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Research Article

REMOVAL OF HEAVY METAL FROM WASTE WATER BY THE USE OF MODIFIED ALOE VERA LEAF POWDER

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ABSTRACT
An adsorbent was developed from the mature leaves of the Aloe vera for removing Pb from waste water. Adsorption was carried out in a batch process with chemically modified Aloe vera which has prepared with the help of phosphoric acid. Chemical modification of aloe vera with H_3PO_4 increased the sorption ability of aloe vera for Pb(II). This work investigated the bisorption characteristics for Pb(II) and examined the optimum conditions of the bisorption processes. Adsorption was carried out in a batch process with several different concentrations of Pb by varying amount of adsorbent, pH, agitation time and temperature. The uptake of the metal was very fast initially, but gradually slowed down indicating penetration into the interior of the adsorbent particles. A small amount of the adsorbent (0.3g/L water) could remove as much as 74.6% of Pb in 30 min from a solution. Uptake capacity can also increases by modifying the aloe vera by treating it with H_3PO_4.With the help of this modification uptake can be increases upto 96.2%. The adsorption continuously increased in the pH range of 1.0–4.0, beyond which the adsorption decreases. Due to its outstanding lead uptake capacity, the aloe vera plant was proved to be an excellent biomaterial for accumulating lead from aqueous solutions. The scanning electron microscopic (SEM) analysis was carried out for structural and morphological characteristics of aloe vera. The surface functional groups (i.e., carbonyl, carboxyl, and hydroxyl) of adsorbent were examined by Fourier Transform Infrared Technique (FT-IR) and contributed to the adsorption for Pb(II).

Keywords: *Modified Aloe Vera Leaf Powder; Adsorption; Elimination; Lead*

INTRODUCTION
Industrial and domestic effluents, as well as indiscriminate application of pesticides /herbicides to crop fields have contributed to the deterioration of environmental quality. Among these pollutants, heavy metals represent a special group because they are not chemically or biologically degraded in a natural manner (Gupta *et al.*, 2001). Several episodes due to heavy metal contamination in aquatic environment increased the awareness about the heavy metal toxicity. Metals can be distinguished from other toxic pollutants, since they are non biodegradable and can accumulate in living tissues, thus becoming concentrated throughout the food chain (Mittal *et al.*, 2005; Yang *et al.*, 2005). With the realization that pollutants present in water adversely affect human and animal life domestic and industrial activities, pollution control and management is now a high priority area. The availability of clean water for various activities is becoming the most challenging task for researcher and practitioners worldwide. Heavy metals have been excessively released into the environment due to rapid industrialization and have created a major global concern. Cadmium, zinc, copper, nickel, lead, mercury and chromium are often detected in industrial wastewaters, which originate from metal plating, mining activities, smelting, battery manufacture, tanneries, petroleum refining, paint manufacture, pesticides, pigment manufacture, printing and photographic industries, etc. (Gupta *et al.*, 2001). Therefore, elimination of toxic heavy metals is attended by many researches. There are various methods for the removal of heavy metals such as chemical precipitation (Homaga *et al.*, 2009). Reverse osmosis, ion exchange, coagulation, and adsorption. In recent years adsorption techniques for wastewater treatment have become more popular with regard to their efficiency in the removal of pollutants, especially heavy metal ions. Adsorption has advantages over other methods for remediation of heavy metals from wastewater because its design is

simple and it is sludge-free and can be of low capital intensive. Among them, low cost sorbents were especially investigated and their technical feasibility for heavy metal removals from the contaminated streams has been reviewed. Few biomasses adsorbents have been investigated for Pb already which is shown in Table-1. In the present study, an agriculture waste material, i.e. modified Aloe vera (MAV leaf powder) was examined as a new sorbent for the removal of Pb (II) ion from aqueous solutions. To the best of our knowledge, this material was not used before for this kind of application. Utilization of modified Aloe vera not only provide a low cost and easily available

Lead has one of most toxic heavy metal so that due to the health hazards the presence of lead in water is of extreme concern to the public, government and industry. Lead has toxic effects on the neuronal system and on the function of brain cells (Bhattacharyya *et al.,* 2004). The undesirable effects of these hazardous chemicals can be avoided by treatment of their Waste waters prior to discharge. Ajmal *et al.,* (1998) studied removal of Cadmium, Zinc, Nickel and Lead from aqueous solutions by Mangifera Indica which mainly depends on pH value and contact time and also obeyed Freundlich adsorption isotherm. Rao *et al.,* (2003) investigated 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). But such type of work can not done on Aloe vera. In the present adsorption of dissolved Pb(II) on to Aloe vera has been investigated.

