

## Potential of Bentonite Clay for Heavy Metal Immobilization in Soil

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**Abstract**—A montmorillonite rich bentonite clay was evaluated for heavy metals (Cu and Zn) removal from aqueous system and its immobilization efficiency of the metals in soil by batch adsorption experiment. The effect of adsorbent amount, pH and initial concentration of metals on the extent of adsorption was investigated. The adsorption data were fitted with Langmuir, Freundlich and Dubinin-Radushkevich adsorption isotherms. The maximum monolayer adsorption capacity of bentonite was obtained from Langmuir adsorption isotherm and its values are 13.95 mg g<sup>-1</sup> and 11.41 mg g<sup>-1</sup> for Cu (II) and Zn (II), respectively. The maximum monolayer adsorption capacity of the soil increased from 1.39 mg g<sup>-1</sup> to 11.76 mg g<sup>-1</sup> and 0.42 mg g<sup>-1</sup> to 10.50 mg g<sup>-1</sup> for Cu (II) and Zn (II), respectively, on addition of bentonite. The study demonstrates that bentonite has potential to remove Cu (II) and Ni (II) ions from aqueous solution and also from heavy metal polluted soil.

**Key words** : Bentonite, Heavy metal, Adsorption, Soil

Heavy metal pollution is one of the most serious environmental problems facing modern society and it has received a great deal of attention due to their toxic effect to the ecosystem, agriculture, and human health. Heavy metal contamination in the surface- and ground water environment prevents any beneficial use of the water bodies as well as makes the soil as barren. Therefore, control of heavy metals in waste

effluents before its disposal into the environment is essential. Conventional technologies in heavy metal removal include precipitation, ion exchange, reverse osmosis, and filtration (Kurniawan *et al.*, 2006). However, these methods have several disadvantages/limitations such as being expensive, generating secondary pollutants like sludge, and ineffective in treating effluents with low metal

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concentrations etc. Among the physico-chemical treatments, adsorption process is easy to operate and can treat waste effluents with high loadings and at very low concentrations (Bhattacharya and Gupta, 2006a). Continuous application of poor quality irrigation water results in soil as sink and makes it barren. To avoid the transfer of metal from soil to human food chain in-situ immobilization of heavy metals is a promising alternative to the expensive and disruptive conventional ex-situ remediation techniques for the contaminated soil.

Use of clays as adsorbents to remove contaminants has been increasingly paid attention because of their mechanical stability, low cost, availability and presence of metal chelating functional groups and negative charge on surface (Fu and Wang, 2011). In this study bentonite clay was evaluated for their potential heavy metal removal from aqueous system as well as metal sorption capacity of a contaminated soil.

## Materials and Methods

### Instrumentation

The X-ray diffraction patterns of the bentonite clay was obtained with a diffractometer (Philips PW1710) using Cu K  $\alpha$  radiation and scanning from 3° to 15° at a step angle 0.1°, 5 s/step. The specific surface area (SSA) of clays was determined by ethylene glycol monoethyl ether method (Carter *et al.*, 1965) and cation exchange

capacity (CEC) by magnesium-calcium replacement method. The SSA and CEC values for normal bentonite were 399 m<sup>2</sup>g<sup>-1</sup> and 83.3 cmol (p<sup>+</sup>) kg<sup>-1</sup>, respectively. The concentration of metal ions was determined by the AAS.

### Materials and reagents

Bentonite clay mineral was purchased from Minerals limited, New Delhi, India. Stock solutions of metals (Zn, and Cu) containing 1000 mg L<sup>-1</sup> metal ion was prepared by dissolving appropriate amount of AR grade sulphate [Cu(SO<sub>4</sub>)<sub>2</sub>·5H<sub>2</sub>O; Zn(SO<sub>4</sub>)<sub>2</sub>·7H<sub>2</sub>O] salts of heavy metals separately in double distilled water. The working standard solutions of metals were prepared from the stock solution by appropriate dilution using double distilled water. The soil (Aridisol) used in batch adsorption study was collected from Pali, Rajasthan, India. The physico-chemical properties of the contaminated soil used for adsorption study were determined by standard methods.

