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Evaluation of kinetics and adsorption isotherms for the Elimination of Pb(II) from aqueous solutions using *Aloe barbadensis* Miller Leaf Powder

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Abstract: An adsorbent was developed from matured leaves of the *Aloe barbadensis* miller plant for removing Pb(II) from aqueous solutions. Adsorption was carried out in a batch process with several different concentrations of Pb(II) by varying amount of adsorbent, pH, agitation time and temperature. The uptake of the metal was initially very fast, but gradually slowed down indicating penetration into the interior of the adsorbent particles. The experimental data closely followed both Langmuir and Freundlich isotherms. A small amount of the adsorbent (1 g/50ml) could remove as much as 86% of Pb(II) in 35 min from a solution of concentration 0.3 mg/50ml at 25°C. The adsorption continuously increased in the pH range of 2.0–5.0, beyond which the adsorption could decrease up to pH 7.0 when the adsorption could not be carried out due to precipitation of the metal. The adsorption was exothermic at ambient temperature and computation of the parameters, *ΔH*, *ΔS* and *ΔG*, which indicated the interactions to be thermodynamically favorable.

Keywords: adsorption, *Aloe barbadensis* miller, aqueous solutions, heavy metals.

INTRODUCTION

Heavy metals are foremost pollutants of environment in the majority parts of the world that perhaps generated at some point in industrialization processes. Contrasting organic pollutants, the mainstream of which are vulnerable to biological degradation, heavy metal ions do not degrade into undamaging end products (Gupta et al., 2001). Heavy metals have been exceptionally released into the environment due to speedy industrialization and have become a major global concern. Cadmium (Cd), zinc (Zn), copper (Cu), nickel (Ni), lead (Pb), mercury (Hg) and chromium (Cr) are habitually detected in industrial wastewaters, which instigate from metal plating, mining activities, smelting, battery manufacture, tanneries, petroleum refining, paint manufacture, pesticides, pigment manufacture, printing and photographic industries, etc. (Forgacs et al., 2004). In the preceding few decades, industrialization in numerous regions has amplified the ejection of heavy metals in the environment and aquatic ecosystems. There are numerous methods to treat the metal contamination, for instance, precipitation, ion exchange, electrolysis, and separation by membrane, etc., but the selection out of assorted methods made available intended for wastewater treatment is based on the

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concentration of waste and cost of treatment (Mittal et al., 2005; Yang et al., 2005).

In recent times, adsorption technique for wastewater treatment has grown to be more popular with gaze at their efficiency in the removal of pollutants, principally heavy metal ions. Adsorption has compensation over other methods for remediation of heavy metals from wastewater for the reason that its design is simple and it is sludge-free and can be of near to the ground capital intensive. Adsorption is one of the popular methods for the removal of metals ions from aqueous solutions. Adsorption is a surface phenomenon, in which molecules of adsorbate are attracted and held to the surface of an adsorbent until equilibrium is reached (Bhattacharyya at el., 2004). Many research work has previously been done as regards the removal of lead (Pb) from wastewater, for example, Bhattacharyya at al. (2004) developed an adsorbent from the matured leaves of Neem (*Azadirachta indica*) tree for removing Pb(II) from water.

A small amount of the adsorbent (1.2 g/L) could remove as much as 93% of Pb(II) in 300 min from a lead- solution concentration of 100 mg/L at 300 K. In the study of Goel et al. (2005), the removal of lead (Pb) was also shown using rice husk in which a small amount of the adsorbent (Rice husk) could remove as much as 80% Pb from waste water. The adsorption of lead (Pb) using rice husk increased when the pH increased from 2 to 6 and the percentage adsorption was 86% at pH 6. In the study of Homaga et al. (2009) apple waste was used to remove lead (Pb) from wastewater and removal efficiency for lead (Pb) metal increased from 65 to 92% over the optimum pH range. Ajmal et al. (1998) studied removal of Cadmium, Zinc, Nickel and Lead from aqueous solutions by using *Magnifera indica* which is mainly dependent on pH value and contact time and also obeyed Freundlich adsorption isotherm. Rao et al. (2003) in his study showed that the removal of Pb^{2+} ions was more at pH 5.0-8.0. Lead adsorption on Tamarind nut carbon which depends on adsorption dosage at an optimum pH of 5.0 was studied by Srinivasan et al. (2005). In the present adsorption of dissolved Pb(II) on to *Aloe barbadensis* miller has been investigated.

Aloe barbadensis miller is a plant, which belongs to the family of Liliaceae, it is succulent with a whorl of elongated, pointed leaves. It is a perennial medicinal herb found almost everywhere in India. It is a xerophyte and can be grown even in dry lands under rain fed conditions. It is an erect plant with an ultimate height of 0.8m/2.6ft and spread of 0.8m/2.6ft with green, dagger-shaped leaves that are fleshy, tapering, spiny, marginated and filled with a clear viscous gel (Langmead et al., 2004). *Aloe barbadensis* miller contains many phytochemicals that are beneficial to humans. It is indigenous to hot countries and has been used medicinally for over 5000 years by Egyptian, Indian, Chinese and European cultures for its curative and therapeutic properties ranging from dermatitis to cancer. Solid material of *Aloe barbadensis* miller (ABM) leaves contains over 75 biologically active compounds including vitamins, minerals, enzymes, polysaccharides, phenolic compounds, and organic acids and has been claimed to have anti-inflammatory, antioxidant, immune boosting, anticancer, anti-ageing, sunburn relief and anti-diabetic properties (Langmead et al., 2004).

