Eurasian J Soil Sci 2015, 4 (2) 126 - 136

Eurasian Journal of Soil Science

Journal homepage : http://fesss.org/eurasian_journal_of_soil_science.asp

Use of synthetic clay for Removal of Diclofenac Anti-inflammatory

Rachid Khatem [a,*], Real Ojeda Miguel [b], Abdellah Bakhti [a]

[a] Mostaganem University, Laboratory of Biodiversity and Conservation of Soil and Water, Mostaganem, Algerie
[b] Institute for Natural Resources and Agrobiology, IRNAS Sevilla, Spain

Abstract

The removal of diclofenac by sorption on a synthetic hydrotalcite and on its calcined product was investigated. The solid [Mg-Al-CO_3], prepared by cooprecipitation at constant pH, its calcined mixed oxide was obtained; both solid were characterized by X-ray diffraction and infrared spectroscopy (FTIR). The interaction of these materials with diclofenac shows that the kinetics of sorption was fast and followed the second order model. The effects on the diclofenac concentration, sorbent concentration and temperature were studied. The sorption capacity of the calcined hydrotalcite was close to 1.9 mmole g^{-1}, which represents only 66% of the AEC, but at the concentrations measured that amount represents up 95% of the diclofenac present in solution in the case of HT-C. This suggests that, particularly HT-C could to constitute interesting adsorbent for the removal of diclofenac. Recycling by restitution and calcination-rebuilding should support the recovery of this pollutant.

Article Info

Received : 18.08.2014
Accepted : 10.01.2015

Keywords: Calcined hydrotalcite, diclofenac, sorption capacity, desorption

Introduction

Pharmaceutical substances are of great interest in the environmental context in recent years because they were developed to be biologically active and can have the same physicochemical behavior for the trans-membrane movement, be persistent, accumulate and present biological effects on organisms that were not foreseen on the aquatic and terrestrial ecosystems (Casellas, 2006; Tixier et al., 2003; Göbel et al., 2007; Feitosa-Felizzola et al., 2007). The presence of certain drug products and their derivatives or metabolites has been widely established worldwide in particular in surface and groundwater, wastewater, mud of water purification plants used in land farming and in soils (Tixier et al., 2003; Göbel et al., 2007; Feitosa-Felizzola et al., 2007; Boxall et al., 2002; Heberer, 2002; Cleuvers, 2004; Tauxe-Wuersch et al., 2005; Vieno et al., 2006; Togola and Budzinski, 2008). Current knowledge of the risks of these substances on the natural environment are limited, but it is important to address the problem of drug residues that are now present at concentrations like many pesticides and some of which have already caused effects on wildlife (Cleuvers, 2004; Tauxe-Wuersch et al., 2005; Ferreira et al., 2007; Lúcia et al., 2010). These threats make it imperative to improve our knowledge of disposal methods of pharmaceutical substances in wastewater.

The anti-inflammatory non steroidal are among the most encountered drug substances in the water cycle in the environment (Cleuvers, 2004). Diclofenac is among the most concerned anti-inflammatory drugs because os it is widely distributed in the World pharmacopoeia under various names (Voltaren, Solaraze, ...) and present an acute toxicity and persistent toward the environment (Andreozzi et al., 2003; Hernando et al.,

---

* Corresponding author.
Mostaganem University, Laboratory of Biodiversity and Conservation of Soil and Water, Mostaganem, 27000 Algerie
Tel.: +213772348545
E-mail address: khatem_rachid@yahoo.fr
ISSN: 2147-4249

2006; Mehinto et al., 2010). It is little removed by treatment plants, which explains its frequent presence in surface waters (Tixier et al., 2003; Heberer and Feldmann, 2005).

Several studies have shown that layered double hydroxides (LDHs) can be used for the trapping of organic and inorganic chemical pollutants, especially those having anionic or acid character, because of their very high anion exchange capacity (Toraishi et al., 2002). The LDHs are similar to the natural hydrotalcite $Mg_6Al_2(OH)_{16}(CO_3)\bullet 4H_2O$, in which magnesium cations are replaced by aluminum cations. The partial substitution of trivalent cations by divalent cations generates an excess of positive charge on the sheets which is compensated by anionic species intercalated into the interlayer space, with water molecules. The most common anions in the interlayer space of LDHs are carbonate due to their small size relative to their charge (Mendiboure and Schöllhom, 1986), which has a very high affinity for these matrices and, therefore, they are difficult to be exchanged.

On another hand, LDHs upon calcinations lossed the carbonate anion and transform in a mixed oxide, which can regenerate, at least partiually, the layered structure by the uptake of carbonate and water from the atmosphere (De Roy et al., 1992). If the anion is destroyed by temperature during calcination, it can be replaced by another anion. In the same way, those mixed oxides in a solution containing the anion are rehydrated to form a new LDH phase with this new anion. By using this property of LDHs to regenerate by rehydration after calcinations, several authors have reported the intercalation of the anti-inflammatory diclofenac in LDHs matrices. Their objective is to incorporate these materials in pharmaceutical formulations as matrices for controlled release formulations (Del Hoyo, 2007; Ambrogi et al., 2002; San Román et al., 2012).

In this work, we were interested to study the possible use of LDH for the elimination of diclofenac in aqueous solution by sorption on a hydrotalcite on Mg-Al-CO_3 and by its calcination product. This environmental use is very different from the slow release supporting of the LDH, because its sorption capacity for diclofenac should be assessed as much lower concentration as it could correspond with its presence in surface or ground waters. We conducted tests of sorption to determine the optimal conditions for sorption of diclofenac on these solids (kinetics, solution pH, initial concentration of diclofenac, the sorbent mass and temperature).

Material and Methods

Synthesis of Materials

All chemicals were technical grade from Sigma-Aldrich ($Mg(NO_3)_2.6H_2O$, 99%; $Al(NO_3)_3.9H_2O$, 98,5%; $Na_2CO_3.10H_2O$, 99,5% and NaOH, 98%. LDHs containing carbonate as the interlayer anion was obtained by using a conventional coprecipitation method at constant pH, was inspired from previous works (De Roy et al., 1992; Del Hoyo, 2007; Ambrogi et al., 2002; San Román et al., 2012; Reichle, 1986). A solution of 0.2 mole of $Mg(NO_3)_2.6H_2O$ and 0,1 mole of $Al(NO_3)_3.9H_2O$ in 160 mL of distilled water were added dropwise with vigorous stirring to 200 mL of aqueous solution containing 0,7 mole of NaOH and 0,18 mole of $Na_2CO_3.10H_2O$. The pH of the resulting suspension was adjusted to 10 by HNO_3 (30%) and left stirred for 24 hours at room temperature. After 20 h of ripening at 65°C, the suspension was filtered and the solid obtained was washed several times with distilled water. The obtained material, denoted HT, was dried at 105 °C for 18 h, ground and sieved to 0.1 mm.