### Adsorption and desorption experiments

All the adsorption equilibrium experiments were conducted by batch method. A known volume (50 mL) of metal solutions of varying initial concentrations (0 to 50 ppm), in polypropylene bottle was shaken with a desired dose of adsorbent for a specified contact time in an end to end shaker. After the pre-determined adsorption time, solution was filtered through Whatman No. 42 filter paper. The

initial and equilibrium concentrations of metal in the aqueous solutions were analysed by atomic adsorption spectroscopy (AAS). The amount of metal adsorbed ( $Q$  in  $\text{mg g}^{-1}$ ) was determined as follows:

$$Q = [(C_0 - C_t) / m] V$$

Where,  $Q$  is the amount of metal ions adsorbed onto unit amount of the adsorbent ( $\text{mg g}^{-1}$ ),  $C_0$  and  $C_t$  are the initial and terminal concentrations of metal in solution ( $\text{mg L}^{-1}$ ),  $V$  is the volume of solution (L) and  $m$  is the mass of the adsorbent (g), respectively. The percentage removal of metal ion was calculated by following equation:

$$\text{Removal (\%)} = [(C_0 - C_t) / C_0] 100$$

where  $C_0$  and  $C_t$  are the initial and terminal concentrations of metal in solution ( $\text{mg L}^{-1}$ ).

To study the effect of bentonite clay on heavy metal sorption by soils, one gram soil and 0.1 g of bentonite were taken in 30 ml polypropylene centrifuge tube and shaken for 24 hours in an end to end shaker with 30 ml of metal solution of varying concentration (0-50 ppm). At the end of shaking hour, centrifugation was done at 8000 rpm for 10 minutes and 15 ml of supernatant was withdrawn. To study the desorption 15 ml of 0.01M  $\text{Ca}(\text{NO}_3)_2$  was added to the contents of centrifuge tube and shaken for 24 hours.

The distribution coefficient of an adsorbent is defined as the ratio of the metal

ion adsorbed to the amount in the liquid phase. The distribution coefficient was calculated according to the following equation:

$$\text{Distribution coefficient } (K_d, \text{L/g}) = [(C_0 - C_t) / C_t] * V / m$$

where,  $C_0$  and  $C_t$  are the initial and terminal concentrations of metal in solution ( $\text{mg L}^{-1}$ ),  $V$  is the volume of the solution (L) taken and  $m$  is the mass of adsorbent (g) taken.

**Effect of adsorbent level:** To examine the effect of adsorbent level on metal adsorption, 50 ml of 25 ppm metal solution with different amount of bentonite (0.01, 0.025, 0.05, 0.1, and 0.2 g) in polypropylene bottle was shaken for a specified contact time (4 hrs) in an end to end shaker. After the pre-determined adsorption time, solution was filtered with Whatman No.42 filter paper. The initial and equilibrium concentrations of metal in the aqueous solutions were analysed by the AAS.

**Effect of pH:** To examine the effect of pH on metal adsorption, 50 mL of 25 ppm metal solution with different pH values (1, 2, 3, 4, 5, 6, 7 and 8) and 0.1 g of adsorbent in polypropylene bottle was shaken for a specified contact time in an end to end shaker. After the predetermined adsorption time, solution was filtered with Whatman No.42 filter paper. The initial and equilibrium concentrations of metal in the aqueous solutions were analysed by the AAS.

## Results and Discussion

### Characterisation of bentonite

Figure. 1 represents the random oriented XRD pattern of the bentonite clay which shows a strong peak at  $2\theta = 7.0^\circ$  ( $d$ =spacing of  $12.2\text{\AA}$ ) corresponds to smectite mineral. Bentonite sample is mainly composed of montmorillonite with minor amounts of quartz and feldspar. Hazem and Masry (2011) reported the basal spacing of commercial bentonite at  $12.1\text{\AA}$ . Kloprogge *et al.* (2002) reported  $11.5\text{\AA}$  to  $15\text{\AA}$  as basal spacing of bentonite clay depending on the different extent of interlayer water molecules possibility related to the differences in interlayer cation composition.

The scanning electron microscopy

(SEM) (Fig. 2) shows that the bentonite with closely associated layers forming a relatively compact lamellar structure and the particles are observed to have layered structure with majority of the platelets have hexagonal and subhedral lamella shapes.

### Effect of adsorbent level

Amount of adsorbent is an important parameter which determines adsorption capacity. The data (Fig. 3 a & b) indicate that in all the cases percentage removal of metal increased from 60% to 95%, and 35% to 95%, for Cu (II) and Zn (II), respectively. The increase in percentage of removal as dosage was increased due to the increase in surface area of adsorbent. A higher adsorbent dosage also reflects a greater number of available adsorption sites (Vidal

