Co^{2+} ions solutions, namely $8.5 \times 10^{-3} \text{ M}$, $2.75 \times 10^{-2} \text{ M}$ and $3.5 \times 10^{-2} \text{ M}$ were prepared. The suspension was stirred for 5 to 90 minutes by using a magnetic stirrer. Care was taken to ensure that all the particles of the adsorbents remained in solution during each run. At the end of the run, the suspension was allowed to settle for about two minutes and the supernatant liquid obtained by using a filter paper. The pH values of the Co(II) ions in solution were maintained at 1 to 6, as measured by using a Hanna pH-meter and the solutions adjusted by using solutions of either HCl or NaOH.

From the measurements of the difference between the initial concentration, C_0 and the concentration at some time, C_t , in moles/L, the percent Co^{2+} ion adsorbed onto these clay materials was calculated as $\%P = (C_0 - C_t)/C_0 \times 100$.

The kinetics of the Co^{2+} ion adsorption was modelled by equations shown in Table 2. The conformity between experimental data obtained and the kinetic models used was expressed by the correlation coefficient values, R^2 . A relatively high R^2 value indicates that the model successfully describes the kinetics data obtained.

Results and Discussion

According to the structures of the kaolinite and smectite clays (Njoya et al., 2007; Tonle et al., 2003) the adsorption of metal ions can be described by two mechanisms (Benhammou et al., 2005; Abollino et al., 2003; Kraepiel et al., 1999): pH-independent adsorption and pH-

Table 1: Chemical composition of the clay samples

Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	$\text{SiO}_2/\text{Al}_2\text{O}_3$	LI	Total
Kaolinite	46.4	34.4	1.0	<1.d	<1 .d	<1.d	0.9	4.0	0.3	1.3	12.	99.9
Smectite	63.3	14.5	4.2	0.2	0.7	0.4	2.3	0.2	<1.d	4.3	13	98.8

LI: Lost at Ignition ($25\text{-}1000^\circ\text{C}$)

Table 2: Equations for fitting different kinetic models

Kinetic models	Linear plots	Equations
First order	$\ln (q_{eq}-q_t)$ vs. t	$\ln (q_{eq}-q_t) = \ln (q_{eq}) - k_1 t$
Second order	t/q_{eq} vs. t	$t/q_t = 1/h + 1/q_{eq} t$
Elovich	q_t vs. $\ln (t)$	$q_t = 1/\beta x \ln (\alpha\beta) + 1/\beta \ln t$
Intraparticle diffusion	$\ln (\%P)$ vs. t	$\ln (\%P) = \ln k_{id} + a \ln (t)$

where q_{eq} is adsorbed Co(II) ion at equilibrium, t is adsorption reaction time, q_t is adsorbed Co(II) ion at time t , k_1 (min^{-1}) is the first order adsorption rate constant, v_0 is the initial sorption rate, ($\text{mol g}^{-1} \text{min}^{-1}$) $= k_2 q_{eq}$, k_2 ($\text{g mol}^{-1} \text{min}^{-1}$) is the second order adsorption rate constant, k_{id} (min^{-1}) is the overall diffusion adsorption rate constant, and a , h and β are constants.

dependent adsorption. Generally, pH-independent adsorption is attributed to cation exchange in the interlayer resulting from electrostatic interactions between ions and negative permanent charge. This has been observed with the isomorphic replacement of Al^{3+} by Mg^{2+} or Fe^{2+} in the octahedral layer. The cationic exchange reaction mechanism implies that the Na^+ is exchanged for the metal cation as follows:



A pH-dependent adsorption is a result of surface complexation reaction mechanisms and uses the silanol (Si-OH) and aluminol (Al-OH) sites located at the edges of the layer (Benhammou et al., 2005; Abollino et al., 2003; Kraepiel et al., 1999). The surface complexation reaction mechanism of the Co^{2+} cation can be described as follows:



where X-OH is the amphoteric surface hydroxyl groups (Si-OH or Al-OH). This mechanism is pH-dependent because in acidic conditions ($\text{pH} \leq 4$) most silanol and aluminol groups are protonated.