Aloe vera (AV leaf powder) is a plant, which belongs to the family of Liliaceae and is mostly succulent with a whorl of elongated, pointed leaves is a highly significant 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 which has 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 vera contains many phytochemicals that are beneficial for human being. 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 AV 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 paper is to study and find out the characteristics of Aloe vera as an adsorbent material for diminish of lead through adsorption from waste water under various conditions of pH.

Experimental

Reagents and Materials

All the chemicals used in the experiments were of analytical grade and they were used without further purification. Lead acetate was used as the source of Pb(II) and all the solutions were made in de-ionised water. The solutions of Pb(II) were made from a stock solution containing 1000 mg of Pb(II) in 1 L. 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 Adsorbent

Mature Aloe vera leaves, collected from a number of places of northern region of India were washed with water to remove dust and cut into small pieces [1 cm broader and 1 cm wide] were allowed to dry at room temperature in a shadow for two weeks. Then leaves were kept in an air oven at 50 to 60 ^{0}C for 3 hours till the leaves became crisp. The dried leaves were then converted into fine powder (Aloe vera leaf powder, AVLP) by grinding in a mechanical grinder. The powder was sieved and the 53–74μm fraction was separated.

Chemical Pretreatment on Aloe vera

In order to increase the specific surface of aloe vera the aloe vera was ground using a disintegrator and after sieving the particle size ⩽1 mm was retained for further experiment. This Aloe vera was mixed with

1 M of H_3PO_4 solution at room temperature for 12 h in 250 ml with a stirring speed of 250 rpm so that the reagents were fully adsorbed onto the raw material ()[26]. After this treatment, the modified aloe vera was filtered and washed with distilled water for several times until the pH reached a constant value. Later on, this adsorbent was oven-dried at 80 to90°C for 6 h. Then the H_3PO_4-treated aloe vera was obtained.

Adsorption Experiments

The adsorption experiments were carried out in a batch process under the following experimental conditions:

Table 1

Initial Pb(II) concentration (g/L)	0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50, 1.0
Amount of adsorbent (g/L)	1
Agitation time (min)	40
Adsorption temperature, T (^{0}C)	35
Particle size (µm)	50–70
pH	5.5

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 also with the precipitation method. The surface study of ABM leaf powder before and after adsorption is shown in Figure 1 and Figure 2 respectively with the help of SEM (Scanning Electron Microscopy) technique.