The HT material was calcined at 550° C with a temperature rise of 60 °C / hour, followed by a plateau of 2 hours at this temperature. The obtained solid is denoted HT-C. Several authors suggest a monitored calcination in order to prevent a too rapid departure of water molecules and carbonate anions, in the case of a phase Mg-Al-CO_3, which lead after the reconstruction, to a phase weakly crystallized (Newman and Jones, 1998).

Diclofenac used was the sodium salt form and it was purchased from Sigma-Aldrich, EC No 239-346-4) with a 98% purity. The solubility in water is 5mg/ml and the pKa of the acid form is 4.16 (Rafols et al., 1997).

Characterization Techniques

Powder X-ray diffraction pattern of the samples were obtained using a Philips diffractometer PW 1800 (line Kα du copper (λ = 1.5418 Å), 40 kV, 20 mA).The FTIR spectra in the range 4000–400 cm−1 of samples as KBr pellets were recorded with a Jasco spectrometer FT/IR-4200 Type A to 4 cm^{-1} resolution. Specific surface areas were measured from nitrogen adsorption/desorption isotherms on a Micromeritic Autochem

II 2920 instrument using N2 gas as adsorbate. The surface morphology of both samples was obtained using a PHILIPS XL 30 (II) scanning electron microscope.

The samples were also characterized by the determination of the point of zero charge (pH_{pzc}) using Malvern Zetasizer Nano ZS.

Sorption and Desorption of Diclofenac on Materials HT and HT-C

The sorption experiments were designed according to assess the diverse variable conditions as contact time, pH, solid/solution ratio, temperature and diclofenac water concentration concentration

A) Kinetic experiment. The time evolution of the adsorption of Diclofenac on the solid HT and HT-C were carried out by dispersing materials (HT and HT-C) samples 25 mg in 50 ml of aqueous solution of the sodium salt of diclofenac with a concentration of 0.1 and 0.3 mmol L^{-1}, The mixtures were shaken at low speed for different time intervals ranging from 10 to 120 minutes. At the end each suspension was centrifuged and the diclofenac concentration in suspension determined.

B) Effect of pH and solid/solution ratio. The influence of pH in diclofenac adsorption on HT and HT-C was studied in the range of values from 5 to 9 of suspensions of 25 mg solid in 50 mL of diclofenac to 0.5 mmol L^{-1}. The pH was adjusted at the beginning of the experiment to the desired value by adding HCl (10^{-2}N) and the obtained suspensions were stirred for 2 hours. In similar way, the effect of solid/solution was examined in a series of aqueous solutions of diclofenac in 50 mL of 0.5 mmol L^{-1} with a mass of calcined hydrotalcite (HT-C) which varied from 20 to 50 mg. At the end of the respective experiments the solids were separated by centrifugation and the concentrations of diclofenac in the supernatant were measured.

C) Adsorption isotherms*.* The adsorption isotherms were established, at room temperature (18-20 ° C), using suspensions of 20 mg of solid in 50 mL of solutions to increasing amounts of diclofenac (0 to 2.0 mmol L^{-1}). The suspensions were stirred for 2 h and then centrifuged. In the supernatant the total concentration of balance (C_e) in diclofenac was measured.

D) Desorption study. The desorption of diclofenac was conducted using the dilution method (You et al., 2001). Samples of HT-C saturated diclofenac were prepared using suspensions of 20 mg of solid HT-C in 50 ml of diclofenac concentration 1 mmol L^{-1}. They were left under stirring for 2 h and then centrifuged. Recovered solids, denoted HT-CD, were washed with distilled water and then dried at 105°C. The quantities of retained diclofenac were determined by the method cited previously, after dissolving 30 mg of the obtained solid in 100 mL of HCl (1N).

30 mg of sample HT-CD were placed in a 250 mL flask with 100 mL of extraction reagent (sodium carbonate to 10^{-2} M). The suspensions were stirred for 2 h and left to decant. 50 mL of the supernatant (clear liquid) were replaced by a second fraction of 50 ml of extraction reagent; second stirring and decantation, this operation was repeated several times, the supernatant from each extraction is separately collected and the quantity of diclofenac extracted was measured.

Analytical Determination of Diclofenac in Solutions

The initial and final concentration of diclofenac, in all the above described experiments, were determined on a Hitachi system (HPLC) LaChrom Elite equipped with a L2130 HPLC pump type, UV detector type L2400 and a column LiChrospher RP18AB 5µm, 250 x 4.6 mm. The analysis was done by isocratic mode with an acetonitrile / 0.1 M sodium acetate (35/65 (v / v)) for eluting. The detection was made by UV at 278 nm. In a field between 0 and 0.1 mmol L^{-1}, the measured chromatographic peak area was linearly proportional to the concentration of diclofenac (C). The equation of the calibration curve is: $= 2{,}11445.10^5 \times C + 67{,}086$, with a correlation coefficient> 0.99.

Results and Discussion

Structural Characterization

The diffractograms of RX of materials, HT and HT-C (Figure 1) are in agreement with those in the literature (You et al., 2001; Roelofs et al., 2002). The set of lines (00l) characteristic of the hydrotalcite were observed (Figure 1a). The diffractogram of the calcined sample RX (Figure 1b) shows the disappearance of those diffraction lines of the lamellar phase, and only a line (200) belonging to MgO phase is observed. At this calcination temperature, the aluminum oxides are in amorphous state and therefore undetectable (De Roy et al., 1992; Roelofs et al., 2002).

