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RICINUS COMMUNIS PERICARP ACTIVATED CARBON AS AN ADSORBENT FOR THE REMOVAL OF Pb(II) FROM AQUEOUS SOLUTION AND INDUSTRIAL WASTEWATER

Activated carbon prepared from the pericarp of *Ricinus communis* was used to adsorb Pb(II) from aqueous solutions. Batch mode adsorption experiments were carried out by changing contact time, metal-ion concentration, carbon concentration and pH to assess kinetic and equilibrium parameters. The adsorption data were modelled by using both Langmuir and Freundlich classical adsorption isotherms. The adsorption capacity (Q_0) calculated from the Langmuir isotherm was 35.08 mg/g of activated carbon at initial pH 5.0±0.2 and the particle size ranging from 125 to 250 μm.

1. INTRODUCTION

The water is mainly polluted with organics, inorganics, sediments, radioactive materials and heavy metals. Among these contaminants, the contribution of heavy metals to the environment pollution is of major concern because of their toxicity, bioaccumulation, persistence and nonbiodegradability. Industrial effluent containing lead plays an important role in polluting water bodies. Additional potential sources of lead-bearing waste include storage batteries, lead smelting, mining, plating, ceramic and glass industries [1]. Lead contamination of drinking water occurs as a result of corrosion and leaching from lead pipes and Pb/Sn soldered joints associated with the copper service lines commonly used in household plumbing [2]. Lead poisoning in humans

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causes severe damage to the kidney, nervous system, reproductive system, liver and brain, and causes sickness or death [1]. Severe exposure to lead has been associated with sterility, abortion, stillbirth and deaths [3]. The permissible limit for lead in drinking water is 0.05 mg/dm^3 [4]. The permissible limit for Pb(II) ion in wastewater, given by the Environmental Protection Agency (EPA), is 0.05 mg/dm^3 and by the Indian Standards Institution is 0.1 mg/dm^3 [5].

A number of technologies have been developed over the years to remove toxic metal ions from water [6]. Such methods consist in chemical precipitation, electrodeposition, ultrafiltration, ion exchange, activated carbon adsorption and biological processes [4]. Utilizing the waste materials from agriculture and industries can make the treatment process economical and solve the problem of solid waste disposal. The feasibility of several low-cost, non-conventional adsorbents obtained from agricultural and industrial wastes was explored. Research has already been conducted on a wide variety of adsorbents. They include waste Fe(II)/Cr(III) hydroxide [7], biogas residual slurry [8] and silk cotton hull carbon [9]. The present study deals with the use of activated carbon prepared from an agricultural waste, i.e. the pericarp of *Ricinus communis*, as an adsorbent of Pb(II) in aqueous solution and industrial wastewater.

2. MATERIALS AND METHODS

2.1. ADSORBENT

In the present study, the pericarp of *Ricinus communis* was used for the preparation of activated carbon. It was dried and then activated chemically by pouring 50% sulfuric acid over it and the constant stirring (w/v) of the mixture obtained. The charred material was kept in hot air oven at 100 ± 5 °C for 12 h, thereafter washed with redistilled water, soaked in 10% sodium bicarbonate solution and allowed to stand overnight to remove the residual acid from the pores of carbon. The material was washed with distilled water, until the pH of the adsorbent reached 7 ± 0.2. Then it was dried in a hot air oven at 100 ± 5 °C for 12 h, ground and sieved to obtain the particle size of 125–250 μm. The sieved adsorbent was stored in an airtight container for further experiments. All the chemicals used were of analytical reagent grade obtained from B.D.H and Merck Co. Ltd. Redistilled water was used for the whole period of experimental studies.