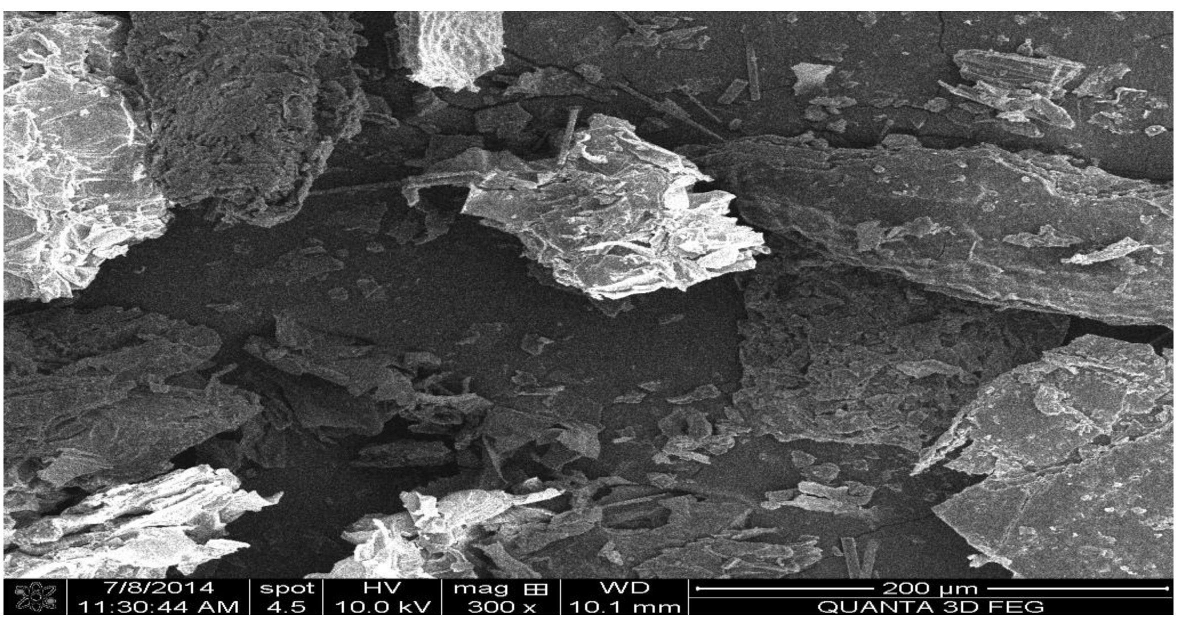

Figure 1: ABM leaf powder before Pb adsorption

Figure 2: ABM leaf powder after Pb adsorption

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 AV taken for 1 L of Pb(II) solution. The percent adsorption efficiency is found from the relation

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

RESULTS AND DISCUSSION

Figure 3 shows that at low concentration of ions absorption is very high. Absorbance is highest at the concentration 0.3g/L water.But with the further increase of ions absorbance is decreses due to the filling of all the active sites.

The adsorption increased rapidly as more and more of the adsorbent was added. The adsorption increased from 66.2% to 96.2 % 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 constant amount of adsorbent, the adsorption came down for the same agitation time. The adsorption decreases from 89.9% to 38 % when the adsorbent amount was increased from 0.4 to 2.0g/L.

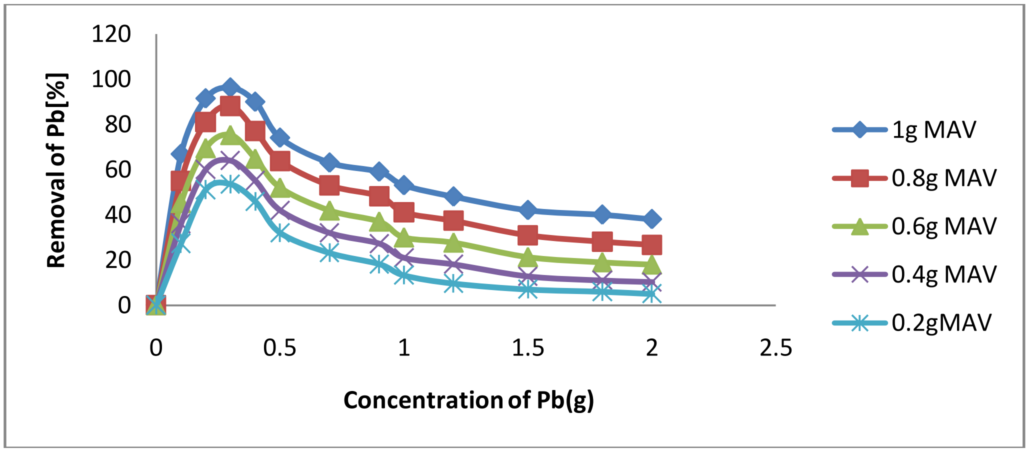

Figure 3: Effect of initial ion concentration on the removal of Pb by modified AVLP

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Thermodynamics of Adsorption

Adsorption is usually an exothermic process and as the temperature increases, the amount adsorbed at a given concentration decreases in accordance with Le Chatelaine's principle. The thermodynamic criteria for the adsorption process were evaluated through computation of Gibbs energy (ΔG), enthalpy of adsorption (ΔH), and entropy of adsorption (ΔS) by carrying out the adsorption experiments at three different temperatures and using the following Eq [1]:

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

$$\log (q_e / C_e) = \Delta H/2.303RT + \Delta S/2.303R \qquad (2)$$

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, the 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 Eq. (2)

Desorption and Regeneration

For carrying out desorption and regeneration studies, modified AVLP was first saturated with Pb by taking 1 g of MAV leaf powder in a pyrex glass column (1.5 cm internal diameter) and continuously passing a solution of Pb(0.3g mg/50ml) through it while keeping a constant head of 2 cm till the concentration at the outlet equaled the initial concentration. Desorption was carried out by passing successively (i) deionised water (pH 7.0) and (ii) dilute nitric acid (pH 4.0) through the column till Pb could not be detected in the outlet in each case.

Influence of pH

The solution pH is one of the parameters having considerable influence on the biosorption of metal ions, because the surfaces charge density of the adsorbent and the charge of the metallic species present on the pH. In the present work, the extent of lead biosorption was investigated in the pH range 1.0–7.0 with a constant amount of aloe vera powder 0.5 g/L solution of concentration. At pH value above optimum pH, there is a net negative charge on the biomass cells and the ionic state of ligands is such to promote the uptake of metal ions.