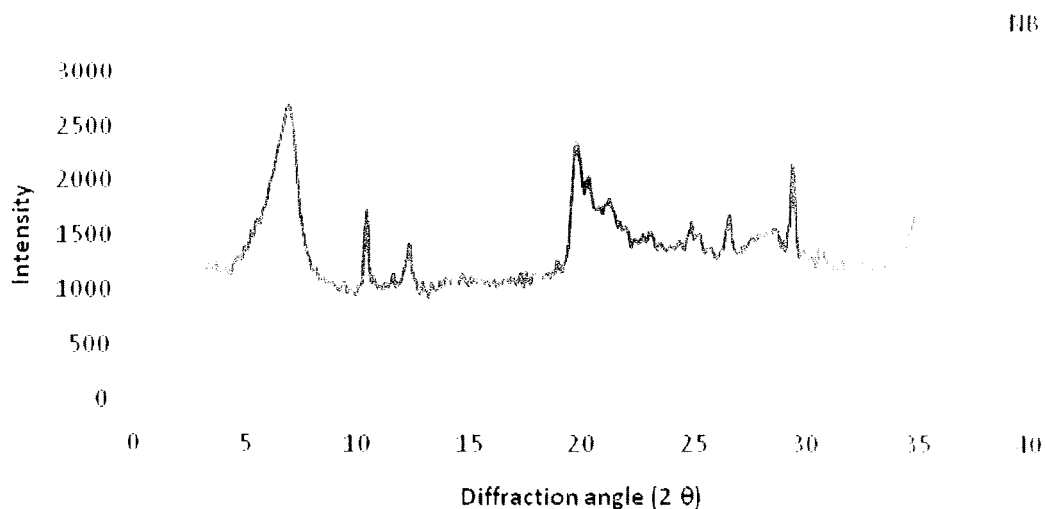


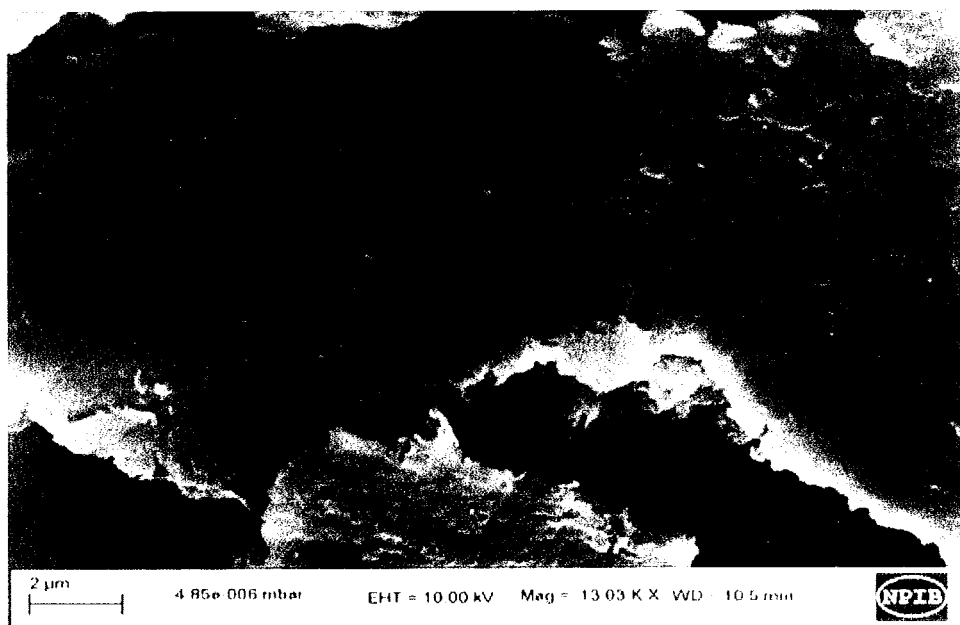
Fig. 1. Random oriented powder XRD of bentonite clay

*et al.*, 2009), indicating more metal ions were able to be adsorbed. However, a reduction in adsorption capacity of bentonite clay with increase in dose of adsorbent was observed for both the metals. As the dosage increased, the ratio of number of adsorption sites to the number of metal ions would increase because fixed amount of metal ions results in more number of unadsorbed sites. At higher adsorbent dose particle aggregation may decrease the total surface area of the adsorbent and leads to lower efficiency of adsorbent.

#### *Effect of pH*

The pH of the solution strongly affects the adsorption capacity of bentonite clay.