2.2. BATCH MODE ADSORPTION STUDIES. ADSORBATE

A stock solution of 1000 mg/dm^3 lead(II) was prepared by dissolving 1.5990 g of anhydrous lead nitrate in water acidified with 1 cm^3 of concentrated nitric acid and made up to 1000 cm^3. The working solutions of 10, 20, 30, 40 mg/dm^3 of Pb(II) were prepared from stock solution. Batch mode adsorption studies were carried out with 50 mg of the adsorbent and 50 cm^3 of Pb(II) solution of desired concentration at pH 5.0±0.2, agitated at 120 rpm in a mechanical shaker at room temperature. The adsorbate solution was separated from the adsorbent by its centrifugation at 5000 rpm and estimated spectrophotometrically at 520 nm using PAR (4-(2-pyridyldazo) resorcinol) reagent [10]. The effect of carbon dosage on percent removal of Pb(II) was studied with the solutions of 30 mg/dm^3 at particle size of 125–250 μm. The effect of pH on Pb(II) removal was studied for metal ion concentration of 20 and 40 mg/dm^3 using 50 mg of carbon dosage/50 dm^3 of the solute or 1 g/dm^3. Langmuir isotherm was studied with different initial concentration of Pb(II) ranging from 5 to 40 mg/dm^3, while maintaining the adsorbent dose at 50 mg/50 cm^3 or 1 g/dm^3. Desorption studies were carried out to confirm the adsorption mechanism proposed above and to recover the metals from the adsorbent using 0.025–0.550 M hydrochloric acid.

2.3. REMOVAL OF LEAD(II) ION FROM RADIATOR-MANUFACTURING INDUSTRY WASTEWATER

The Pb(II) ion-containing wastewater was collected from the radiator-manufacturing industry and characterized. This allowed us to study the effect of adsorbent dosage under optimum conditions of pH and agitation time on lead removal. The treated samples were then centrifuged and analyzed.

3. RESULTS AND DISCUSSION

3.1. ADSORBENT CHARACTERIZATION

Characteristic of activated carbon prepared from the pericarp of *Ricinus communis* is presented in table 1. The determined surface area of *Ricinus communis* pericarp (RCP) activated carbon was 495 m^2/g and is comparable to various low-cost adsorbents, namely porogen-free banana pith carbon (37 m^2/g) [11], palm pith carbon (188 m^2/g) [12], cassava carbon (200 m^2/g) [13], peanut hull carbon (208 m^2/g) [14], silk cotton hull carbon (228 m^2/g) [9], coconut tree sawdust carbon (325 m^2/g) [15] and maize cob carbon (468 m^2/g) [16]. The moisture content of the carbon was found to be 2.50% (table 1). This would not influence the adsorptive capacity of activated carbon. Based on the literature it can be inferred that if the moisture content of the adsorbent is higher, it will dilute the action of activated carbon and some extra load of carbon should be used [17]. The decolorizing power of carbon was 21.0 mg/g, which indicates that the carbon prepared by acid activation method has good adsorptive capacity and can be considered for adsorption of organic dyes. The surface morphology of activated carbon (RCP) was visualized via scanning electron microscopy (SEM), the corresponding SEM micrographs being obtained using a JSM-840 JEOL microscope of JEOL Techniques LTD, Japan, at 2000× magnification (figure 1). The examination of SEM micrographs of the RCP particles showed rough areas of the surface of the carbon and the micropores were identifiable. The activation process of RCP by adopting sulphuric acid treatment leads to the corrosion of the surface of a carbonaceous material and the appearance of micro-, macro- and mesopores.

Table 1

Characteristics of activated carbon

Parameters	Value
pH, 1% solution	6.90
Moisture content (%)	2.50
Ash content (%)	6.50
Decolorizing power (mg/g)	21.00
Ion-exchange capacity (equi/g)	0.80
Average surface area (m^2/g)	495
Bulk density (gm /dm^3)	0.46
Porosity (%)	68.27
Specific gravity	1.46
Particle size (μm)	125–250
Iodine number (mg/g)	468
Yield (%)	70
Calcium (mg/g)	20.0
Sodium (mg/g)	28.8
Potassium (mg/g)	2.3
Water-soluble matter (%)	1.29
HCl-soluble matter (0.25 N) (%)	2.45