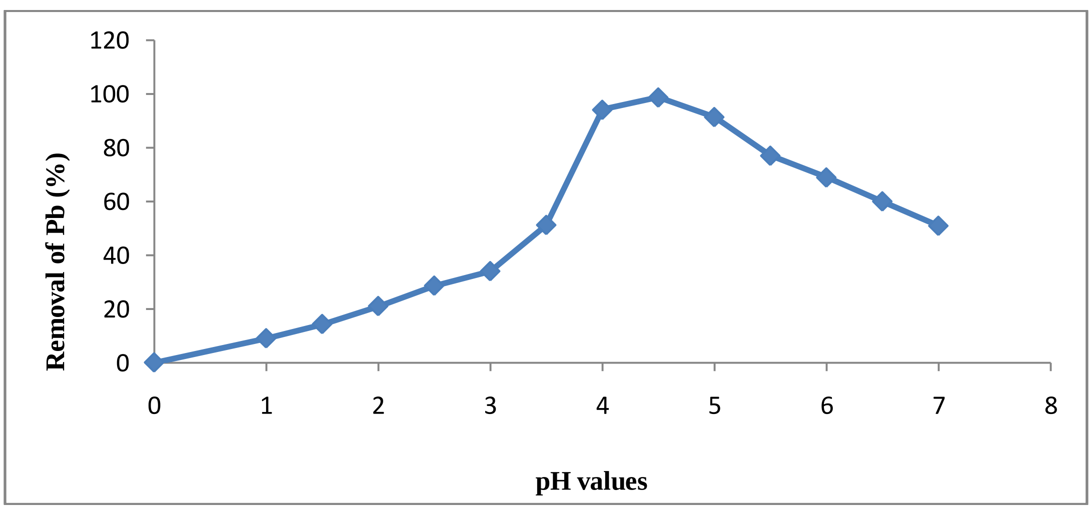

Figure 4: Effect of pH on the removal of Pb by MAV leaf powder

As the pH lowered, however the overall surface charge on the biomass cells become positive, which will inhibit the approach of positively charge metal cations. It is likely that protons will then compete with metal ions for ligands and thereby decreases the interaction of metal ions with the cells. Whereas at higher pH (above 5), the ligands attract positively charged metal ions and binding occurs, indicating that the major process is an ion exchange. Mechanism that involve an electrostatic interaction between the positively charged groups in cell walls and metallic cations (Sag *et al.*, 1995) Similar trend was reported for biosorption of lead by aloe vera when the extent of biosorption increased continuously pH range of 1.0–4.0.Biosorption is maximum at pH-4.5 than it becomes slower down (Figure 4). The authors interpreted the process as due to ion-exchange and the large discrepancies at higher pH were attributed to metal removal by other possible mechanisms such as precipitation.

Effect of Time on Biosorption

Previous experimental studies showed that biosorption is dependent on different time intervals. Batch biosorption experiments were carried out at optimum conditions. Kinetic studies revealed that maximum adsorption capacities and metal removal efficiencies for lead were achieved generally in first 25 min biosorption takes place very rapidly and then it continues at slower rate upto maximum biosorption. In first 25 min., biosorption is sharp due to decrease in pH of solution because protons were released by biosorbent (Figure 5). Kinetic study revealed that biosorption takes place in two phases, rapid surface biosorption within 25 min and slow intracellular biosorption upto end time agrees with pervious experimental studies (Rao *et al.*, 2003).

Initial Pb(II) concentration (g/L)	0.3
Amount of adsorbent (g/50ml)	1
Agitation time (min)	5, 10,15, 20,25, 30,35, 40,45,50,55, 60, 80, 100, 120, 160
Adsorption temperature, T (^{0}C)	35
Particle size (µm)	53–74