Effect of Initial Concentration

The percentage Co^{2+} ions removed at two different initial concentrations on the two adsorbents, used in this work for the same mass of adsorbent, decreases with increased initial concentration (Figure 1). At this low initial concentration, the kaolinite adsorbs better than the smectite.

Effect of Contact Time

Figure 1 represents the percent Co(II) ions removed from solution and increases with increased contact time for both the smectite and the kaolinite. It was observed that 60 minutes was enough time to reach equilibrium. The

silanol (Si-OH) and aluminol (Al-OH) sites located at the edges of the layer (Benhammou et al., 2005; Abollino et al., 2003; Kraepiel et al., 1999; Bouras, 2003) are well exposed and the adsorption mechanism is easier (Bouras, 2003). When Co^{2+} ions are fixed on specific sites in the first 60 minutes, the pores are occluded and the percent adsorption of the Co(II) ion becomes constant. A maximum adsorption is observed at 90% for the kaolinite and 70% for the smectite. As the positively charged ion approaches the surfaces of the adsorbents, it induces the surface to exhibit negatively charged property and the attraction between the two dipoles which are likely to lower the potential energy between them occurs and eventually brings about adsorption.

Similar results on the equilibrium adsorption capacity were reported for the removal of metal ions from synthetic waste water by activated carbon obtained from eucalyptus bark (Kongsuwan and Patnukao, 2006). It has been shown that adsorption takes place on the edge-surface Al^{3+} present on clays (Siffert and Trescol, 1982). The enhanced adsorption of cobalt(II) ions with increased

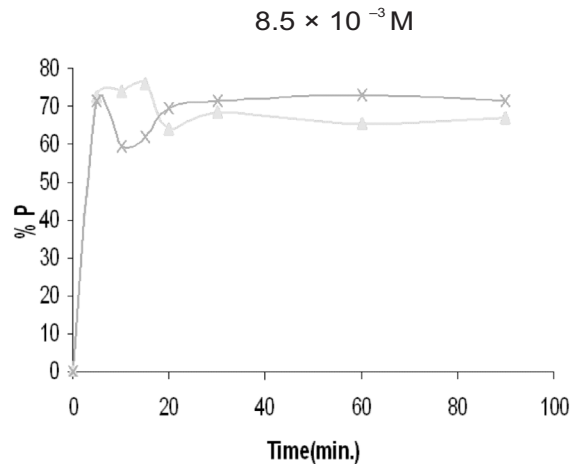


Figure 1: Percentage of Co(II) ions adsorbed by different adsorbents (A = Kaolinite; B = Smectite) as a function of time.

agitation time may be due to the decrease in boundary layer resistance to mass transfer in the bulk solution and an increase in the kinetic energy of hydrated ions.

Effect of pH

The adsorption of Co^{2+} ions on kaolinite and smectite shows a significant variation with pH in the range of 1-6 as shown in Figure 2. For the same concentration ca 8.5×10^{-3} M, the plots of %P against pH show that the removal on smectite increases from pH = 1 and reaches a maximum at pH = 3; there is then a slight decrease to pH = 5 before getting finally to pH = 6. At the high Co(II) ion initial concentration ca 3.5×10^{-2} M, both the kaolinite and the smectite show a decrease percent Co(II) ion removal with a decreased pH from pH = 1 to pH = 3 before showing an increase from pH = 5 to pH = 6. Clays can accumulate ionic species at their surfaces by many types of interactions due to the presence of hydroxyls groups: silanol and aluminol. The mechanism is an exchange of Co^{2+} ions for Al-O^- groups at the rate of one cation per adsorbing anion (Hefne and Mekhemer, 2008). It was concluded in this work that the adsorption of Pb(II) ions on natural bentonite over a pH range of 2-8 at a constant clay amount of 10 g/L, the system controls the adsorption capacity due to its influence on the surface properties of the adsorbents and ionic forms of the lead ions in solution (Hefne and Mekhemer, 2008; Demirbas, 2003).