The objective of this research is therefore, to study and find out the characteristics of *Aloe barbadensis* miller [ABM] as an adsorbent material for the removal of lead(Pb) through adsorption from waste water under various conditions of pH .

EXPERIMENTAL

MATERIALS AND METHODS

All the chemicals used in the experiments were of analytical grade and were used without further purification. Lead acetate (Qualigens Fine Chemicals, Mumbai; minimum assay 99%) was used as the source of Pb(II) and all the solutions were made in de-ionized water. Different solutions of Pb(II) were prepared from a stock solution containing 1000 mg of Pb(II) in 1 L water. The pH of the aqueous solution was 5.0, which did not change much with dilution. For experiments at different pH, the acidity of Pb(II) solutions were adjusted by addition of drops of 0.1M HNO_3 and 0.1M NaOH solutions.

Preparation of *Aloe barbadensis* miller [ABM] leaf powder

Matured leaves of *Aloe barbadensis* miller were collected from various places in the northern region of India and washed with water so as to remove dust and were then cut into small pieces [1 cm broad and 1 cm wide]. They were allowed to dry at room temperature in a shadow for 30 days and the dried leaves kept in air oven at 50 to 55°C for 3 hours till the leaves turned crispy. After that, the dried leaves were converted into fine powder (ABM leaf powder) by grinding in a mechanical grinder. Furthermore, this ABM leaf powder was ground using a disintegrator. The powder of the ABM leaf powder was obtained from molecular sieves which have molecular size ranging from 53–74µm. To determine the concentration of the remaining metal ions, the biomass in the sample solutions were removed by using filtration method and the filtrate analyzed to measure the lead concentration. The amount bound on the biomass was assumed to be the difference between the initial metal concentration and that found in the supernatant. The effects of following the parameters such as pH, biomass size, biomass dose, initial metal ion concentration and contact time were studied. Adsorption experiments were also carried out in duplicate.

Adsorption experiments

The adsorption experiments were carried out in a batch process (Table 1) under the following experimental conditions.

The adsorption was carried out in 100mL borosil conical flasks by agitating a pre-weighed amount of the powder with 50mL of the aqueous Pb(II) solution in a constant temperature water bath using magnetic stirrer for a pre-determined time interval at a constant speed. After adsorption, the mixture was filtered using Whatman filter paper (41). After that, this filtrate was analyzed for unabsorbed Pb(II) which remained in the solution with atomic absorption spectrometry and precipitation method.

The amount of Pb(II) adsorbed per unit mass of the adsorbent (q in mg/g) was computed by using the following expression:

$$q = C_0 - C_t / M$$

where C_0 and C_t are Pb(II) concentrations in mg/L before and after adsorption respectively for time t, and M (g) is the amount of ABM leaf powder taken for 1 L of Pb(II) solution. The percent adsorption efficiency was found from the relation:

$$Adsorption(\%) = C_0 - C_t \times 100 / C_0$$

Table 1. The adsorption experiments were carried out in a batch process under the following experimental conditions

Initial Pb(II) concentration (g/50ml)	0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 0.9, 1.0, 1.2, 1.5, 1.8, 2.0
Amount of adsorbent (g/50ml)	0.3, 0.5, 0.7, 0.9, and 1.0
Agitation time (min) Adsorption	35
Temperature, T (^oC)	25
Particle size (µm)	**53–74**
pH	**5**

RESULTS AND DISCUSSION

Characterization of the adsorbent

ABM leaf powder is a tropical or subtropical plant used in medicinal folk, cosmetics, supplement and food material. Recently, t part of ABM leaf powder was used as food processing. However, ABM skin contained pharmaceutical compound such as antioxidant, this makes it very possible to be processed into natural antioxidant powder. ABM is a stem less or very short-stemmed succulent plant growing to 60–100 cm tall, and spreading by offsets (Langmead et al., 2004).The leaves are thick and fleshy, green to grey-green, with some varieties showing white flecks on their upper and lower stem surfaces (Beckford et al., 2000). The margin of the leaf is serrated with small white teeth. The flowers are produced in summer on a spike up to 90 cm (35 in) tall, each flower being pendulous, with a yellow tubular corolla 2–3 cm (0.8–1.2 in) long. Like other *Aloe* species, ABM forms arbuscular mycorrhiza, a symbiosis that allows the plant better access to mineral nutrients in soil (Beckford et al., 2000). ABM leaf contain phytochemicals under study for possible bioactivity, such as acetylated mannans, polymannans, anthraquinone C-glycosides, anthrones, anthraquinones, such as emodin, and various lectins. The structure of ABM which was the first active ingredient isolated from ABM is shown in Figure 1.

The adsorption was carried out in 100mL borosil conical flasks by agitating a pre-weighed amount of the powder with 50mL of the aqueous Pb(II) solution in a constant temperature water bath using magnetic stirrer for a pre-determined time interval at a constant speed. After adsorption, the mixture was filtered with Whatman filter paper (41). After that, this filtrate was analyzed for unabsorbed Pb(II) which remained in the solution with atomic absorption spectrometry and precipitation method. Figure 2 shows the surface study of ABM leaf powder before and after adsorption and Figure 3 respectively with the help of SEM (Scanning Electron Microscopy) technique.