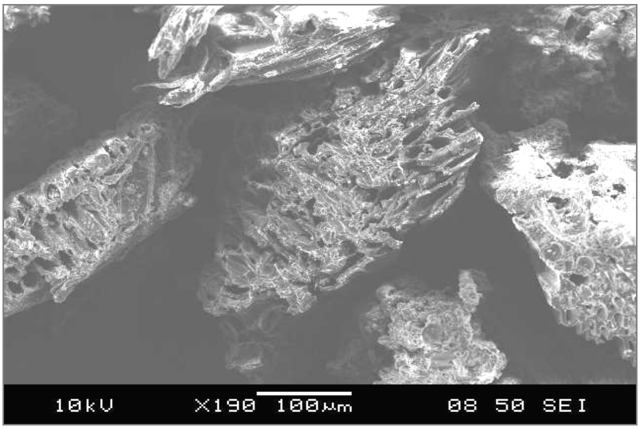

Fig. 1. SEM of the RCP carbon

3.2. EFFECT OF AGITATION TIME ON Pb(II) ADSORPTION

The effect of agitation time on the percent removal of Pb(II) by RCP carbon is shown in figure 2. The longer the agitation time, the higher the percent removal, and the equilibrium was attained within 130 min for all the concentrations studied (10 to 40 mg/dm^3). The curves were single, smooth and continuous till the saturation of activated carbon surface with Pb(II).

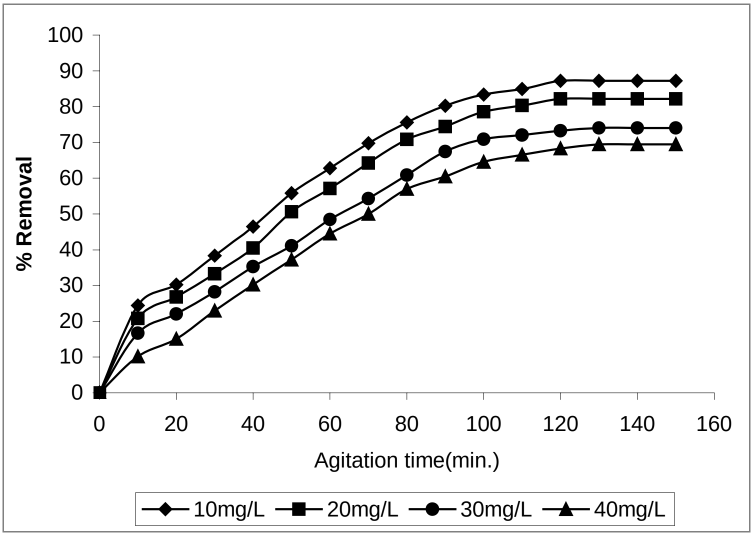

Fig. 2. Effect of agitation time and initial Pb(II) concentration on Pb(II) adsorption (adsorbent dosage: 50 mg/50 cm^3, Pb(II) concentration: 10–40 mg/dm^3)

3.3. ADSORPTION KINETICS

The adsorption kinetics of Pb(II) on the adsorbent follows the first-order reaction given below:

$$\log_{10}(q_e - q) = \log_{10} q_e - \frac{K_{\mathrm{ad}} t}{2.303},$$

where K_{ad} (1/min) is the rate constant of adsorbent, q and q_e are the amount of Pb(II) adsorbed (mg/g) in the time t (min) and equilibrium time, respectively. Linear plots of $\log_{10}(q_e - q)$ versus t (figure 3) show the applicability of the above equation. The K_{ad} values for different Pb(II) ion concentrations, i.e. 10, 20, 30 and 40 mg/dm^3, calculated from the slope of the plots were 0.0329, 0.0338, 0.0375 and 0.0333 1/min, respectively.

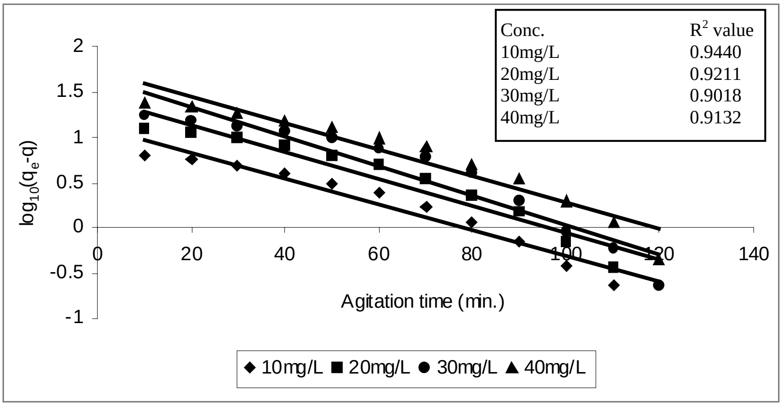

Fig. 3. Lagergren plots for Pb(II) adsorption
(adsorbent dosage: 50 mg/50 cm^3, Pb(II) concentration: 10–40 mg/dm^3)

3.4. EFFECT OF ADSORBENT DOSAGE ON Pb(II) ADSORPTION

The effect of carbon dosage on percent removal of Pb(II) is shown in figure 4. When the carbon dosage increases, the percent removal also increases. It was found that for the removal of 30 mg of Pb(II) in 1 dm^3, the maximum adsorbent dosage of 110 mg/50 cm^3 was required. An increase in the adsorbent dosage increases the removal because of the availability of larger surface area and more functional groups.