There is a strong dependence of pH on the kinetic adsorption of Co(II) ions on these clay materials used in this work, consistent with work reported in the literature. In solution, species that tend to ionise are more affected by pH of the solution; and as the pH changes, the surface charge also changes and the adsorption of charged species are affected. At pH = 1, the affinity for H^+ ions to adsorb on the clays is higher than Co^{2+} ions. The clay fixes H^+ ions in the medium at the same moment with Co^{2+} ions, such that there is competitive adsorption on same sites on the clays. This will reduce the possibility of Co^{2+} ions adsorbing and explains why for both clays, the percent uptake is lower. Similar phenomena were observed for the adsorption of Copper(II) and Cadmium(II) ions onto activated carbon from rice hulls (Tekere and Imamoglu, 1999).

At low pH values, where the initial pH values are between 1 and 3, a decrease in Co(II) ions removal efficiency is observed. This phenomenon has been attributed to the fact that in solution, cobalt species exist only in the divalent ionic form (Co^{2+}), which is favourable for removal by the clays (Kim and Lee, 2001). At pH = 5 and pH = 6, metallic ions in solution are in the hydrolysed form. These are the species that are most favoured by

the reaction mechanism whereby there is a direct exchange of the Co^{2+} ions with specific silanol (Si-OH) and aluminol (Al-OH) sites located at the edges of the layer clay adsorbents (Benhammou et al., 2005; Abollino et al., 2003; Kraepiel et al., 1999; Bouras, 2003).

A variety of the chemical forms of cobalt (CoOH^+ , CoX^+) existing at high pH regions may play roles that diminishes the overall Co(II) ion removal efficiency on smectite. However, at the pH of 6, the performance of kaolinite is unaffected by the appearance of hydrolysed species. This could be explained by the fact that the high surface area of kaolinite: $700 \text{ m}^2/\text{g}$ as against $86 \text{ m}^2/\text{g}$ for smectite, also plays a significant role. It further explains why the amplitude of oscillation is less in kaolinite than in smectite. As shown in Figure 2, the pH of the solution is clearly a key factor affecting the adsorption characteristics of Co^{2+} ions onto clays in aqueous solution (Serpaud and Alshukry, 1994).

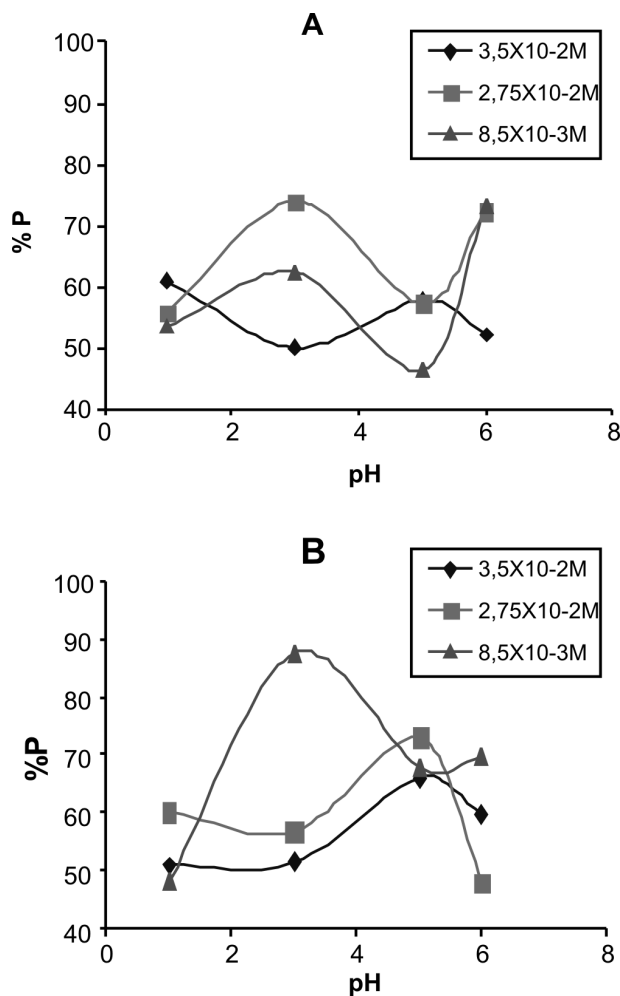


Figure 2: Influence of pH on the percentage of adsorption of cobalt(II) ions at different initial concentrations on A = Kaolinite and B = Smectite.