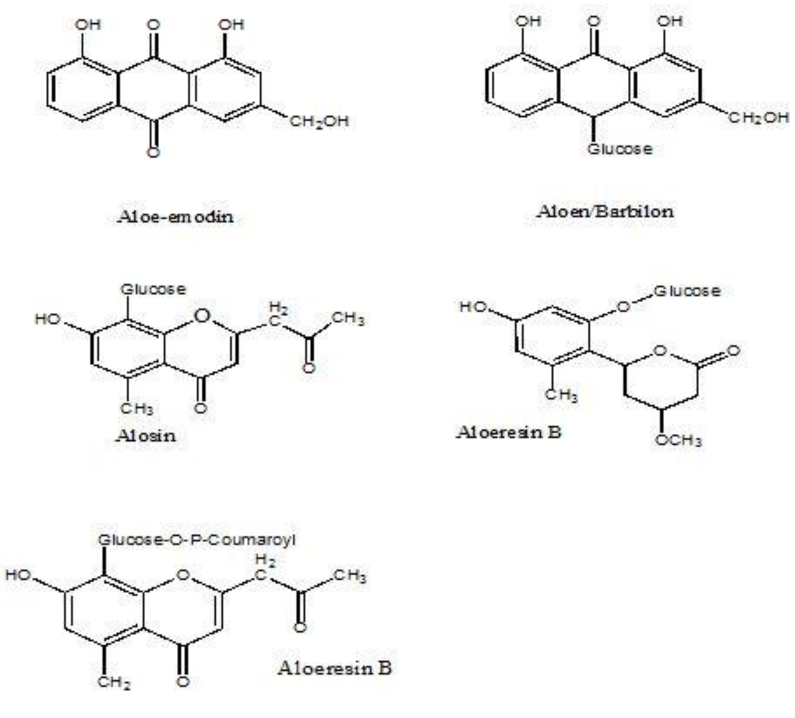

Fig. 1. Structures of the main ABM latex derived anthraquinones, chromones and anthrones

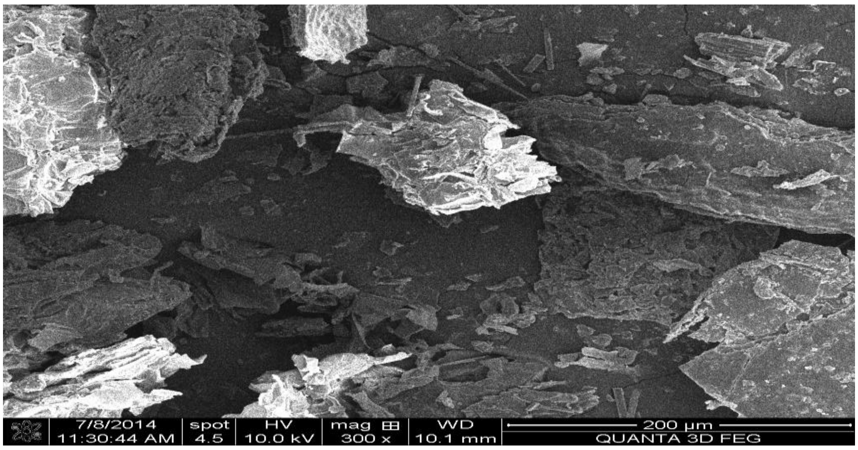

Fig. 2. ABM leaf powder before Pb adsorption

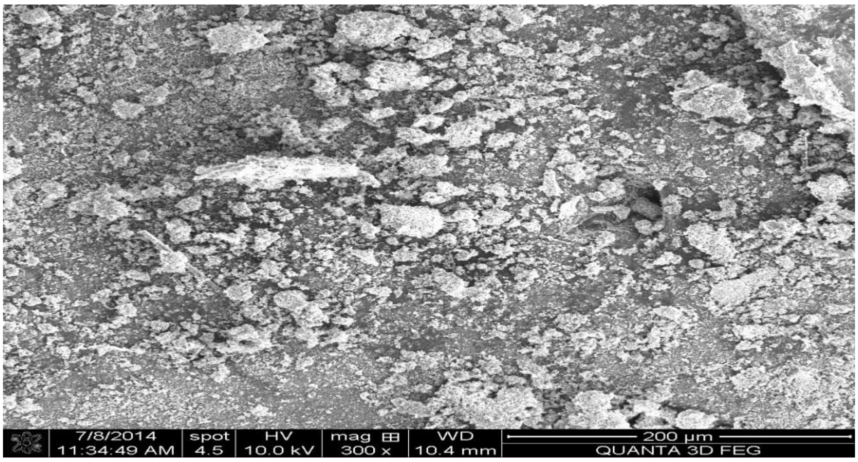

Fig. 3. ABM leaf powder after Pb adsorption

The amount of Pb(II) adsorbed per unit mass of the adsorbent (q in mg/g) was computed using the following expression:

$$q = C_0 - C_t / M$$

where C_0 and C_t are Pb(II) concentrations in mg/L before and after adsorption respectively for time t, and M (g) is the amount of ABM leaf powder taken for 1 L of Pb(II) solution. The percent adsorption efficiency was found from the relation:

$$Adsorption(\%) = C_0 - C_t \times 100 / C_0$$

Adsorption studies

The adsorption characteristics of Pb by ABM leaf powder were studied at varying concentrations range from 0.1 to 1.0g, at a fixed pH of 5.0 at 35°C (Fig. 4), it also indicates that the adsorption of Pb by ABM leaf powder increases with increase in temperature, demonstrating that the process is endothermic in nature. It was also observed that the initial removal of Pb is fast and with the rise in concentration, the percentage uptake gradually decreases.