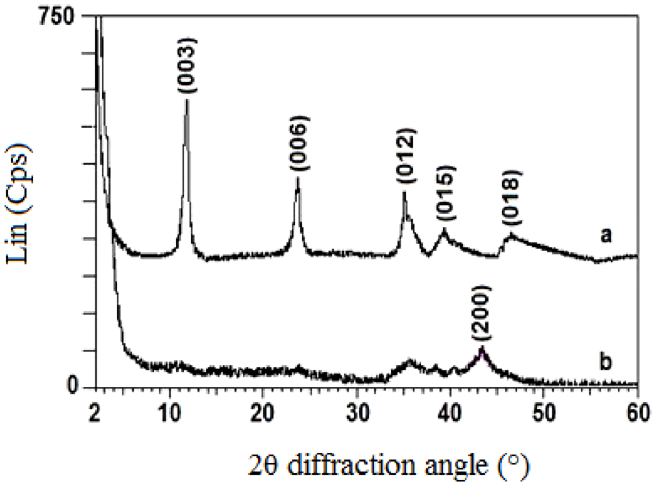


Figure 1. DRX of synthetic hydrotalcites HT (a) and HT-C (b)

The infrared spectrum of HT material (Figure 2a) is comparable to those in the literature (De Roy et al., 1992; Roelofs et al., 2002; Aisawa et al., 2007). We observe: a) Two absorption band centered 3461 cm^{-1} and to 1633 cm^{-1} attributed respectively to stretching vibrations and deformation of water molecules intercalated and adsorbed; b) Three absorption bands around 1361, 887 and 669 cm^{-1} attributable to interlayer carbonate ions and c) Three bands at 783, 549 and 431 cm $^{-1}$ corresponding to vibration characteristics of Mg-O and Al-O bonds.

The infrared spectrum of the calcined material HT-C (Figure 2b) shows the relative decrease in the intensity of the characteristic absorption bands of the water molecules and the increase in those corresponding to the vibration characteristics of Mg-O and Al-O bonds. In addition, we observe that the band located at 1361 cm^{-1} is still detectable. Nevertheless, the low intensity of this band, compared to that observed for the starting material, suggests that carbonate ions are adsorbed on the surface of the grains of the calcined material. The presence of these later would be due to contamination by atmospheric carbon dioxide. Similar observations were reported by other authors (Roelofs et al., 2002).

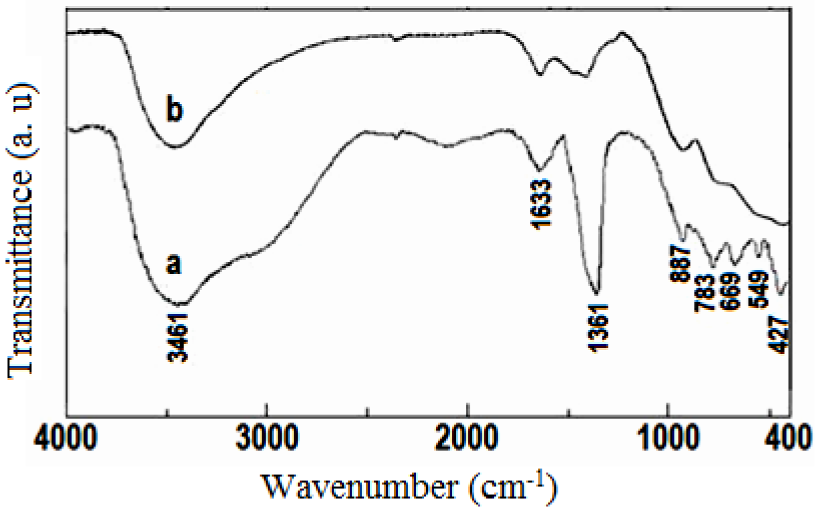


Figure 2. IR Spectra of synthetic hydrotalcite HT (a) and HT-C (b)

The Brunauer-Emmett-teller (BET) surface area of Mg-Al-CO_3 was 91,85 m^2/g (Chéttelet et al., 1996). Scanning electron micrograph of Mg–Al–CO_3 LDH sample was obtained and is presented in Figure 3. The structural morphology of the LDH can be clearly observed from the figure. It showed aggregated mass of irregularly shaped particles. Moreover it can be remarked that LDH forms a highly porous network and is responsible for the high surface areas shown by these materials [30-32]. The zeta potential of LDH was positive with pH range of 4 to 10 (Chéttelet et al., 1996). .

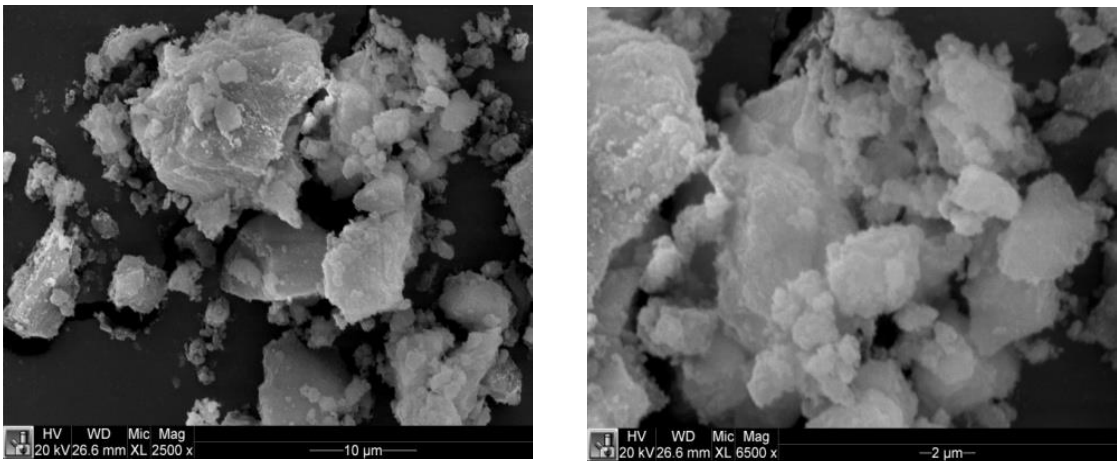


Figure 3. SEM micrographs of Mg-Al-CO_3 LDH

Sorption of Diclofenac

Kinetic

Graphs representing quantities of diclofenac fixed to the HT materials and HT-C in function of contact time are shown in Figure 4. We noted first of all that the material HT has a holding capacity of diclofenac almost zero. This can be explained partly by the displacement of carbonate anions of LDHs which is known to be very difficult, in particular because of the small size of the carbonate anion with respect to its electric charge (Mendiboure and Schöllhom, 1986), and secondly, by the presence in the solution of alkali species mainly from the dissolution of atmospheric CO_2, there by disadvantaging the exchange reaction of carbonate anions intercalated by diclofenac anions. The same result was obtained by other authors (Kaneyoshi and Jones, 1999; You et al., 2002) who reported the unsuccessful exchange of anions carbonate interlayer space by anions nitrilotriacetate and 3,6-dichloro-2-methoxybenzoate.