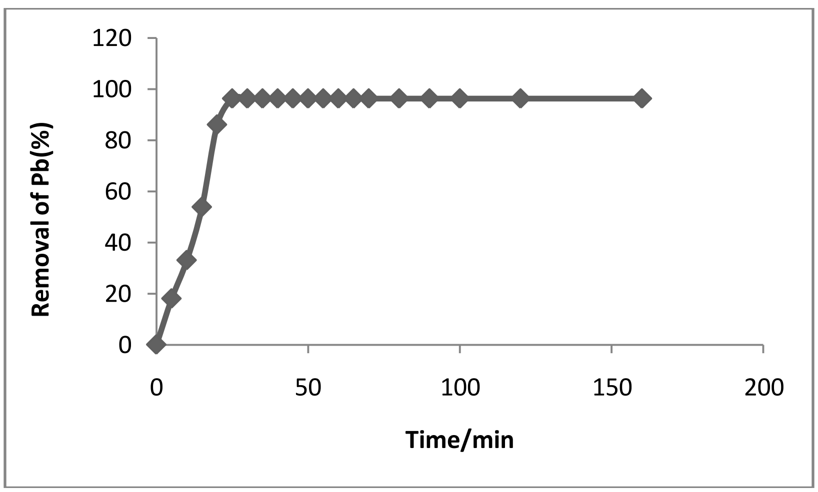

Figure 5: Effect of time on removal of Pb by MAV leaf powder

Thermodynamics of Adsorption

The thermodynamic criteria for the adsorption progression were evaluated through working out of 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]:

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

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

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, the 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 the largest part extensively used two-parameter equation, describing the adsorption process is the Langmuir equation, which has the form:

$$\theta = q_e/C_1 = K_dC_e / (1+K_dC_e)$$

where θ is the fractional coverage and C_1 is the amount adsorbed per unit mass of the adsorbent corresponding to 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 concentration and amount of solute adsorbed at equilibrium, respectively. Equation (1) can be rearranged to the form:

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

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).

$$1/q_e = (1/C_1) + (1/K_dC_1)(1/C_e)$$

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

$$R_L = 1/(1 + K_dC_{ref})$$

where C_{ref} is any equilibrium liquid phase concentration of the solute. It is shown that for favourable adsorption as shown in Table 2.

Table 2: 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

$$qe = K_fC_e^n$$

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 ($\Delta S^{\ 0}$) are determined by carrying out the adsorption experiments at four different temperatures and using the following equations (Sag *et al.*, 1995)

$$\Delta G^0 = \Delta H^0 - T\Delta S^0$$

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

where (q/C_e) is called the adsorption affinity and is 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 is given in Table 3.Thermodynamic parameters for adsorption of Pb(II) ions on MAV leaf powder for different concentrations at 30–100^{0}C (pH- 5) is given in Table 4.

Table 3: Isotherms constants

Amount of AV g/50ml	Langmuir constants R^2	Freundlich constants R^2	Lagergren constants R^2
0.2g AV	0.99	0.98	0.94
0.4g AV	0.98	0.99	0.97
0.6g AV	0.97	0.98	0.96
1.0g AV	0.98	0.98	0.95

Table 4: Thermodynamic parameters for adsorption of Pb(II) ions on MAV leaf powder for different concentrations at 30–100^{0}C (pH- 5).

Amount of MAV(mg/L)	ΔS	-ΔH	-ΔG (kJ/mol) at temperature				
	$kJKmol^{-1}$	$kJKmol^{-1}$	30^{0}C	45^{0}C	60^{0}C	75^{0}C	100^{0}C
0.2g MAV	65.399	9.8708	18.46	14.37	7.19	-0.74	-5.08
0.4gM AV	13.40	2.8994	3.889	3.16	2.07	-1.11	-2.09
0.6g MAV	5.9014	1.2684	1.597	1.490	0.78	-0.24	-3.94
1.0g MAV	3.7997	0.0169	0.869	0.61	0.09	-0.12	-2.02

Adsorption of the Pb on MAVL leaf powder yielded good fits with the Langmuir isotherm as well as the empirical Freundlich Isotherm. These isotherm plots are shown in Figure 6 and Figure 7 respectively. In all cases, the correlation coefficient shows excellent agreement with the theoretical equations. The Langmuir plots obtained for different MAV 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 3). In all different solutions, a fixed dose of adsorbent was used as given in Figure 6. The good correlation coefficients showed that Langmuir model is more suitable than Freundlich for adsorption equilibrium of Lead.