Figure 4 shows that at low concentration of ions , adsorption is very high, specifically, it is maximum at the concentration 0.3g/50ml water, but with further increase of Pb ions adsorption decreses due to the filling of all the active sites. In addition,, the adsorption increased rapidly as more and more of the adsorbent was added and increased from 33.2 to 86.4% when the adsorbent amount was increased from 0.1 to 0.3g/50ml for an agitation time of just 30 min. Increasing the amount of the adsorbent makes a large number of sites available leading to an increase in adsorption. With an increase in the concentration of Pb at a constant amount of adsorbent, the adsorption came down for the same agitation time. The adsorption decreased from 86 to 30% when the adsorbent amount was increased from 0.4 to 2.0g/50ml.

Effect of pH

The solution pH is one of the parameters having considerable influence on the adsorption of metal ions, because the surface charge density of the adsorbent and the charges of the metallic species present on the adsorbent are both dependent on pH.. In the present work, the extent of lead adsorption was investigated in the pH range 1.0–7.0 with a constant amount of ABM leaf powder 0.5 g/50mL. At optimum pH which is 4.0, there was a net negative charge on the biomass cells and the ionic state of ligands so as to promote the uptake of metal ions. However, towards lower pH values, the overall surface charge on the biomass cells became positive, thereby, inhibiting the approach of positively charged metal cations. It is likely that protons will then compete with metal ions for ligands and thereby decrease the interaction of metal ions with the cells, whereas at higher pH > 5, the ligands attract positively charged metal ions and binding occurs, indicating that the major process is an ion exchange and adsorption mechanism that involves an electrostatic interaction between the positively charged groups in cell walls and metallic cations. When the extent of adsorption increased continuously at pH range of 1.0–4.0, biosorption was maximum at pH-4 which later became slow later (Fig. 5). Similar trend was also observed for adsorption of lead by other adsorbents (Sag et al., 1995).

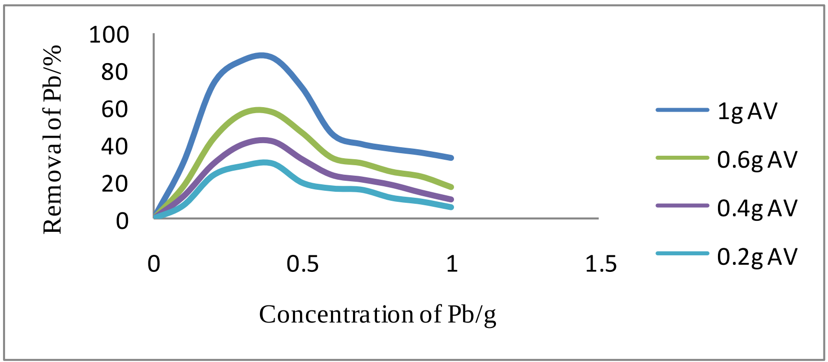

Fig. 4. Effect of initial ion concentration on the removal of Pb by ABM leaf powder

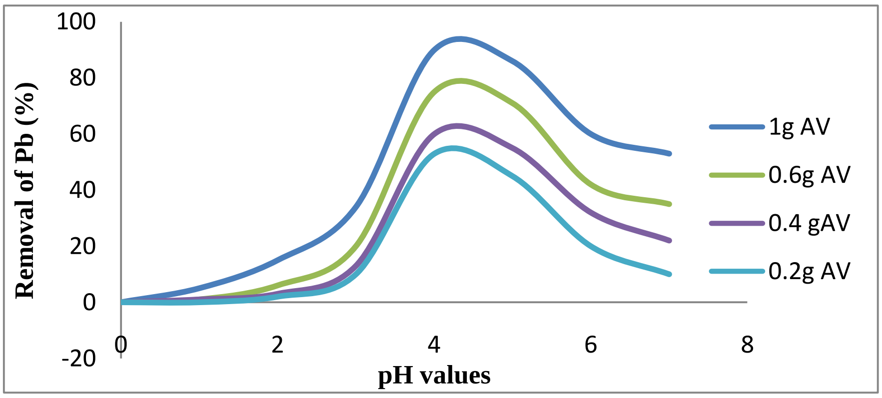

Fig. 5. Effect of pH on the removal of Pb by ABM leaf powder

Effect of contact time

Previous experimental studies showed that adsorption was dependent on contact time between the adsorbent and adsorbate. Batch adsorption experiments (Table 2) were carried out at optimum conditions of pH and temperature.

Kinetic studies revealed that maximum adsorption capacities and metal removal efficiencies for lead were achieved in the first 30 min. Adsorption took place rapidly and then continued at a slower rate up to maximum adsorption. In the first 30 min., adsorption was sharp due to automatic decrease in pH of solution (Fig. 6) as a result of protons released by adsorption. In addition, kinetic study also revealed that adsorption took place in two phases rapid surface adsorption within 30 min and slow intracellular adsorption up to end time which is in line with pervious experimental studies (Rao et al., 2003).