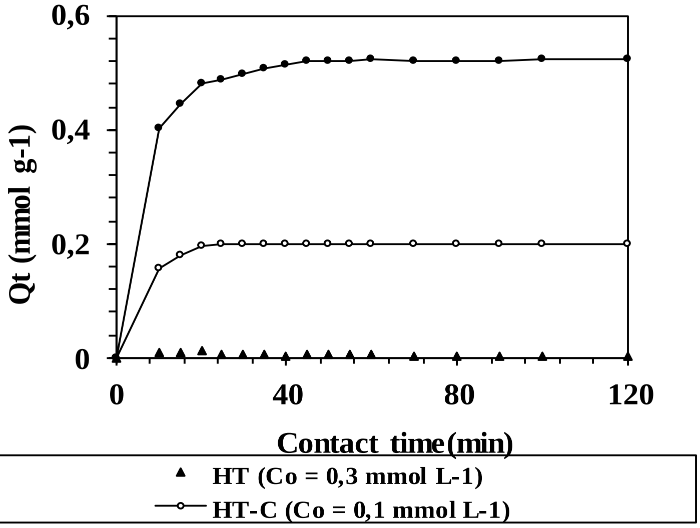


Figure 4. Fixation kinetics of diclofenac on HT and HT-C materials

Figure 4 illustrates also that the sorption on HT-C material was relatively fast. Indeed the equilibrium was reached after 50 minutes of contact. This result was confirmed by many experiments (You et al., 2002; Bruna et al., 2006; Hermosin et al., 1996). In our case, the fact that the experiments were performed in contact with air raised the question of possible displacement of diclofenac retained by the carbonate ions (due to contamination by atmospheric carbon dioxide). Therefore, we extended the experiments for 120 minutes while the equilibrium time is less than 60 minutes. The equilibrium was manifested by a constancy of the residual concentration of diclofenac.

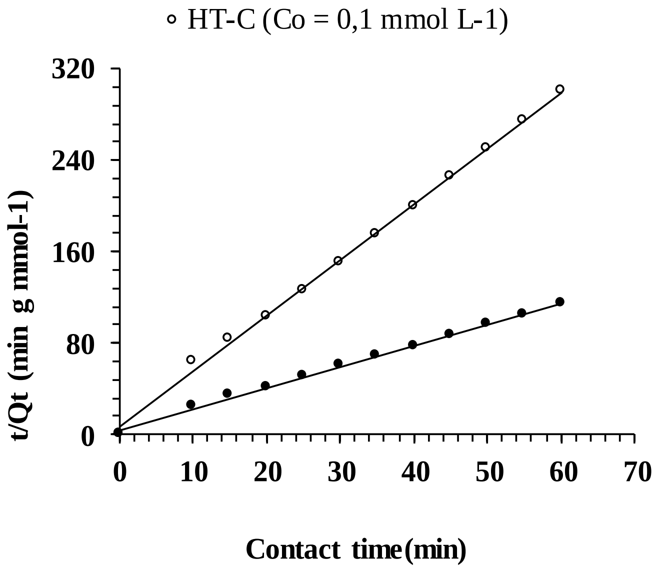


Figure 5. Speed constants for the sorption of diclofenac on HT-C

Finally, it can be noted that the sorption was faster in the beginning than in the end; phenomenon probably due to the resistance to matter transfer inside the grain solids. And the equilibrium time varied with the initial concentration of diclofenac.

Applying the model of second order pseudo (Equation 1) (Lazaridis et al., 2003) to all experimental points gave the results plotted in Figure 4. They indicated that the sorption kinetics are correctly described by this model, with correlation coefficients greater than 0.99.

$$\frac{t}{Q_t} = \frac{1}{k_2 Qe^2} + \frac{1}{Qe} t \tag{1}$$

where Q_e and Q_t (mg/g) represent the dye amounts fixed per gram of solid at equilibrium and at any time t, respectively. k_2 (g/(mmole.mn)), the constant of apparent speed of second order and t (minute), time of contact. These results corroborate several studies (Ni et al., 2007; Zhu et al., 2005), who found that the sorption kinetics of brilliant blue and methyl orange on calcined LDHs obey the pseudo-second order. These results allowed us also to determine the speed constants apparent k_2 of material HT-C for both initial concentrations chosen. The rate constants deduced from these curves are equal to 3.92 and 0.82 mmol g^{-1} min^{-1} for the calcined material for concentrations 0.1 and 0.3 mmol L^{-1} respectively.

However it is important to note that the % removed from both solutions in the case of HT-C were of 100% for 0.1mmol/l and 95% for 0.3mmol/l, both amounts are relevant from the point of view of the removing diclofenac from water as emerging contaminant.

Influence of pH

Figure 6 shows the effect of initial pH of the solution on the sorption of ions from diclofenac. We noted that the pH in the range 5.8 to 9 had no significant effect on the sorbed quantities of diclofenac. The pH of equilibrium solutions was always higher than the initial pH of the solutions and that these values are approximately equal to 10. Such effects have been reported by other authors (You et al., 2001; Kameda et al., 2003), and could be justified by the fact that during the rehydration process of HT-C material, OH^- ions were liberated leading to an increase in pH of the solution (Kameda et al., 2003).