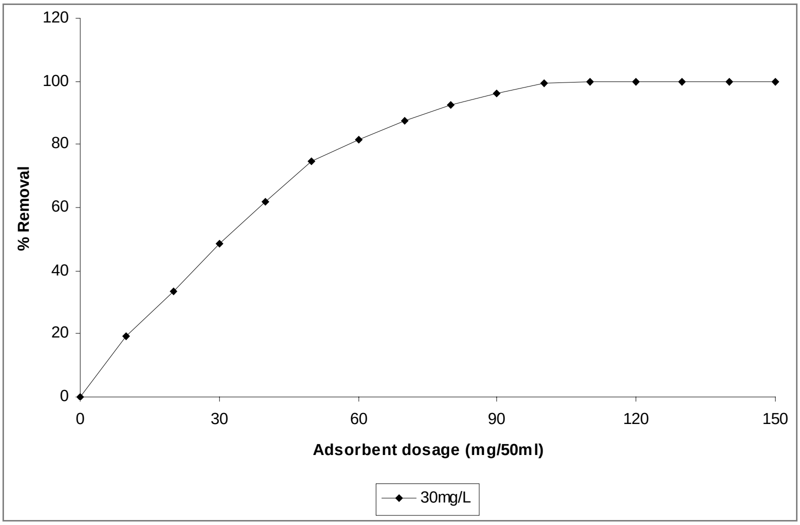

Fig. 4. Effect of carbon dosage on Pb(II) adsorption
(adsorbent dosage: 0–150 mg/50 cm^3, Pb(II) concentration: 30 mg/dm^3)

3.5. ADSORPTION ISOTHERMS

The Langmuir isotherm can be applied to the adsorption equilibrium of Pb(II) onto RCP carbon [18]

$$\frac{C_e}{q_e} = \frac{1}{Q_0.b} + \frac{C_e}{Q_0},$$

where C_e is the equilibrium concentration (mg/dm^3), q_e is the amount of Pb(II) adsorbed (mg/g), Q_0 and b are the Langmuir constants related to adsorptive capacity and energy of adsorption, respectively. The linear plot of C_e/q_e versus C_e (figure 5) shows that the adsorption follows the Langmuir isotherm, where Q_0 = 35.08 mg/g and b = 0.2577 for 5–40 mg/dm^3 concentration. The Langmuir isotherm can be expressed in terms of dimensionless separation factor of equilibrium parameter

$$R_L = \frac{1}{1 + bC_0},$$

where C_0 is the initial Pb(II) concentration (mg/dm^3) and b is the Langmuir constant (dm^3/mg). R_L values for different Pb(II) ion concentration (table 2) were found to be between 0 and 1 and indicative of favourable adsorption of Pb(II) onto RCP carbon.