Table 2. Batch adsorption experiments were carried out in following experimental conditions

Initial Pb(II) concentration (g/L)	0.5
Amount of adsorbent (g/L)	1
Agitation time (min) Adsorption	10, 20, 30, 40, 60, 80, 100, 120, 160
Temperature, T (^{o}C)	28
Particle size (µm)	**53–74**
pH	**5.5**

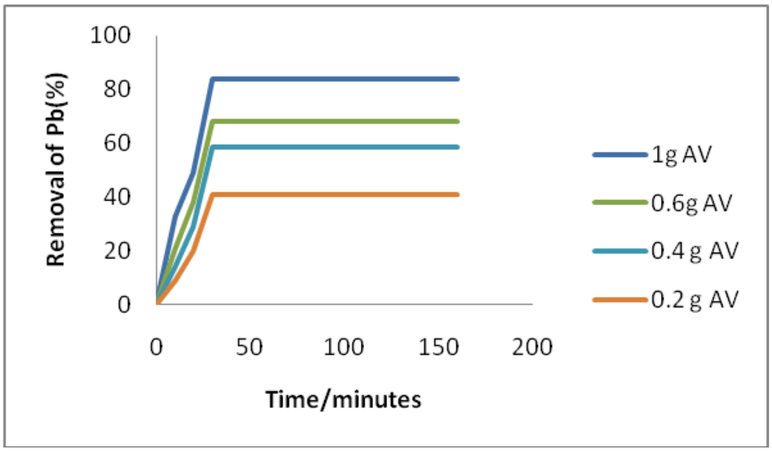

Fig. 6. Effect of contact time on removal of Pb by ABM leaf powder

Thermodynamics of adsorption

The thermodynamic criteria for the adsorption progression were evaluated using Gibbs energy (ΔG), enthalpy of adsorption (ΔH), and entropy of adsorption (ΔS) by hauling out the adsorption experiments at different temperatures and using the subsequent Equation (1):

$$\Delta G = \Delta H - T\,\Delta S \quad (1)$$

$$log\ \left(q_e / C_e\right) = -\Delta H / 2.303RT + \Delta S / 2.303R \quad (2)$$

where (q_e /C_e) is called the adsorption affinity and is the ratio of q_e, the amount adsorbed per unit mass at equilibrium to Ce, and equilibrium concentration of the adsorbate. The values of ΔH and ΔS were determined from the slope and the intercept of the plots of log (q_e /C_e) versus 1/T. The ΔG values were calculated using Equation (2) (Rao et al., 2003).

The two-parameter equation describing the adsorption process used in the course of this research is the Langmuir equation, which has the form:

$$\theta = q_e / C_1 = K_d C_e / \left(1 + K_d C_e\right)$$

where θ is the fractional coverage and C_1 is the amount adsorbed per unit mass of the adsorbent corresponding to the formation of a complete monolayer, K_d is the Langmuir constant related to the equilibrium constant of the adsorption equilibrium. C_e and q_e are the equilibrium liquid phase concentrations and amount of solute adsorbed at equilibrium, respectively. Equation (1) can be rearranged to the form:

$$C_e / q_e = \left(1/K_d C_1\right) + \left(1/C_1\right) C_e$$

which shows that a plot of (C_e/q_e) vs. C_e should give a straight line if the Langmuir equation is obeyed by the adsorption equilibrium and the slope and the intercept of this line will give the values of C_1 and K_d. These expressions have been shown to be valid in higher concentration ranges. For lower concentrations, the following form of Langmuir equation is found to be more satisfactory (Sag et al., 1995):

$$1/q_e = \left(1/C_1\right) + \left(1/K_d C_1\right)\left(1/C_e\right)$$

A further analysis of the Langmuir equation can be made on the basis of a dimensionless equilibrium parameter, R_L [26], also known as the separation factor given by:

$$R_L = 1/\left(1 + K_d C_{ref}\right)$$

where C_{ref} is any equilibrium liquid phase concentration of the solute. Table 3 shows a favourable adsorption.

Table 3. Type of isotherms

$R_L$value	Type of isotherm
$R_L > 1$	Unfavourable
$R_L = 1$	Linear
$0 < R_L < 1$	Favourable
$R_L = 0$	Irreversible

Another empirical isotherm given by the Freundlich equation is often used to describe the adsorption data. This equation has the form:

$$qe = K_f C_e^{\,n}$$

where K_f and n are known as Freundlich coefficients which can be determined from the plots of log q_e versus log C_e on the basis of the linear form of the equation:

$$log\ q_e = log\ K_f = n\ log\ C_e$$

The thermodynamic parameters for the adsorption process, namely; Gibbs energy (ΔG^0), enthalpy of adsorption (ΔH^0), and entropy of adsorption (ΔS^0) are determined by carrying out the adsorption experiments at four different temperatures and using the following equations (Sag et al., 1995):

$$\Delta G^0 = \Delta H^0 - T\Delta S^0 log\ \left(q/Ce\right) = -\Delta H^0/\left(2.303RT\right) + \Delta S^0/2.303R)$$

where (q/C_e) is called the adsorption affinity and the ratio of q, the amount adsorbed per unit mass to C_e, the equilibrium concentration of the solute. The values of ΔH^0 and ΔS^0 were determined from the slope and the intercept of the linear plot of log (q/C_e) versus 1/T. These values were used to calculate ΔG^0. R_L values of different isotherms are given in Table 4. Table 5 shows the thermodynamic parameters for adsorption of Pb(II) ions on ABM leaf powder for different concentrations at 30–100°C (pH- 5).