Adsorption Kinetics Models

The kinetics of Co^{2+} ion adsorption on kaolinite and smectite in aqueous solution to obtain kinetic parameters was modelled by equations represented in Table 2. The conformity between experimental data and model predicted values was expressed by the correlation coefficient, R^2 , values that were close or equal to 1 as shown in Table 3. A relatively high R^2 value indicates that the model successfully describes the kinetics of the adsorption of Co(II) ion. The kinetic parameter values obtained for each model including the correlation coefficient, R^2 values are represented in this table. For the pseudo 1st order equation, with the least R^2 value of 0.423 is obtained for smectite and the highest value of 0.645 is obtained for kaolinite. It would appear it may not be a straight forward linear mechanism and the transfer resistances are important. The non-applicability of the pseudo 1st order model shows that the adsorption rate does not directly depends only on Co(II) ions concentration, but on other surface interactions. The k_1 value increases from kaolinite to smectite confirming the fact that greater adsorption occurs at the surface of the smectite.

The plot of the equation of the pseudo 2nd order gave very good straight lines values of the correlation coefficient, R^2 close to 1. These values of R^2 show that the pseudo 2nd order equation gave a better fit to the adsorption process (Kim and Lee, 2001). It has been shown in the literature that the rate mechanism is appreciably controlled by chemisorption of the different species that exist at the surface of the adsorbents (Hefne and Mekhemer, 2008). Thus, exchanges between the cationic exchange reaction mechanism implies that the Na^+ is exchanged for the metal cation OR surface complexation reaction mechanisms that uses the silanol (Si-OH) and aluminol (Al-OH) sites located at the edges of the layer to complex the Co(II) ions that are more determinant than forces of physisorption (Benhammou

et al., 2005; Abollino et al., 2003; Kraepiel et al., 1999). This is because pH-independent adsorption is attributed to cation exchange in the interlayer resulting from electrostatic interactions between ions and negative permanent charge; and pH-dependent adsorption is a result of surface complexation reaction mechanisms and uses the silanol (Si-OH) and aluminol (Al-OH) sites located at the edges of the layer. This has been observed with the isomorphic replacement of Al^{3+} by Mg^{2+} or Fe^{2+} in the octahedral layer. Therefore, chemisorption is the rate limiting step. It involves valence forces caused by the sharing or exchange of electrons between adsorbent and adsorbate as shown by the complexation reaction mechanism equations 2, 3, 4 and 5 above.

As regards the Elovich model, the variation of the correlation coefficient, R^2 value shows that this model gives a better fit with the experimental data for the adsorption of Co(II) ions on kaolinite. The higher value of the desorption constant β shows that during this process, desorption occurs. It has been shown from published results that this can be due to the phenomenon of bond breaking and bond forming of ionic bonds on specific sites on the adsorbents during the adsorption process of Co^{2+} ion (Gupta et al., 2007).

The plots of $\text{Ln}(\%P)$ against $\text{Ln } t$ of the intraparticle diffusion model equation are straight lines. The highest correlation coefficient, R^2 value obtained is $R^2 = 0.9228$ for the adsorption of Co(II) ions on kaolinite (Table 3). In the equation, in the Table 1, a represents the adsorption mechanism and k_{id} is a rate factor. Higher values of k_{id} illustrates an enhancement in the rate of adsorption, whereas larger a values show a better adsorption mechanism.

Therefore, the intraparticle mass transfer resistance is the rate limiting step. A similar result has been reported in the literature for the kinetic study of nitrite adsorption onto Sepiolite and powdered Activated Carbon (Kose and Ozturk, 2007).