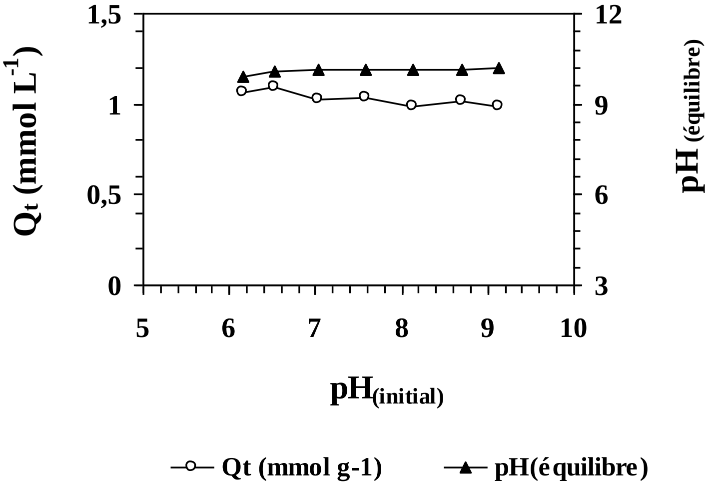


Figure 6. Influence of pH (initial) on the sorption of diclofenac by HT-C

The effect of ratio solid / solution

According to The results obtained (Figure 7), we found that the sorption of diclofenac on the HT-C material was affected by variation in the solid/solution ratio (R). Indeed, for a decrease of R from 0.5 to 0.2 g L^{-1}, the sorption was multiplied by a factor 2.04. This is in agreement with results obtained by other authors (Lazaridis et al., 2003), and commonly interpreted by that when the mass of sorbent increases the crystallites tend to agglomerate, which causes a decrease in total area of sorbent particles available to the retention of diclofenac.

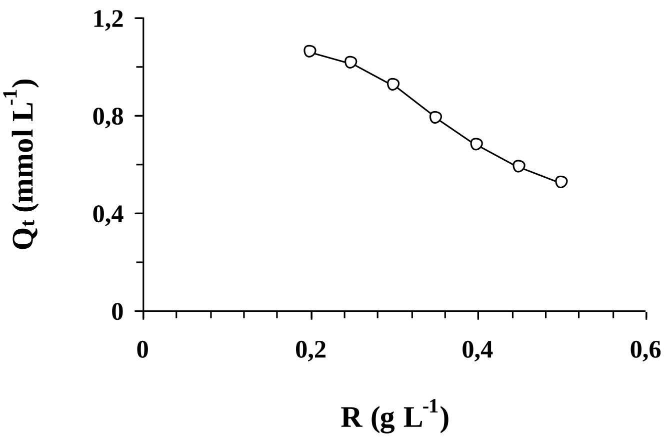


Figure 7. Effect of ratio solid/solution on the removal of diclofenac

Sorption isotherm of Diclofenac

The sorption isotherm of diclofenac (Figure 8) shows that it was L-type (Giles et al., 1960). L-type isotherms can be explained by the models of Freundlich and Langmuir, which we applied in our sorption experiments. The experimental results were treated according to the linearized Freundlich equation (Equation 2) and Langmuir (equation 3) (Giles et al. 1960):

$$\ln (Qt) = \ln (k) + (1/n) \ln (Ce) \qquad (2)$$

$$C_e/(Q_t) = C_e/Q_0 + 1/(Q_0\, b), \qquad (3)$$

where k represents the relative amount of sorption (Lg-1); 1 / n is the intensity parameter of the sorption reaction reflecting the degree of nonlinearity of the isotherm; Q_0, the maximum capacity of sorption (g $mmol^{-1}$) and b, a constant function of the energy of sorption.

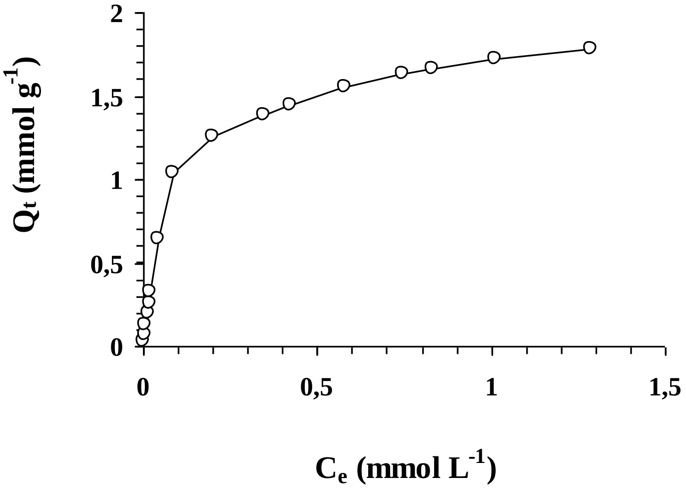


Figure 8. Isotherme of the sorption of diclofenac on calcined hydrotalcite

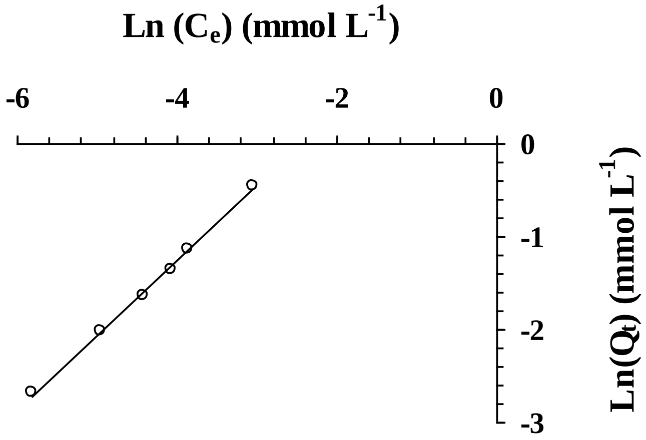
Examining the results presented in Figures 9 and 10 showed that the Freundlich model, in the initial concentrations below 0.3 mmol L^{-1}, was appropriate to describe the sorption of diclofenac. However, retention of diclofenac on the HT-C material appeared to be well correlated with the Langmuir model at concentrations above 0.3 mmol L^{-1}. The use of straight lines equations allowed us to calculate the parameters of Langmuir and Freundlich k, n, and Q_0 and b which are given in Table 1.

Table 1. Calculate the parameters of Langmuir and Freundlich

Freundlich parameters ($0 < C_0 < 0{,}3$ mmole L^{-1})			Langmuir parameters ($0{,}3 \le C_0 \le 2$ mmole L^{-1})		
k (mmole.g^{-1})	n	r	Q_0 (mmole.g^{-1})	b	r
7,05	1,24	0,99	1,91	8,87	0,99

r: correlation coefficient.