The data (Fig. 4 a & b) indicate that adsorption of metals increases with increasing pH of the solution and maximum adsorption of Cu (II) and Zn (II) occurs at pH 6 and 7, respectively. Lower adsorption of metals at acidic pH is attributed to higher concentration of H<sup>+</sup> and hydronium (H<sub>3</sub>O<sup>+</sup>) ions and their competition with metal ions for adsorption sites (Newton *et al.*, 1976) and diminution of the cation exchange capacity (CEC) of the sorbent (bentonite). At pH above isoelectric point the surface becomes negatively charged and the functional groups such as hydroxyl, silanol and aluminol attract metal cation there by resulting in electrostatic interaction. At higher pH metal adsorption increases due to reduced inhibitory effect of H<sup>+</sup>. Cu (II)



**Fig. 2.** Scanning electron micrograph of bentonite clay

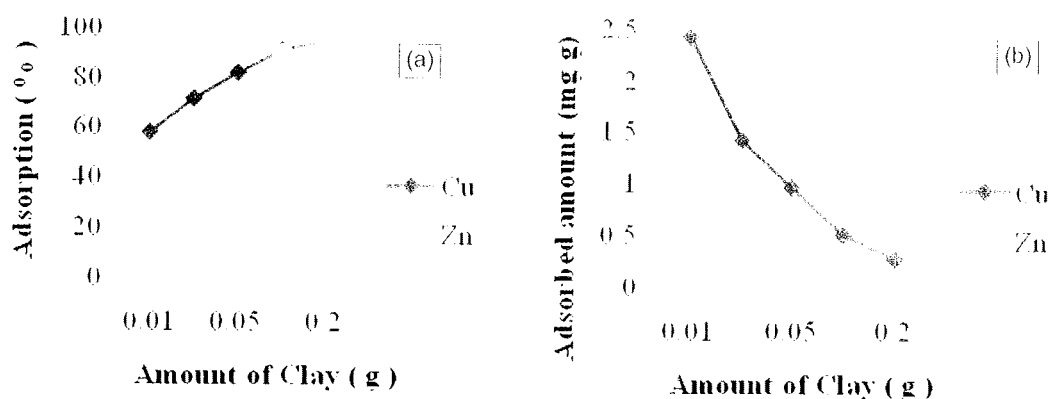


Fig. 3. Effect of adsorbent dose on percentage removal (a) and amount of metal adsorbed per unit amount of adsorbent (b)

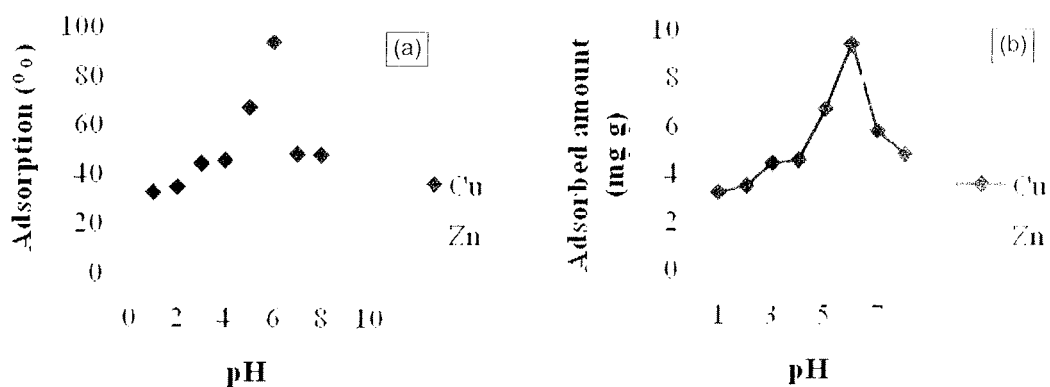


Fig. 4. Effect of pH on percentage removal (a) and adsorption capacity (mg/g) of bentonite clay (b)

and Zn (II) get precipitated at pH above 6 and 7, respectively resulted in lower adsorption.

#### *Effect of initial metal concentration*

Percentage removal of metal decreased with increase in initial concentration and

the reverse trend observed in case of sorption capacity per unit amount of adsorbent (Fig. 5 a & b). At low metal concentration, the adsorption capacity significantly increased with increasing metal concentration because of increased level of metal ions in the solution enhanced

the interactions between metal ions and the active sites of the adsorbent. The initial concentration of metal ions act as an important driving force to overcome all mass transfer resistance of metal ions between the solid and solution phase.

**Adsorption isotherms**

An adsorption isotherm indicates the mathematical relationship between the adsorption capacity and equilibrium concentration of an adsorbent at a constant temperature. The adsorption data were analysed with the Langmuir, Freundlich and Dubinin-Radushkevich (DR) isotherm models. The Langmuir and Freundlich models are often used to describe the adsorption isotherm. DR isotherm gives the idea about the nature of adsorption i.e. whether it is chemisorption or physisorption based on the free energy of