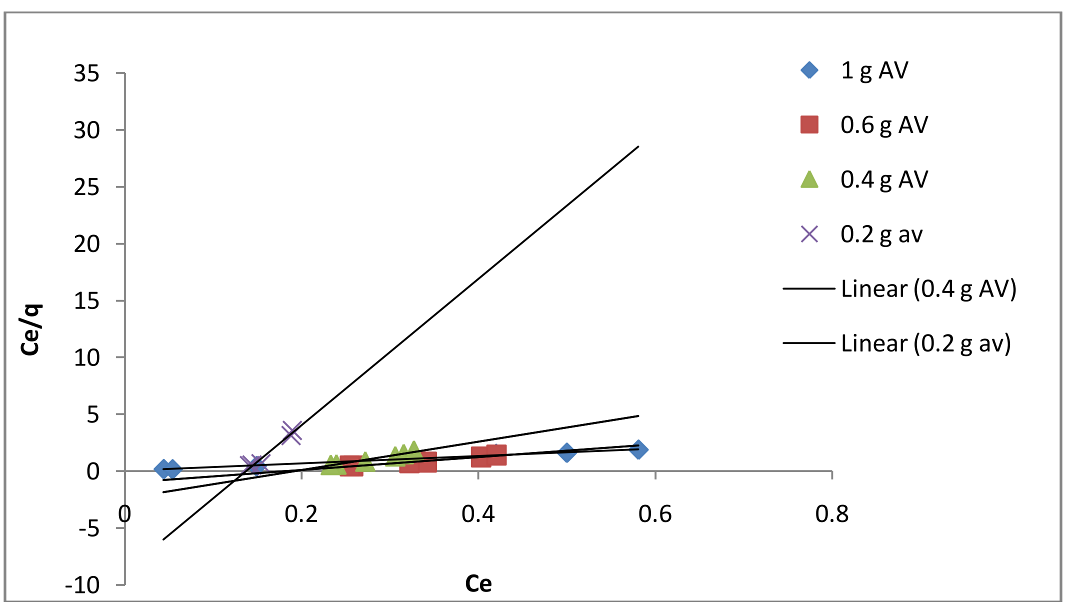

Figure 6: Langmuir plots for adsorption of Pb(II) on MAV leaf powder

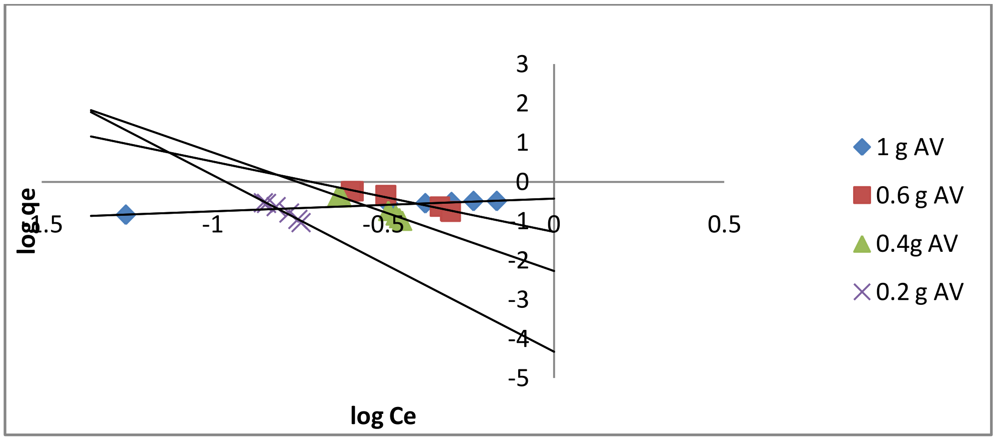

Figure 7: Freundlich isotherm plots for adsorption of Pb(II) on MAV leaf powder

Kinetic Studies

For the effectual designing and representation of the ongoing process, kinetics parameters were calculated by monitoring the effects of contact time, amount of adsorbent and concentration of adsorbate solution on adsorption of the Lead over MAV leaf powder. Preliminary studies suggested that 3 h were sufficient for the attainment of equilibrium (Figure 8). 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 was found to decrease with increase in temperature. These results once again confirm endothermic nature of the ongoing process. Figure 9 shows the results of adsorption study carried out with different adsorbent dose. It was found that with the increasing dosage of adsorbent, the rate of removal of adsorbate increases. The data obtained reveals that there is a substantial increase in adsorption when amount of adsorbent is increased from 0.2 to 1.0 g.