The binding capacity of the material HT-C (1.91 mmol g^{-1}) seemed to be important. This suggested, in agreement with several previous observations for the sorption of other organic species (You et al., 2002; Pavan et al., 2000; Bascialla and Regazzoni, 2008), that in addition to the adsorption process on the outer surface there was also a process of diclofenac intercalation, during the reconstruction of the interlamellar domain.



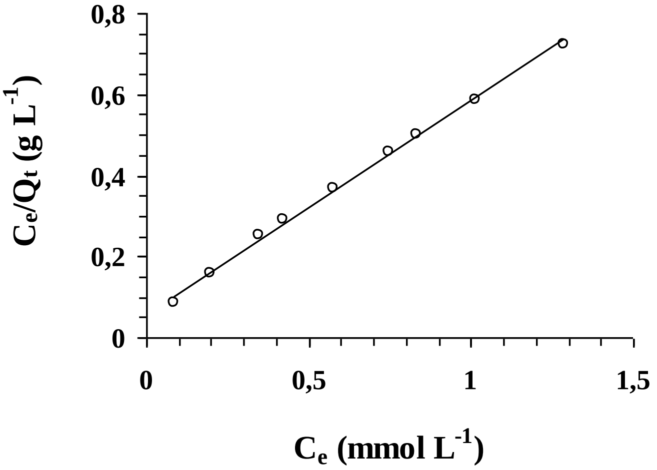


Figure 9. Linear transformation of Freundlich's isotherm

Figure 10. Linear transformation of Langmuir's isotherm

DRX and FT-IR characterization. The X-ray diffractogram obtained after rehydration of the HT-C material (Figure 11b) in the presence of diclofenac, revealed the presence of a diffraction line corresponding to the interlayer distance of 21 Å. This value was in agreement with that reported by other authors (San Román et al., 2012; Ambrogi et al., 2008; Perioli et al., 2011) for Mg-Al-(diclofenac) phase, suggested that the intercalation diclofenac in the interlayer space has occurred. However, close to this, another diffraction line appeared at 7.66 Å, which was the signature of a layered Mg-Al phase containing intercalated carbonate anions (Figure 11), and can be attributed to carbonate ions co-intercalated in a pseudo mixed –layer structure. This was not surprising, given that the operation is performed in air atmosphere.

The IR spectrum of the material HT-C after treatment with diclofenac (Figure 12b) showed that the vibrational band between 3000 and 3500 cm^{-1}, compared with that observed for LDH (CO_3) (Figure 2a) and attributed to stretching vibrations of water molecules intercalated and adsorbed was slightly enlarged and widened. This suggested that some anions from diclofenac were intercalated, as confirmed by DRX, in the interlayer space and they were subjected to interactions with the OH groups of water molecules and hence the medium becames disordered (Vaysse, 2001). The presence of bands located at 1794, 1577, 1552, 1508, 1284, 1044, 957 and 747 cm^{-1} (Figure 12b) were attributed in the literature to combinations of vibrations due to diclofenac species (Palomo et al., 1999), confirming the fact that certain diclofenac anions were interposed in the space interlayer or adsorbed on the surface of the HT-C solid particles. Similar observations were reported by other authors (Ambrogi et al., 2002). Finally, Figure 12b showed a vibration band around 1380 cm^{-1}, assigned to carbonate ions cointercalated, confirms the presence of carbonate anions in the material, and hence the observation of a phase LDH (Mg-Al-CO_3) parasitic on the X-ray diffraction pattern (Figure 11b).

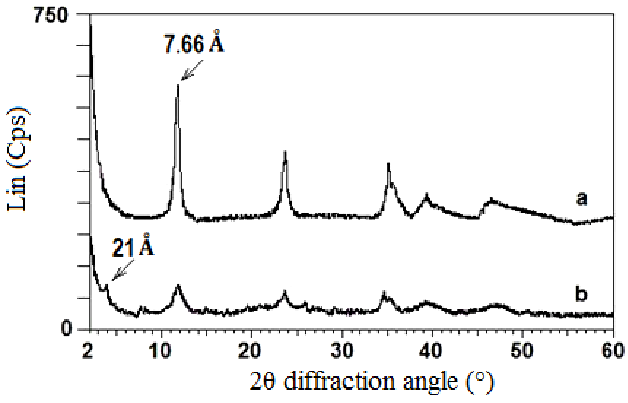


Figure 11. DRX of HT (a) and HT-C after diclofenac treatment (b)

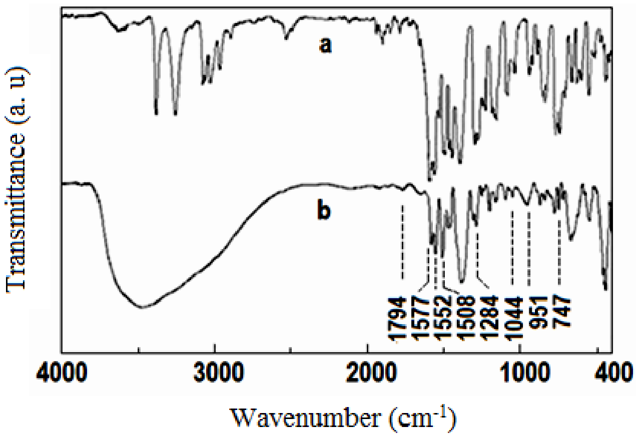


Figure 12. IR spectra of diclofenac (a) and HT-C after diclofenac treatment (b)

Desorption of diclofenac

Examining the results of desorption of diclofenac, shown in Figure 13, illustrate that the anions of diclofenac retained by the solid HT-C can be extracted by CO_3^{2-} ions. It also appeared that the displacement of these anions was relatively slow. This result supports the hypothesis that sorption on HT-C, involves other sites that the of ionizable groups sheets. We think that these are the sites of the interlamellar domain because border exchanges were easier ant they should corresponds to those removed in the first extraction. By contrary, when there must be penetration between the layers, the exchange would be more difficult.