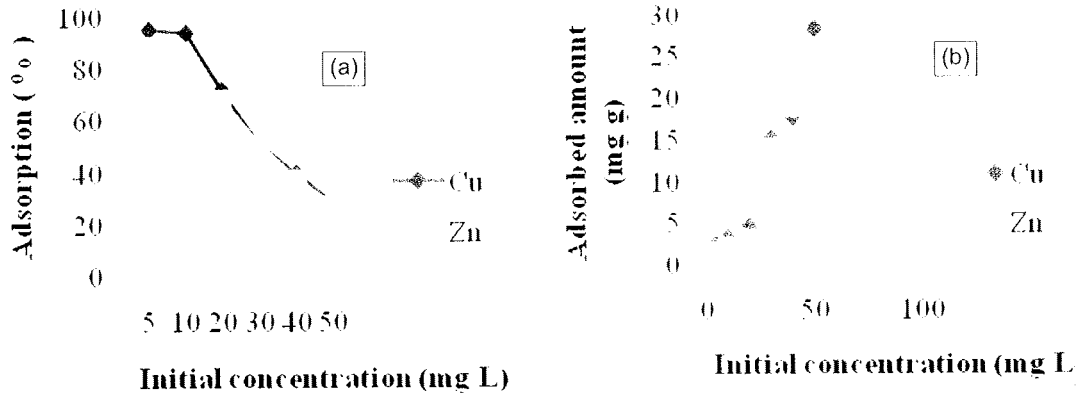
adsorption.

The Langmuir equation suggests that the sorption occurs at the solid surface that is made up of elementary sites, each of which can adsorb one sorbate molecule, i.e., monolayer sorption (Langmuir, 1918). The Langmuir equation is given below:

$$Q_e = (Q^{\circ}bC_e)/(1+bC_e)$$

The linear version of Langmuir equation is:  $C_e / q_e = 1/Q^{\circ}b + C_e/Q^{\circ} + 1$

Where,  $Q^{\circ}$  is the maximum adsorption at monolayer ( $mg\ g^{-1}$ ),  $C_e$  is the equilibrium concentration of metal ( $mg\ L^{-1}$ ),  $q_e$  is the amount of metal adsorbed per unit weight of composite,  $b$  is the Langmuir constant related to affinity of binding site ( $L\ mg^{-1}$ ) and is a measure of energy of adsorption. A linearized plot of  $C_e / q_e$  against  $C_e$  gives  $Q^{\circ}$  and  $K_L$ .



**Fig. 5.** Effect of initial concentration on metal adsorption capacity (a) and percentage removal of metals (b) by bentonite clay

Langmuir constant  $Q^0$ , represent the maximum monolayer adsorption capacity of the composite. The values are 14.0 mg g<sup>-1</sup> and 11.4 mg g<sup>-1</sup> for Cu (II) and Zn (II), respectively (Table 1). Based on the maximum adsorption capacity values the sequence of metal sorption was found to be Cu (II) > Zn (II). This result is in consistent with Ayala *et al.*, (2009) and they reported that the sequence of metal sorption for Peruvian bentonite was Cu (II) > Zn (II) > Ni (II) > Co (II). The high adsorption of Cu (II) ions is due to its paramagnetism, high electronegativity, coordination geometry and Jahn-Teller distortion (Vidal *et al.*, 2009). The sequence of  $Q^0$  was consistent with the first hydrolysis constants ( $K_h$ ) of the metals studied i.e., Cu ( $10^{-7.7}$ ) and Zn ( $10^{-9.2}$ ). Metals with larger  $K_h$  (lower  $pK_h$  values) form surface hydroxy species

within given pH range and are chemisorbed to the surface to a greater extent. Greater adsorption of Cu than that Zn might be due to precipitate phase formation by Cu on the clay surfaces (Hui *et al.*, 2005). The sequence of  $Q^0$  was positively correlated with the hardness of metals (5.55 and 5.40 for Cu and Zn, respectively). Degree of hardness shows the polarizability of the metal cation and its affinity for ligands. Higher the hardness, more the affinity to surface functional groups such as mineral – OH groups resulted in higher adsorption of Cu (Sparks, 2003).

The Freundlich (1906) isotherm is an empirical equation and is one of the most widely used isotherms for the description of multi-site adsorption where the adsorbent surface is heterogeneous in nature. Mathematically, it is expressed as

$$q_e = K_f \times C_e^{1/n}$$

where  $q_e$  is the amount of metal ion adsorbed (mg g<sup>-1</sup>) onto bentonite clay.  $K_f$  and  $n$  are the parameters of Freundlich isotherm, indicating the sorption capacity and intensity, respectively. Linear plots of  $\log q_e$  versus  $\log C_e$  ( $\log q_e = \log K_f + 1/n \log C_e$ ) for the different initial metal ion concentrations provides  $K_f$  and  $n$ . The Freundlich constant  $n$  value indicates the favourability of the adsorption process with values < 1 for poor adsorption, 1-2 for moderately good and 2-10 represent the beneficial adsorption (Sparks, 2003). Cu (II) has the larger  $K_f$  and  $n$  values over Zn (II) (Table 1). Cu (II) with the highest  $n$  value