Table 4. Isotherms constants

Amount of AV g/50ml	Langmuir constants R^2	Freundlich constants R^2	Lagergren constants R^2
0.2g AV	0.98	0.99	0.91
0.4g AV	0.97	0.97	0.96
0.6g AV	0.97	0.97	0.98
1.0g AV	0.99	0.98	0.91

Adsorption of the Pb on ABM leaf powder yielded good fits with the Langmuir isotherm as well as the empirical Freundlich Isotherm. These isotherm plots are shown in Figure 7 and Figure 8 respectively. In all cases, the correlation coefficient shows excellent agreement with the theoretical equations. The Langmuir plots obtained for different ABM leaf powder doses at four different concentrations almost converged towards the Ce/qe axis indicating that they had widely differing slopes, but similar intercepts. This is also reflected in the values of the Langmuir coefficients obtained from these plots (Table 4). In all different solutions, a fixed dose of adsorbent was used as given in Figure 7. The good correlation coefficients showed that Langmuir model is more suitable than Freundlich for adsorption equilibrium of Lead.

Table 5. Thermodynamic parameters for adsorption of Pb(II) ions on ABM leaf powder for different concentrations at 30–100^{0}C (pH- 5)

Amount of AV(mg/50ml)	**ΔS kJKmol^{-1}**	**-ΔH kJKmol^{-1}**	**-ΔG (kJ/mol) at temperature**				
			30^{0}C	**45^{0}C**	**60^{0}C**	**75^{0}C**	**100^{0}C**
0.2g AV	64.299	8.8308	19.46	11.37	6.79	-0.84	-5.88
0.4g AV	12.40	2.3994	3.759	2.96	1.87	-1.21	-2.79
0.6g AV	5.7054	1.0694	1.637	1.50	0.68	-0.14	-3.44
1.0g AV	3.2967	0.0069	0.969	0.51	0.08	-0.11	-2.12

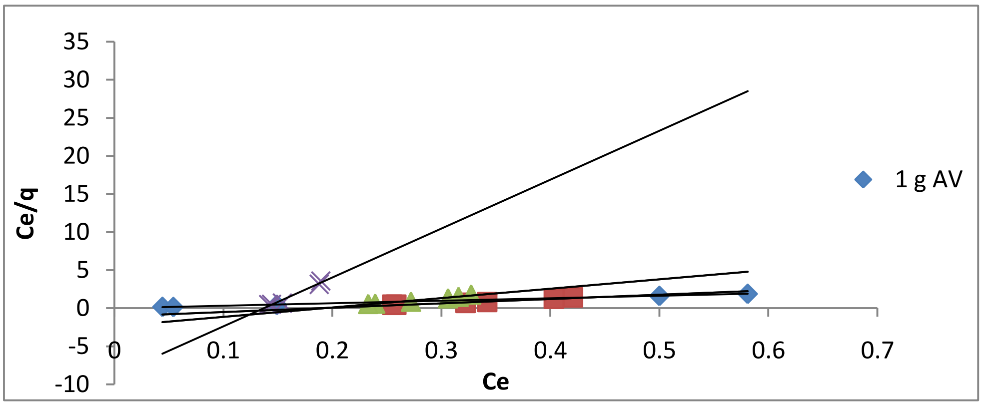

Fig.7. Langmuir plots for adsorption of Pb(II) on ABM leaf powder

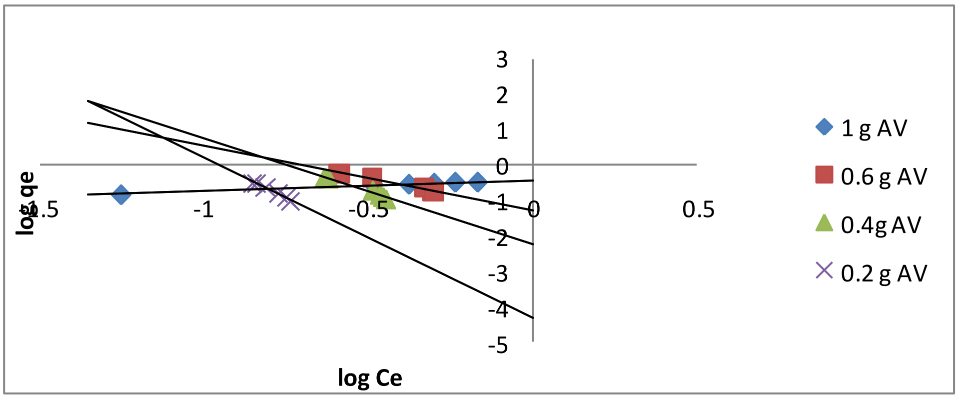

Fig. 8. Freundlich isotherm plots for adsorption of Pb(II) on ABM leaf powder

Kinetic studies

For the effectual designing and representation of the ongoing process, kinetic parameters were calculated by monitoring the effects of contact time, amount of adsorbent and concentration of adsorbate solution on adsorption of the Lead over ABM leaf powder. Preliminary studies suggested that 3h was sufficient for the attainment of equilibrium (Fig. 9). Moreover, the kinetics of adsorption process at different concentrations exhibited an increase in adsorption with the increase in temperature. The half-life of each process was also calculated and found to decrease with increase in temperature. These results once again confirmed the endothermic nature of the ongoing process. Figure 10 shows the results of adsorption study carried out with different dosage of the adsorbent. It was found that with the increasing dosage of adsorbent, the rate of removal of adsorbate increases. The data obtained revealed that there is a substantial increase in adsorption when amount of adsorbent is increased from 0.2 to 1.0 g.