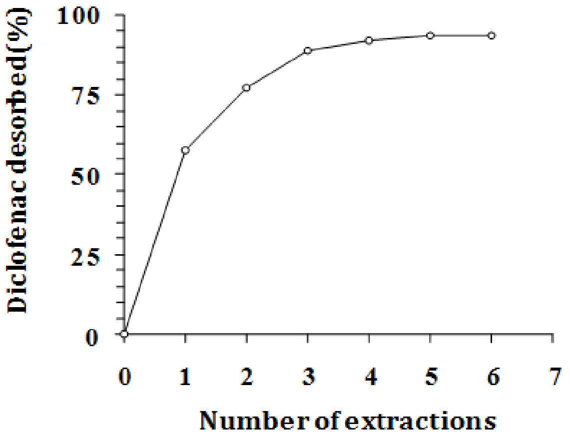


Figure 13. Desorption of diclofenac

Conclusion

The layered phase Mg-Al-CO_3 is not a good sorbent for diclofenac whereas its calcination product is revealed usefull to remove diclofenac from solutions. Diclofenac present in solutions at a rate of 0,2 mml/ l was removed up to 95% at a solid solution ratio of 30mg/50mlThe sorption capacity of the calcined hydrotalcite was about 1.9 mmol g^{-1}, equivalent to 66% of the AEC. XRD and IR characterization of the sorption products showed that diclofenac was adsorbed by HT-calcined some in the interlayer space as anion and other in the external surface.

Acknowledgements

The support of the Environmental Agrochemistry group (AGR-264) from the IRNAS is acknowledged. The advising, revision and suggestion of Prof, M. Carmen Hermosin is also acknowledged.

References

Aisawa, S., Higashiyama, N., Takahashi, S., Hirahara, H., Ikematsu, D., Kondo, H., Nakayama, H., Narita, E., 2007. Intercalation behavior of L-ascorbic acid into layered double hydroxides. *Applied Clay Science* 35: 146—154.

Ambrogi, V., Fardella, G., Grandolini, G., Perioli, L., Tiralti, M.C., 2002. Intercalation compounds of hydrotalcite-like Anionic clays with anti-inflammatory agents, II: Uptake of diclofenac for a controlled release formulation. *An Official Journal of the American Association of Pharmaceutical Scientists* 3: 1—6.

Ambrogi, V., Perioli, L., Ricci, M., Pulcini, L., Nocchetti, M., Giovagnoli, S., Rossi, C., 2008. Eudragit and hydrotalcite-like anionic clay composite system for diclofenac colonic delivery. *Microporous Mesoporous Mater* 115: 405—415.

Andreozzi, R., Marotta, R., Praéxus, N.A., 2003. Pharmaceuticals in STP effluents and their solar photodegradation in aquatic environment. *Chemosphere* 50: 1319—1330.

Bascialla, G., Regazzoni, A.E., 2008. Immobilization of anionic dyes by intercalation into hydrotalcite. *Colloids and Surfaces A: Physicochemical and Engineering Aspects* 328: 34—39.

Boxall, A.B., Blackwell, P., Cavallo, R., Kay, P., Tolls, J., 2002 The sorption and transport of a sulphonamide antibiotic in soil systems. *Toxicology Letters* 131: 19—28.

Bruna, F., Pavlovic, .I, Barriga, C., Cornejo, J., Ulibarri, M.A., 2006. Adsorption of pesticides Carbetamide and Metamitron on organohydrotalcite. *Applied Clay Science* 33: 116—124.

Casellas, C., 2006. Les médicaments : Contaminants émergents ? *Environnement. Risques & Santé* 5: 225.

Chéttelet, L., Bottero, J.Y., Yvon, J., Bouchelaghem, A., 1996. Competition between monovalent and divalent anions for calcined and uncalcined hydrotalcite: anion exchange and adsorption sites. *Colloids and Surfaces A: Physicochemical and Engineering Aspects.* 111: 167-175

Cleuvers, M., 2004. Mixture toxicity of the anti-inflammatory drugs diclofenac, ibuprofen, naproxen and acelylsalicylid acid. *Ecotoxicology and Environmental Safety* 59: 309—315.

De Roy, A., Forano, C., El Malki, K., Besse, J.P., 1992. Anionic clays: trends in pillaring chemistry, In: *Synthesis of microporous materials* (M.L. Occelli & H.E. Robson, ed.). Van Nostrand Reinhold, New-York, USA, pp. 108—169.

Del Hoyo, C., 2007. Layered double hydroxides and human health: An overview. *Applied Clay Science* 36: 103—121.

Feitosa-Felizzola, J., Temine, B., Chiron, S., 2007. Evaluating on-line solid-phase extraction coupled to liquid chromatography- ion trap mass spectrometry for reliable quantification and confirmation of several classes of antibiotics in urban wastewaters. *Journal of Chromatography A* 1164: 95—104.

Ferreira, C.S.G., Nunes, B.A., De Melo Henriques-Almeida, J.M., Guilhermino, L., 2007. Acute toxicity of oxytetracycline and florfenicol to the microalgae *Tetraselmis chuii* and to the crustacean *Artemia parthenogenetica*. *Ecotoxicology and Environmental Safety* 67: 452—458.

Francis, R. C., Andreas, L., Udo, W., Dieter, J., Liane, H., Gert, H., 2008. Intercalation of Mg–Al layered double hydroxide by anionic surfactants: Preparation and characterization. *Applied Clay Science* 38: 153–164.

Giles, C.H., MacEwan, T.H., Nakhwa, S.N., Smith, D., 1960. Studies in adsorption. Part XI. A system of classification of solution adsorption isotherms, and its use in diagnosis of adsorption mechanisms and in measurement of specific surface areas of solids. *Journal of Chemical Society (London)* 3973—3993.

Göbel, A., Mc Ardell, C.S., Joss, B., Siegrist, H., Giger, W., 2007. Fate of sulfonamide, macrolides, and trimethoprim in different wastewater treatment technologies. *Science of the Total Environment* 372: 361—371.

Heberer, T., 2002. Tracking persistent pharmaceutical residues from municipal sewage to drinking water. *Journal of Hydrology* 266: 175—189.

Heberer, T., Feldmann, D., 2005. Contribution of effluents from hospitals and private households to the total loads of diclofenac and carbamazépine in municipal sewage effluents. *Journal of Hazardous Materials* B122, 211—218.

Hermosin, M.C., Pavlovic, I., Ulibarri, M.A., Cornejo, J., 1996. Hydrotalcite as sorbent for trinitrophenol: Sorption capacity and mechanism. *Water Research* 30: 171—177.

Hernando, M.D., Mezcua, M., Fernandez-Alba, A.R., Barcelo, D., 2006. Environmental risk assessment of pharmaceutical residues in wastewater effluents, surface waters and sediments. *Talanta* 69,:334—342.