**Table 1.** Isotherm constants for metal sorption on bentonite in aqueous system and correlation coefficients

Parameters	Zn	Cu
Langmuir Isotherm		
$Q_m$ (mg/g)	11.4	14.0
$K_L$ (L/g)	0.64	0.29
$R^2$	0.97	0.97
Freundlich isotherm		
$K_f$ (mg/g) (L/g) <sup>1/n</sup>	4.50	5.12
1/n	0.23	0.26
$R^2$	0.92	0.94
Dubinin-Radushkevich isotherm		
$q_{DR}$ (mmol/g)	1.99	13.6
$K_d$ (mmol <sup>2</sup> /kJ <sup>2</sup> )	0.14	0.46
$E$ (kJ/mol)	0.54	0.96
$R^2$	0.94	0.89



means it has highest affinity towards the functional groups of the composite and stronger bond results in higher  $K_f$ . According to Freundlich adsorption theory, the  $n$  values between 1 and 10 indicate beneficial adsorption, and in this study the  $n$  values are more than unity for both the metals which demonstrates the beneficial adsorption. The correlation values (Table 1) of adsorption isotherms indicate that Langmuir isotherm fits better than Freundlich. The Freundlich adsorption isotherm considers the surface heterogeneity of surface and the exponential distribution of the active sites, as well as their energies. On the other hand, Langmuir adsorption model is based on the assumption of a sorption on homogeneous surface by monolayer adsorption, while considering no interaction between adsorbed species. Moreover, Langmuir model assumes that the adsorptive forces are similar to the forces of the chemical interaction. Consequently, the Langmuir isotherm is a better applicable model for adsorption of metal on bentonite clays (Bhattacharya and Gupta, 2006).

Dubinin and Radushkevich (1947) isothermal model is rarely applied onto liquid phase biosorption due to its complex nature. It assumes heterogeneous surface with Gaussian energy distribution. It defines an important parameter namely mean free energy which is used to differentiate the physical and chemical adsorption as follows:

$$q_c = q_{DR} \exp(-k_d \varepsilon^2)$$

where,  $k_d$  ( $\text{mol}^2 \cdot \text{kJ}^{-2}$ ) is the constant related to the calculated average sorption energy  $E$ , and  $q_{DR}$  ( $\text{mol} \cdot \text{g}^{-1}$ ) is the maximum adsorption capacity which can be calculated respectively from the slope and intercept of following linearized equation:

$$\ln q_c = \ln q_{DR} - k_d \varepsilon^2$$

The polyanionic potential  $\hat{a}$  can be calculated by the following expression:

$$\varepsilon = RT \ln (1 + 1/C_c)$$

where,  $k_d$  represents adsorption energy and  $q_{DR}$  is the maximum adsorption capacity of adsorbent. As an index of consumed energy in adsorption,  $E$  represents the free energy per mol of metal ion transferring from infinity in solution to the adsorbent surface  $k_d$  is used to estimate mean free energy by the following expression:

$$E = 1 / (2 k_d)^{0.5}$$

Value of  $E$  less than 1 to 8 KJ/mol corresponds to the physical while 8 to 16 KJ/mol corresponds to chemisorption. In order to estimate the constants of Dubinin-Radushkevich (DR) model a plot between  $\ln(q_c)$  and  $\varepsilon^2$  was obtained at 303K. Mean free energy for adsorption of both Zn and Cu was found to be less than 1 KJ/mol implies that adsorption process is physical mechanism.

The arid soil used for the adsorption study was alkaline in reaction (pH <sub>1:2</sub>-8.95), sandy in texture with organic carbon

content of 2.43 g/kg and CEC of 9.2 (cmol(p<sup>+</sup>) kg<sup>-1</sup>) (Table 2). Effect of bentonite addition on soil metal sorption was described by the most commonly used isotherms such as Langmuir and Freundlich. Both Langmuir and Freundlich models described the sorption data best for both the metals on soil based on the correlation coefficient (Table 3). Langmuir constant Q<sup>o</sup>, represent the maximum monolayer adsorption capacity of soils. The values are 1.08 mg g<sup>-1</sup> and 1.39 mg g<sup>-1</sup> for Zn (II) and Cu (II), respectively for arid soil. Based on values of the maximum adsorption capacity calculated from the fitted Langmuir equations the sequence of metal sorption was greater for Cu (II) than Zn (II). The maximum monolayer adsorption capacity of the soil treated with the bentonite clay