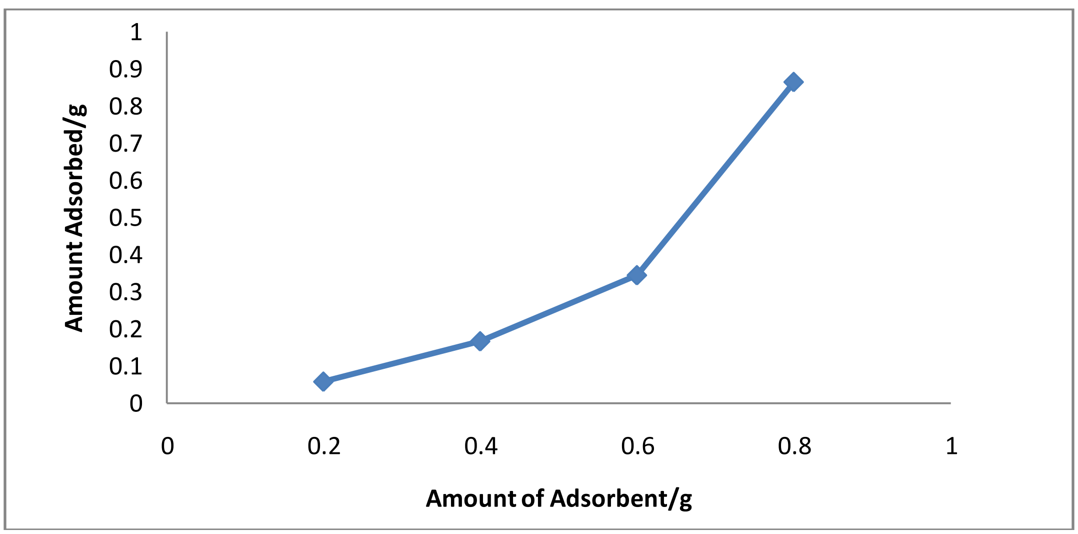

Figure 8: Effect of amount of adsorbent for the removal of Pb(II) using MAV leaf powder: temperature = 30 ◦C; concentration =0.3g/50ml H_2O; pH 5.0; time = 1 h

Adsorption Rate Constant Study

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

$$\log(q_e - q_t) = \log q_e - k_{ad}/2.303t \qquad (5)$$

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 (Figure 10) exhibits straight lines at different concentrations and hence confirm the first order rate kinetics for the ongoing adsorption process.

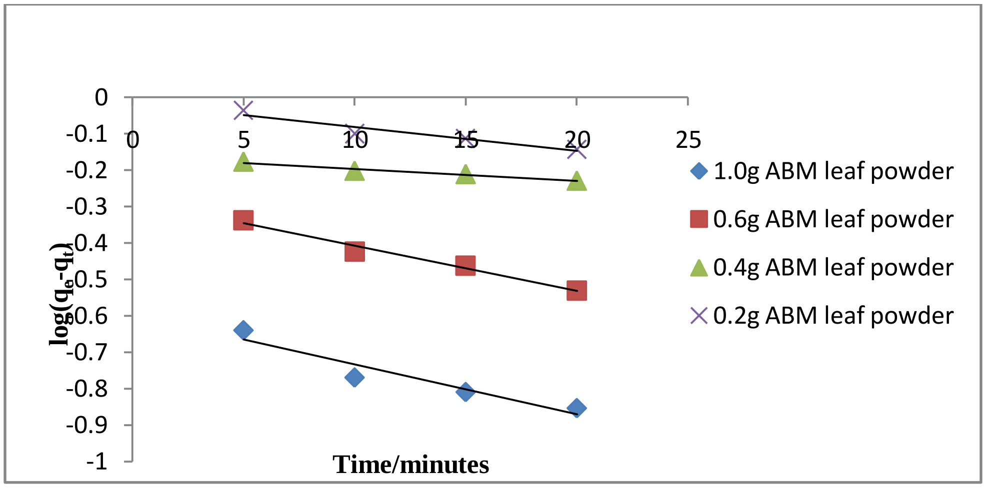

Figure 9: Lagergren's plot of time vs. $\log(q_e - q_t)$ for Pb(II) adsorption MAV leaf powder at different concentrations (at 30^{0}C)

Effect of Temperature

Lead biosorption on MAV leaf powder is affected by temperature change. No change in pH was observed during the experiments. The adsorption was very rapid initially with maximum uptake with 40^{o}C, then slowing down a little bit. When we do adsorption at 0^{0}C than no uptake is shown. But when temperature increases adsorption is also increases very rapidly it reaches maximum at 40^{0}C than slower down as show in Figure 10.