Jean-C, D., Herve´, M., Claude, G., Emil, D., Ioana, F., 2004. Intercalation compounds of Mg–Al layered double hydroxides with dichlophenac: different methods of preparation and physico-chemical characterization. *Applied Clay Science* 27: 95– 106

Kameda, T., Yabuuchi, F., Yoshioka, T., Uchida, M., Okuwaki, A., 2003. New method of treating dilute mineral acids using magnesium-aluminium oxide. *Water Research* 37: 1545—1550.

Kaneyoshi, M., Jones, W., 1999. Formation of Mg-Al Layered double hydroxides intercalated with nitrilotriacetate anions. *Journal of Materials Chemistry* 9: 805—811.

Kentaro, O., Nobuo, I., Takayoshi, S., 2007. Factors affecting the crystal size of the MgAl-LDH (layered double hydroxide) prepared by using ammonia-releasing reagents. *Applied Clay Science* 37: 23–31

Lazaridis, N.K., Karapantsios, T.D., Georgantas, D., 2003. Kinetic analysis for the removal of a reactive dye from aqueous solution onto hydrotalcite by adsorption. *Water Research* 37: 3023—3033.

Lúcia, H.M.L.M., Santos Araújo, A.N., Adriano, F., Pena, A., Delerue-Matos, C., Montenegro, M.C.B.S.M., 2010. Ecotoxicological aspects related to the presence of pharmaceuticals in the aquatic environment. *Journal of Hazardous Materials* 175: 45—95.

Mehinto, A.C., Hill, E.M., Tyler, C.R., 2010. Uptake and biological effects of environmentally relevant concentrations of the nonsteroidal anti-inflammatory pharmaceutical diclofenac in rainbow trout (Oncorhynchus mykiss). *Environmental Science and Technology* 44: 2176—2182.

Mendiboure, A., Schöllhom, R., 1986. Formation and anion exchange reaction of layered transition metal hydroxides $[Ni_{1-x} M_x](OH)_2(CO_3)_{x/2}(H_2O)_x$ (M=Fe,Co). *Revue De Chimie Minerale* 23: 819—827.

Newman, S.P., Jones, W., 1998 Synthesis, characterization and applications of layered double hydroxides containing organic guests. *New Journal of Chemistry* 22: 105—115.

Ni, Z.M., Xia, S.J., Wang, L.G., Xing, F.F., Pan, G.X., 2007. Treatment of methyl orange by calcined layered double hydroxides in aqueous solution: Adsorption property and kinetic studies. *Journal of Colloid and Interface Science* 316: 284—291.

Palomo, M.E., Ballesteros, M.P., Frutos, P., 1999. Analysis of diclofenac sodium and derivatives. *Journal of Pharmaceutical and Biomedical Analysis* 21: 83—94.

Pavan, P.C., Crepaldi, E.L., Valim, J.B., 2000. Sorption of anionic surfactants on layered double hydroxides. *Journal of Colloid and Interface Science 229*: 346—352.

Perioli, L., Posati, T., Nocchetti, M., Bellezza, F., Costantino, U., Cipiciani, A., 2011. Intercalation and release of antiinflammatory drug diclofenac into nanosized ZnAl hydrotalcite-like compound. *Applied Clay Science* 53: 374—378.

Rafols, C., Roses, M., Bosh, E., 1997. A comparison between different approach to estimate aqueous pKa of several non-steroid antiinflamatory drugs. *Analytica Chimica Acta* 338: 127

Reichle, W.T., 1986. Synthesis of anionic clay minerals (mixed metal hydroxides, Hydrotalcite). *Solid State Ionics* 22: 135—141.

Roelofs, J.C.A.A., Van Bokhoven, J.A., Van Dillen, A.J., Geus, J.W., De Jong, K.P., 2002. The thermal decomposition of Mg-Al hydrotalcites: Effects of interlayer anions and characteristics of the final structure. *Chemistry A European Journal* 8: 5571—5578.

San Román, M.S., Holgado, M.J., Salinas, B., Rives, V., 2012. Characterisation of Diclofenac, Ketoprofen encapsulated in layered double hydroxides. *Applied Clay Science* 55: 158—163.

Tauxe-wuersch, A., De Alencostro, L.F., Grandjean, D., Tarradellos, J., 2005. Occurence of several acidic drugs in sewage treatement plants in Switzerland and risk assessement. Water Research 39: 1761—1772.

Tixier, C., Singer, H.P., Oellers, S., Muller, S.R., 2003. Occurence and fate of carbamazepine, clofibric acid, diclofenac, ibuprofen, ketoprofen and naproxen in surface waters. *Environmental Science and Technology* 37: 1061—1068.

Togola, A., Budzinski, H., 2008. Multi-residue analysis of pharmaceutical compounds in aqueous samples. *Journal of Chromatography A* 1177: 150-158.

Toraishi, T., Nagasaki, S., Tanaka, S., 2002. Adsorption behavior of IO_3^- by CO_3^{2-} - and NO_3^- hydrotalcite. *Applied Clay Science* 22: 17—23.

Vaysse, C., 2001. *Caractérisation structurale d'hydroxydes doubles lamellaires contenant des anions oxométallates (Mo, W) ou acrylate intercalés*. Thèse de Doctorat, Ecole Doctorale des Sciences Chimiques, Université Bordeaux I.

Vieno, N.M., Tuhkanen, T., Kronberg, L., 2006. Analysis of neutral and basic pharmaceuticals in sewage treatment plants and in recipient rivers using solid phase extraction and liquid chromatography-tandem mass spectrometry detection. *Journal of Chromatography A* 1134: 101—111.

You, Y., Vance, G.F., Zhao, H., 2001. Selenium adsorption on Mg-Al and Zn-Al layered double hydroxides. *Applied Clay Science* 20: 13—25.

You, Y., Zhao, H., Vance, G.F., 2002 Adsorption of dicamba (3,6-dichloro-2-methoxy benzoic acid) in aqueous solution by calcined-layered double hydroxide. *Applied Clay Science* 21: 217—226.

Zhu, M.X., Li, Y.P., Xie, M., Xin, H.Z., 2005. Sorption of an anionic dye by uncalcined and calcined layered double hydroxides: a case study. *Journal of Hazardous Materials B120*, 163—171.