Table 3: Determination of the kinetic parameters for cobalt(II) ions adsorption on the different clays from linear plots

Samples	Pseudo 1 st order		Pseudo 2 nd order			Elovich			Intraparticle diffusion		
	$k_1 \times 10^3$ (min^{-1})	R^2	$k_2 \times 10^3$ (g/mol min)	h	R^2	$\alpha \times 10^4$	β	R^2	K_{id} (min^{-1})	$a \times 10^2$	R^2
Kaolinite	4.8	0.65	22.5	12.55	1.000	1.67	38.02	0.915	85.48	9.70	0.923
Smectite	6.5	0.42	665.2	1.50	0.998	185.45	14.62	0.438	69.29	5.09	0.440

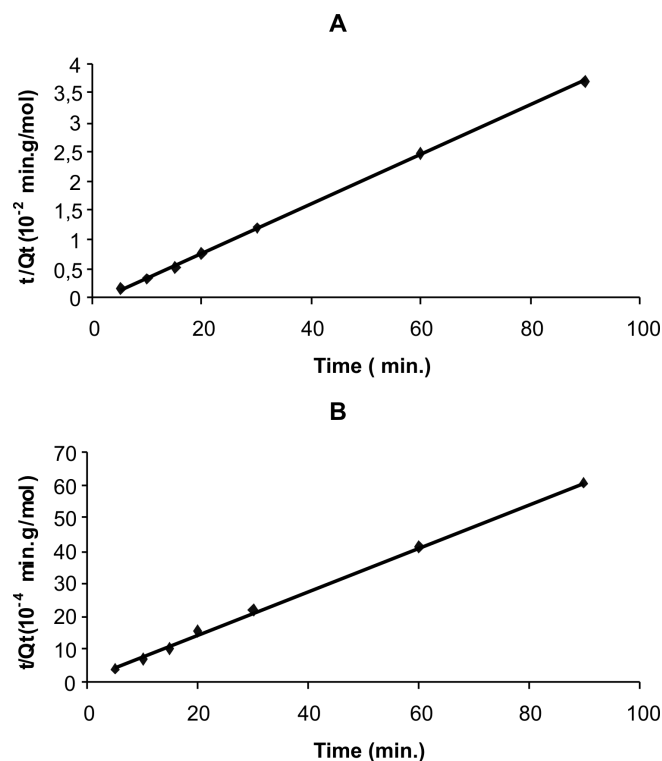


Figure 3: Kinetic model of pseudo 2nd order for A = Kaolinite and B = Smectite at 8.5×10^{-3} M pH = 6 and 8.5×10^{-3} M pH = 3 respectively.

Conclusion

The Cameroonian kaolinite and smectite clays can be suitable adsorbents for the efficient removal of Co^{2+} ions at low concentrations from water and wastewaters, as the kinetics are highly favourable. The results reported here show that they can be compared to other adsorbents used to treat Co(II) ions contaminated wastewaters. The kinetics of their adsorption is rapid in the initial stages of the adsorption process, followed by a slow rate. The adsorption of Co(II) ions onto these clay materials was complete in 60 minutes.

The adsorption of Co^{2+} ions from synthetic solutions was examined. The process of uptake was found to be pH-dependent; the efficiency of the adsorption onto the two Cameroonian clay samples generally increases with increasing pH from 3 to 6. The variation of pH for the three different initial concentrations of Co(II) ions in solution on the two clays shows that the maximum condition of elimination of Co^{2+} ions are at 8.5×10^{-3} M at pH = 6 (73.13%) and at 2.75×10^{-2} M at pH = 3 (76.20%) for kaolinite and at 8.5×10^{-3} M at pH = 3 (87.46%) for smectite.

The adsorption kinetic model that gives the best fit for the adsorption conditions used to obtain the experimental data in this work is the pseudo 2nd order. The limiting step is therefore the chemisorption of Co^{2+} ions at the surfaces of kaolinite and smectite.

Acknowledgement

We thank all the members of the Research Group: "Adsorption and Surface", of the Physical and Theoretical Chemistry Laboratory of the University of Yaoundé I, for their useful remarks and suggestions.