Adsorption rate constant study

In order to study the specific rate constant of ABM leaf powder system, the well-known Lagergren first-order rate equation was employed [20]. Values of log (q_e −q_t) were calculated for each time interval at different temperatures using the formula:

$$log(q_e - q_t) = log q_e - k_{ad} / 2.303t \quad (3)$$

where q_e and q_t signify the amount adsorbed at equilibrium and at any time t. The graph of log(q_e −q_t) versus t (Fig. 10) exhibits straight lines at different concentrations and hence, confirmed the first order rate kinetics for the ongoing adsorption process.

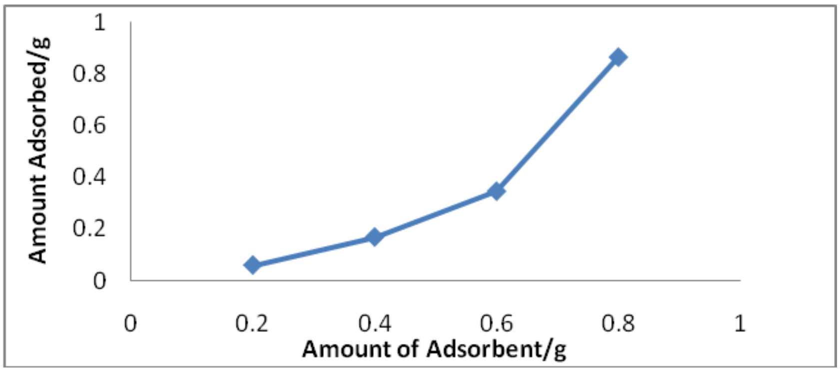

Fig. 9. Effect of amount of adsorbent for the removal of Pb(II) using ABM leaf powder temperature = 30 ◦C; concentration =0.3g/50ml H_2O; pH 5.0; time = 1 h.

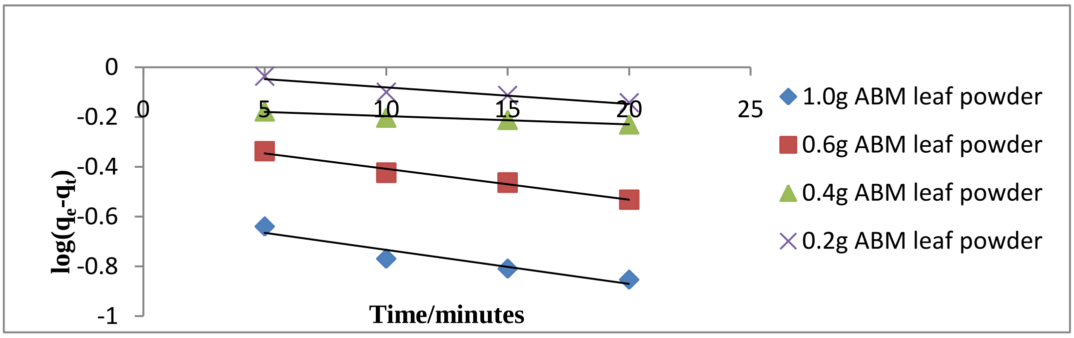

Fig. 10. Lagergren's plot of time vs. log(q_e −q_t) for Pb(II) adsorption ABM leaf powder at different concentrations(at 30^{0}C)

Effect of temperature

Lead adsorption on ABM leaf powder was affected by temperature change. No change in pH was observed during the experiments. The adsorption initially was very rapid with maximum uptake at 30°C, and later slowed down.. When adsorption was carried out at 0°C no uptake was shown, but when the temperature increased, there was a rapid increase in adsorption increased to a maximum of 30°C which later became slow as shown in Figure 11.