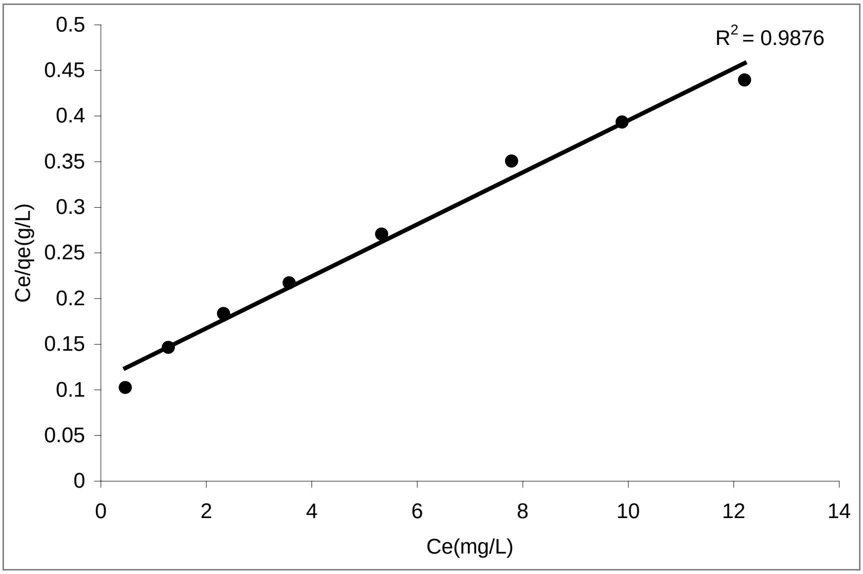

Fig. 5. Langmuir plot for Pb(II) adsorption
(adsorbent dosage: 50 mg/50 cm^3, Pb(II) concentration: 5–40 mg/dm^3)

Table 2

Analysis of Langmuir isotherm for Pb(II) adsorption

Sample No.	Initial Pb(II) conc. (mg/dm^3)	R_L	Q_0 (mg/g)	b (dm^3/mg)
1	5	0.4369	35.08	0.2577
2	10	0.2795		
3	15	0.2055		
4	20	0.1624		
5	25	0.1343		
6	30	0.1145		
7	35	0.0998		
8	40	0.0884		

The linear form of the Freundlich equation can be given by:

$$\log_{10}\frac{X}{m} = \log_{10} K_f + \frac{1}{n\log_{10} C_e},$$

where X is the amount of Pb(II) adsorbed at equilibrium (mg), m is the weight of the adsorbent used (mg), C_e is the equilibrium concentration of Pb(II) in solution (mg/dm^3), K_f and n are constants. Linear plot of $\log_{10}X/m$ versus $\log_{10}C_e$ shows that the adsorption follows the Freundlich isotherm (figure 6). The Freundlich constants K_f and n are found to be 16.553 and 7.117, respectively, for 5–40 mg/dm^3 concentration.

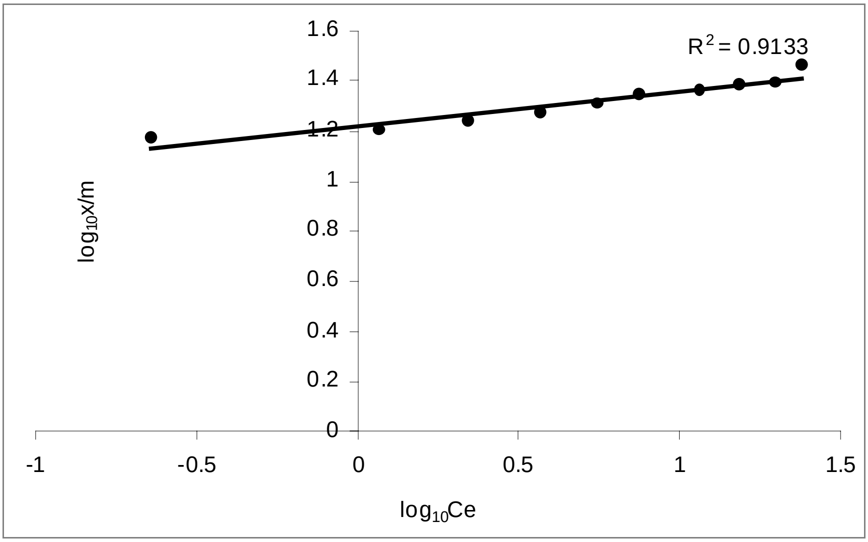

Fig. 6. Freundlich plot for Pb(II) adsorption
(adsorbent dosage: 50 mg/50 cm^3, Pb(II) concentration: 5–40 mg/dm^3)

3.6. EFFECT OF pH ON Pb(II) ADSORPTION

The effect of pH ranging from 2.0 to 10.0 on the removal of Pb(II) ions from the aqueous solution with adsorbent was studied (figure 7). The precipitation of Pb(II) was observed from pH 6.0 onwards and the intensity of precipitation increases with an increase in pH from 6.0 to 10.0. Similar observations were reported for coir pith carbon [19]. The removal of metal ions increases with an increase in pH from 6.0 to 10.0 even in the solution without adsorbent, and this is may be due to the formation of metal hydroxide which precipitates. As a result, adsorption and precipitation occur simultaneously and we are not able exactly differentiate between the amount of Pb(II) removed by adsorption and precipitation. Thus pH 5 was taken as the optimum for adsorption. Similar observations were also made by other researchers [5], [19].