References

- Abollino, O., Aceto, M., Malandriho, M., Sarzanini, C. and E. Mentasti (2003). Adsorption of Heavy Metals on Na-Montmorillonite Effect of pH and Organic Substances. *Water Res.*, **37**: 1619-1627.
- Benhammou, A., Yaacoubi Nibou, L. and B. Tanouti (2005). Adsorption of Metal Ions onto Moroccan stevensite: Kinetics and Isotherm studies. *J. Colloid Interface Sci.*, **282**: 320-326.
- Baek, K. and J.W. Yang (2004). Sorption and desorption characteristics of cobalt in clay: Effects of humic acids. *Korean J. Chem. Eng.*, **21**: 989-993.
- Bouras, O. (2003). Propriétés Adsorbantes d'Argiles Pontées Organophiles : Synthèse et Caractérisation. Thèse de Doctorat en Chimie et Microbiologie de l'Eau, Université de Limoges, Limoges, France.
- Boyle-Wight, E.J., Katz, L.E. and K.F. Hayes (2002). Macroscopic studies of the effects of selenate and selenite on cobalt sorption to $\gamma\text{-Al}_2\text{O}_3$. *Environ. Sci. Technol.*, **36**: 1212-1218.
- Chiu, H.S. and J.J. Wang (2009). Adsorption Thermodynamics of Cobalt Ions onto Attapulgite. *JEPS*, **3**: 102-106.
- Demirbas E. (2003). Adsorption of Co(II) ions from Aqueous Solution onto Activated Carbon prepared from Hazelnut Shells. *Adsorpt. Sci. Technol.*, **21(10)**: 951-963.
- Ebner, A.D., Ritter, J.A. and J.D. Navratil (2001). Adsorption of cerium, strontium and cobalt ions on magnetite and a magnetite-silica composite. *Ind. Eng. Chem. Res.*, **40**: 1615-1623.
- Gupta, B., Begum, Z. and G. Rajput (2007). Equilibrium and Kinetic Studies for the Adsorption of Mn(II) and Co(II) from Aqueous Media using Agar-agar as Sorbent. *Res. J. Chem. Environ.*, **11**: 16-20.
- Hefne, J. and W. Mekhemer (2008). Kinetic and Thermodynamic Study of the Adsorption of Pb(II) from Aqueous solution to the Natural and Treated Bentonite. *Internat. J. Phys. Sci.*, **3(11)**: 281-288.

- Kara, M., Yuzer, H., Sabah, E. and M.S. Celik (2003). Adsorption of cobalt from aqueous solutions onto sepiolite. *Water Res.*, **37**: 224-232.
- Kim, K.R., Lee, K.J. and J.H. Bae (1995). Characteristics of cobalt adsorption on prepared TiO_2 and Fe-Ti-O Adsorbents in High-Temperature Water. *Sep. Sci. Technol.*, **30**: 963-979.
- Kim, Y. and K. Lee (2001). Synthesis of a Magnetic Composite Resin and its Cobalt Removal Characteristics in Aqueous Solution. *J. Nucl. Sci. Technol.*, **38(9)**: 785-792.
- Kocaoba, S. (2008). Adsorption of Nickel(II) and Cobalt(II) Ions and Application of Surface Complex Formation Model to Ion Exchange Equilibria. *Environ. Eng. Sci.*, **25(5)**: 697-702.
- Kocaoba, S. and T. Akyuz (2005). Effects of conditioning of sepiolite prior to cobalt and nickel removal. *Desalination*, **181**: 313-318.
- Kongsuwan, A. and P. Patnukao (2006). Removal of Metal Ion from Synthetic waste water by Activated Carbon from Eucalyptus Camaludulensis Dehn Bark, 2nd Joint International Conference on Sustainable Energy and Environment, Thailand.
- Kose, E. and N. Ozturk (2008). A Kinetic Study of Nitrite Adsorption onto Sepiolite and Powdered Activated Carbon. *Science Direct*, **223**: 174-179.
- Kraepiel, A.M.L., Keller, K. and F.M. Morel (1999). A Model for Metal Adsorption on Montmorillonite. *J. Colloid Interface Sci.*, **210**: 43-54.
- Misak, N.Z., Shabana, E.S.I., Mikhail, E.M. and H.F. Ghoneimy (1992). Kinetics of isotopic exchange and mechanism of sorption of Co(II) on hydrous stannic oxide. *Reactive Polymers*, **16**: 261-269.
- Netzer, A. and D.E. Hughes (1984). Adsorption of copper, lead and cobalt by activated carbon. *Water Res.*, **18**: 927-933.
- Njoya, D., Elimbi, A., Nkoumbou, C., Njoya, A., Njopwouo, D., Lecomte, G. and J. Yvon (2007). Contribution à l'Etude physico-chimique et Mineralogique des Argiles de Mayoum (Cameroun). *Annale de Chimie de Science des Matériaux*, **32(1)**: 55-68.
- Serpaud, B. and R. Alshukry (1994). Heavy Metals Adsorption (Cu, Zn, Cd, Pb) by Superficial Stream Sediments: Effect of pH, Temperature and Sediment Composition. *Revue des Sciences de l'eau*, **7**: 343-365.
- Siffert, B. and J. Trescol (1982). Adsorption of Alkylphosphoric acid on kaolinite and smectite in Water/Decane. *Clays Clay Miner*, **30(3)**: 185-190.
- Teker, M. and M. Imamoglu (1999). Adsorption of Copper and Cadmium ions by Activated Carbon from Rice Hulls. *Turkey Journal of Chemistry*, **23**: 185-191.
- Tonle, I., Ngameni, E., Njopwouo, D., Carteret, C. and A. Walcarius (2003). Functionalization of natural Smectite-type Clays by Grafting with Organosilanes: Physico-chemical Characterisation and Application to Mercury (II) Uptake. *Phys. Chem. Chem. Phys.*, **5**: 4951-4961.
- Yavuz, O., Altunkaynak, Y. and F. Guzel (2003). Removal of copper, nickel, cobalt and manganese from aqueous solution by kaolinite. *Water Res.*, **37**: 948-952.