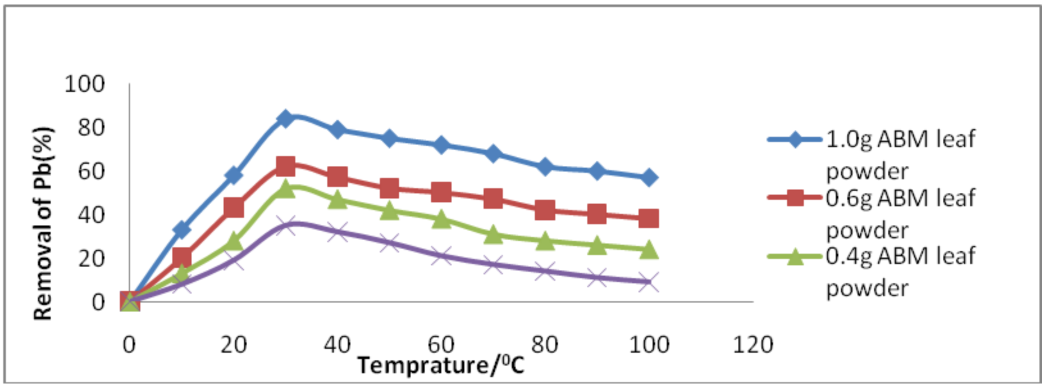

Fig. 11. Effect of temperature on removal of Pb by ABM leaf powder

Effect of adsorbent particle size and adsorbent dose

The effect of altering the particle size of adsorbent on the adsorption process showed that there was a more dominant removal of lead by the smaller particles. This was most probably due to the increase in the total surface area, which provided more adsorption sites for the metal ions. This was not the case with the adsorption of lead for the larger particles of ABM leaf powder. The enhanced removal of adsorbate by smaller particles has been noted previously during a study for the color removal by silica. The maximum (Kumar et al., 2011) adsorption occurred with 0.2 to 0.3mm adsorbent particle size for ABM leaf powder. It was suggested that an increase in adsorbent dose interferes between the binding sites and caused electrostatic interaction between cells. The amount of adsorbent dose added into the solution determines the number of binding sites available. An increase in adsorbent quantities strongly affects the extent to which lead is removed from aqueous solutions to a certain limit and then decreases. This effect was also reported in the literature for adsorption phenomenon of heavy metals (Kumar et al., 2011).

MECHANISM OF ADSORPTION

The most probable mechanism of adsorption in ABM involves chemical reaction between functional groups present on the adsorbent surface and the metal ions. This involves formation of metal-organic complexes which is shown in Figure 12, where bonding between Pb ions and ABM leaf powder was clearly indicated. indicated. Other possible mechanisms involve mass-transport processes, bulk transport in the liquid phase, diffusion across the liquid film surrounding the solid particles, and diffusion into micro and macro pores. The important characteristics of the adsorbent that determine equilibrium capacity and rate are the surface area, physicochemical nature of the surface, availability of the surface to adsorbate molecules or ions, physical size and form of the adsorbent particles. System parameters such as temperature and pH can also markedly influence adsorption as they affect one or more of the earlier mentioned parameters. The order of adsorbate–adsorbent interactions has been described using various kinetic models (Srinivasan et al., 2005). Traditionally, the pseudo-first-order model derived by Lagergren found wide application. Researchers (Gosset et al., 1986) reported that the removal of metal ions from aqueous streams using agricultural materials was based upon this mechanism. On the other hand, several authors have shown that second-order kinetics can also be used effectively to describe these interactions in certain specific cases (Upatham et al., 2009).

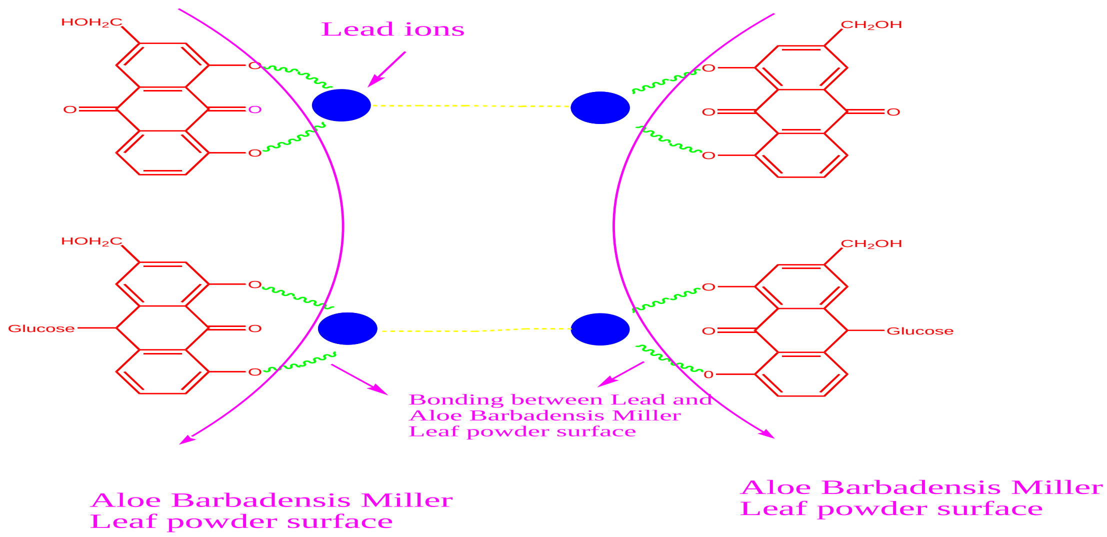

Fig. 12. Mechanism of adsorption

CONCLUSION

From the aforementioned study, it can be concluded that the adsorbent (ABM leaf powder) can be used efficiently to treat Pb(II) contaminated wastewater. Adsorption method was applied for the treatment of Pb(II) contaminated waste water. The maximum uptake capacity of the adsorbent was observed at pH 4.5. The percentage adsorption as well as uptake capacity of the adsorbent increased with decrease in pH. The percentage adsorption also increased with increase in adsorbent dose whereas it decreased with increase in adsorbate concentration. Therefore, ABM leaf powder could effectively be used as a source of removal of Pb(II) from an aqueous solution and the adsorption process had the support of appropriate thermodynamic parameters. The adsorption process was exothermic and spontaneous at ambient and slightly higher temperatures. ABM particles have a large number of polar and non-polar functional groups on the surface and some of these groups can bind metal ions to the surface through the formation of strong chemisorptive bonds or ion exchange mechanism. The experimental data gave good fits with both Langmuir and Freundlich isotherms and the adsorption coefficients were in line with the conditions of favourable adsorption. ABM leaf powder had a higher monolayer capacity than a large number of similar plant-based, low-cost adsorbents. From the study, adsorbed Pb(II) could be recovered and the adsorbent regenerated by washing the Pb(II)-loaded NLP with deionised water and dilute acid successively.

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