**Table 2.** Basic physical and chemical properties of the soil used in adsorption study

Mechanical composition	
Sand (%)	67.1
Silt (%)	22.1
Clay (%)	10.9
Soil Texture	Sandy
pH (1:2)	8.95
EC (1:2) (dSm <sup>-1</sup> )	1.09
CEC (cmol(p <sup>+</sup> ) kg <sup>-1</sup> )	9.2
Soil organic carbon (g kg <sup>-1</sup> )	2.43
Available soil N (mg kg <sup>-1</sup> )	85
Available soil P (mg kg <sup>-1</sup> )	3.8
Available soil K (mg kg <sup>-1</sup> )	102
DTPA extractable	
Zinc (mg kg <sup>-1</sup> )	0.5
Copper (mg kg <sup>-1</sup> )	0.2
Nickel (mg kg <sup>-1</sup> )	Nd

**Table 3.** Isotherm constants for metal sorption on soil in presence and absence of bentonite and correlation coefficients

Parameters	Zn	Cu
<i>Langmuir Isotherm</i>		
Arid soil		
Q <sub>m</sub> (mg/g)	1.08	1.39
K <sub>L</sub> (L/g)	0.11	0.15
R <sup>2</sup>	0.95	0.99
Arid soil + Bentonite		
Q <sub>m</sub> (mg/g)	10.5	11.76
K <sub>L</sub> (L/g)	0.62	0.52
R <sup>2</sup>	0.95	0.99
<i>Freundlich isotherm</i>		
Arid soil		
K <sub>r</sub> (mg/g) (L/g) <sup>1/n</sup>	0.12	0.18
1/n	0.43	0.7
R <sup>2</sup>	0.96	0.97
Arid soil + Bentonite		
K <sub>r</sub> (mg/g) (L/g) <sup>1/n</sup>	3.72	2.27
1/n	0.63	0.64
R <sup>2</sup>	0.95	0.99

was 10.5 mg g<sup>-1</sup> and 11.76 mg g<sup>-1</sup> for Zn (II) and Cu (II), respectively. The higher adsorption of Cu than that of Zn might be due to its higher relative binding strength, electronegativity and hydrolysis constant and lower ionization potential. The maximum adsorption capacity of soil for Zn (II) and Cu (II) increased in presence of the bentonite than that of untreated soil. This might be due to the increased adsorption sites available for the metals in presence of the bentonite. Application of bentonite increased the monolayer maximum adsorption capacity of soil by 8.5 fold and 9.7 fold for Cu and Zn, respectively. Similar findings are reported

sorption on  
of bentonite

Cu
1.39
0.15
0.99
11.76
0.52
0.99
0.18
0.7
0.97
2.27
0.64
0.99

by authors that application of clay minerals (including vermiculite also) enhances the metal sorption capacity of the soils (Xiong *et al.*, 2005; Xiong *et al.*, 2005).

The Freundlich parameter  $K_f$  and  $n$  values are 0.12, 0.18 for Zn and Cu, respectively and 3.72, 2.27 respectively for soil unamended and amended soil. The  $n$  value for both the metals studied was greater than 1, reflecting a favourable adsorption.

The distribution coefficient ( $K_d$ ) is a useful index for comparing the sorptive capacities of materials for a particular ion under the same experimental conditions (Alloway, 2008). Therefore, a further analysis of the data based on the distribution coefficients was done. The distribution coefficient ( $K_d$ ) has been calculated over all the initial concentrations of heavy metals

(Fig. 6). It is defined as the ratio of the metal concentration in the solid phase to that in the equilibrium solution after a specified reaction time. A high  $K_d$  value indicates a higher metal retention by the adsorbent through sorption and chemical reactions. However, a low  $K_d$  value indicates a high amount of the metal remains in the solution. Over all initial concentrations of heavy metals, the highest  $K_d$  values were found for Cu and followed by those of Zn (Fig. 6). The results also indicated that the  $K_d$  value decreased with increasing the initial metal concentration. This indicates that changes occur in the nature of the sites that are involved in the sorption process, depending upon the metal concentration. The higher  $K_d$  value that was obtained in the experiment with lower metal concentrations is associated with the sorption sites of high selectivity, which have