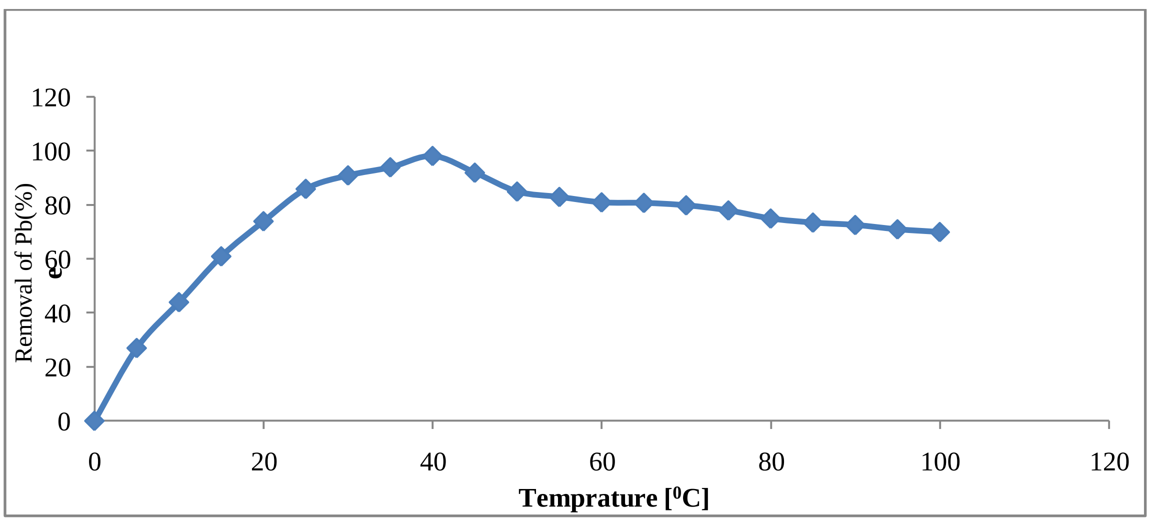

Figure 10: Effect of temperature on removal of Pb by modified AVLP

Effect of Adsorbent Particle Size and Adsorbent Dose

The effect of altering the adsorbents particle size on the 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 biosorption sites for the metal ions. This was not the case with the biosorption of lead for the larger particle size. The enhanced removal of sorbate by smaller particles has been noted previously during a study for the color removal by silica (Kumar *et al.*, 2011). The maximum biosorption was occurred with 0.2 to 0.3mm adsorbent particle size for aloe vera leaves powder. It was suggested that an increase in adsorbent dose interferes between the binding sites and caused electrostatic interaction between cells. Adsorbent dose added into the solution determines the number of binding site available. An increase in adsorbent quantities strongly affects the quantities of lead removed from aqueous solutions to a certain limit and then decreases. This effect was also reported in literature for biosorption phenomenon of heavy metals (Kumar *et al.*, 2011).

Mechanism of Action

The most probable mechanism of adsorption in MAV involves chemical reaction between functional groups present on the adsorbent surface and the metal ions. This involves formation of metal-organic complexes, where bonding between Pb ions and MAV leaf powder is indicated clearly. 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 pores and macro pores. The important characteristics of the adsorbent that determine equilibrium capacity and rate are the surface area, the physicochemical nature of the surface, the availability of that surface to adsorbate molecules or ions, the 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 above parameters. The order of adsorbate–adsorbent interactions has been described by using various kinetic models (Srinivasan *et al.*, 2005). Traditionally, the pseudo-first-order model derived by Lagergren has found wide application. Researchers (Gosset *et al.*, 1986) reported that the removal of metal ions from aqueous streams using agricultural materials is based upon this mechanism. On the other hand, several authors have shown that second-order kinetics can also very well describe these interactions in certain specific cases (Upatham *et al.*, 2009).

Conclusion

From the above study, it can be concluded that the adsorbent (MAV 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 was also found to be increased with increase in adsorbent dose whereas it decreased with increase in adsorbate concentration.

MAV leaf powder could very efficiently remove 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.

MAV 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 through ion exchange mechanism. The experimental data gave good fits with both Langmuir and Freundlich isotherms and the adsorption coefficients agreed well with the conditions of favourable adsorption. MAV leaf powder had a higher monolayer capacity than a large number of similar plant-based, low-cost adsorbents. Adsorbed Pb(II) could be recovered and the adsorbent could be regenerated by washing the Pb(II)-loaded MAV leaf powder with deionised water and dilute acid successively.

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