Contents

<i>Editorial</i>	i
□ <i>Snapshot</i>	ii
Sustainable Design of Ship Breaking Industry in Developing Countries <i>Iftekhhar Khan, Harun Chowdhury, Firoz Alam and Arun Kumar</i>	1
The Impacts of Land-use/cover Change on Loktak Lake Water Quality in North-Eastern Region, India <i>S.C. Rai and Adon Raleng</i>	13
A Study on Arsenic Uptaking Capacity of Water Hyacinth <i>M.A. Islam, M.S. Rahman, S. Islam, A.N.M. Zakaria and K.M.R. Islam</i>	25
Detention Time as a Critical Parameter in Septic Tank Design <i>Chidozie Charles Nnaji and Jonah Chukwuemeka Agunwamba</i>	31
Genotoxicity of Bisphenol A on Root Meristem Cells of <i>Allium cepa</i> : A Cytogenetic Approach <i>V.V. Jadhav, A.S. Jadhav, C.A. Chandagade and P.D. Raut</i>	39
Treatment of Pharmaceutical Effluent by Photochemical Oxidation on Titanium Dioxide <i>S. Safiullah, G. Mohammad, M.A. Sabur and B.K. Howlader</i>	45
Triclosan Residues in Estuarine Sediments from Valliyar Estuary, Kanyakumari District, Tamil Nadu, India <i>T. Jeyakumar, P. Kodisundaram, A. Rajavel, Rajendra Kumar, M. Anbu, P. Latha and P. Roselet</i>	53
Physicochemical Investigation of Surface Water Quality of Urban Wetlands of Bangalore, India <i>Aboud S. Jumbe and N. Nandini</i>	59
Artificial Neural Network Model to Forecast the Concentration of Pollutants Over Delhi: Skill Assessment of Learning Rules <i>Sutapa Chaudhuri and Rajashree Acharya</i>	71
Increasing Pollution Level in River Yamuna—A Challenge to Sustainable Development of an Urban Centre, Delhi, India <i>Ghuncha Firdaus and Ateeque Ahmad</i>	83
Suitability of Ground Water for Irrigation in the Sheri Nala Basin, Sangli District, Maharashtra, India <i>A.S. Yadav and P.T. Sawant</i>	91
Approaches to Groundwater Vulnerability to Pollution: A Literature Review <i>Jawed Iqbal, A.K. Gorai, Poonam Tirkey and Gopal Pathak</i>	105
□ <i>Short Note</i>	
Assessment of Surface Water Quality of Godavari River at Aurangabad <i>Sachin Eknath Pote, S.K. Singal and D.K. Srivastava</i>	117
<i>Environment News Futures</i>	123