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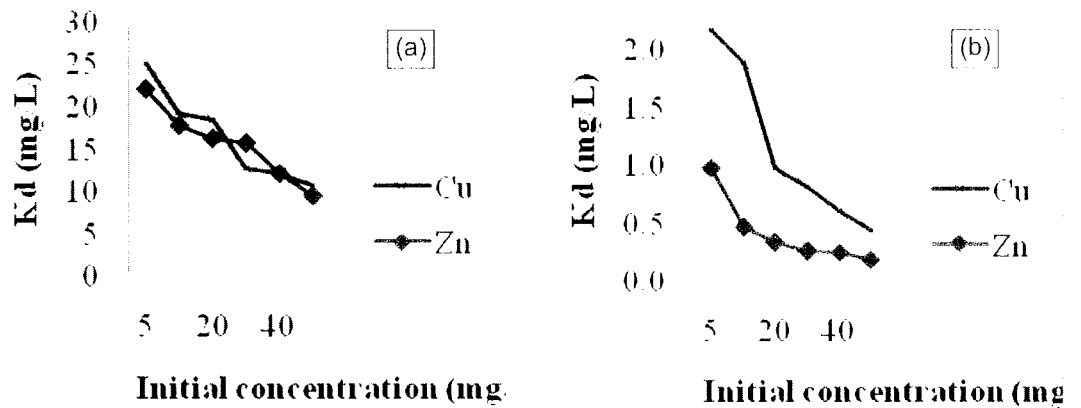
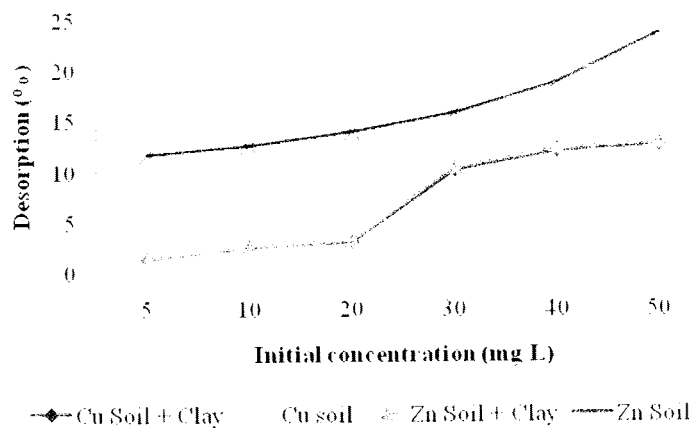


Fig. 6. Distribution coefficients of Cu and Zn in soil (a) with bentonite and without (b) bentonite clay

relatively strong bonding energies. Otherwise, heavy metal sorption becomes unspecific at higher metal concentrations, when the specific bonding sites become increasingly occupied, resulting in lower  $K_d$  values (Abidin and Kahan, 2005). Higher the  $K_d$  value for Cu indicate large affinity of soil with and without the bentonite. From the study it is clear that application of bentonite had positive impact on the metal adsorption capacity of the soil. The higher  $K_d$  value in the amended soil indicate that application of bentonite provide additional adsorption sites for the metals in the form of chelating functional groups.

The desorption rate can be used to characterize the degree of metal binding to the adsorbent. Higher the percentage of desorption, the more the loose binding. The desorption of the metals were decreased in

presence of bentonite clay from the soil compared to non-treated soil (Fig. 7) indicating the amended soil has more potential to retain the metals than that of untreated soil. This might be due to the strong binding of metals by the functional groups of the bentonite clay. The desorption percentage was higher at higher metal loading for both the metals from the soil both in presence and absence of bentonite. The desorption percentage at all initial concentration was lower for strongly adsorbed metal Cu (0.02% at 5 ppm to 0.27% at 50 ppm) than that of Zn (0.07% at 5 ppm to 3.03% at 50 ppm) in treated soil. The percentage desorption sequence followed the same trend in non-treated soil. The lower percentage of desorption of Cu might be formation of strong complexes with the bentonite clay and at higher loading the desorption might be due to



**Fig. 7.** Percentage desorption of Cu and Zn from soil (a) with bentonite and without (b) bentonite clay

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sorption at edges of composite. For the loosely bound metals the mechanism might be of ion exchange which resulted in higher desorption percentage.

### Conclusion

The effect of adsorbent level, initial metal concentration and pH on metal sorption capacity of bentonite clay showed maximum sorption of Cu and Zn at pH 6 and 7, respectively. The percentage removal of metal decreased with increase in initial concentration and the reverse trend observed in case of sorption capacity per unit amount of adsorbent. Amongst the adsorption isotherms, Langmuir equation fitted well and the study demonstrated the usefulness of bentonite in removal of metals from aqueous solution by adsorption mechanism. Freundlich sorption model fitted well the sorption data of bentonite clay treated soil. Amendment of soil with bentonite clay enhanced the sorption intensity of metals as well as decreased the desorption of metals and could be used as a potential immobilising agent for metals in soil.

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