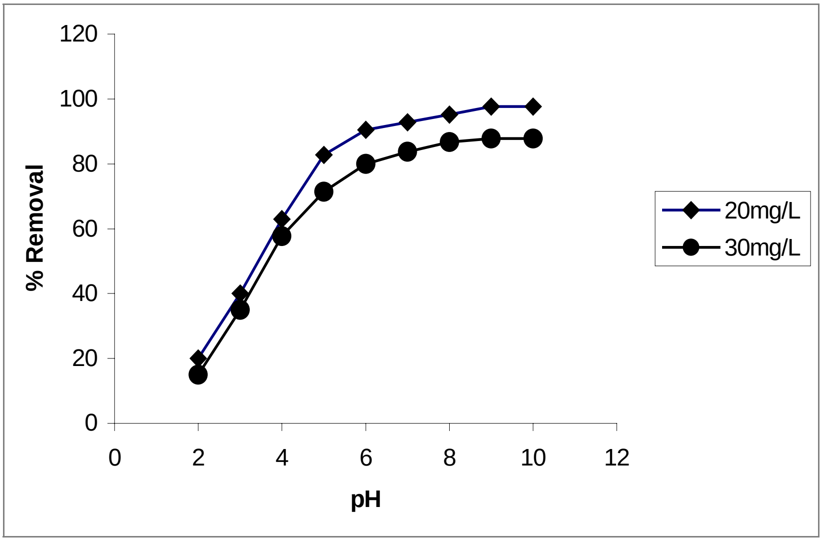

Fig. 7. Effect of pH on Pb(II) adsorption
(adsorbent dosage: 50 mg/50 cm^3, Pb(II) concentration: 20 and 30 mg/dm^3)

3.7. DESORPTION STUDIES

Desorption studies were carried out to confirm the adsorption mechanism proposed above and to recover the metals from the adsorbent. The quantitative recovery of metal ion indicated that carbon regeneration was possible. This is further evidence that ion exchange is involved in the adsorption mechanism. Desorption was carried out at different concentration of hydrochloric acid (0.025–0.550 M). The results are shown in figure 8. Maximum desorption occurs at the acid strength of 0.450 M.

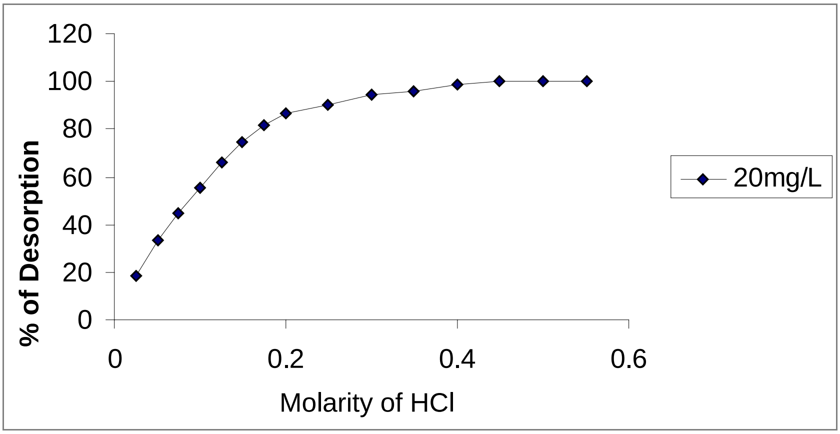

Fig. 8. Desorption of Pb(II) ions from RCP carbon

3.8. CHARACTERISTICS AND TREATMENT OF RADIATOR-MAUFACTURING INDUSTRY WASTEWATER

The wastewater produced by radiator-manufacturing industry had acidic reaction, high hardness and high content of sodium, solids, chloride and Pb(II) (table 3). In the treatment study, 30 mg/dm^3 of lead is prepared by diluting the radiator-manufacturing industry wastewater. The effect of adsorbent dosage on Pb(II) removal from the wastewater under the optimum conditions (pH 5 ± 0.2 and the contact time of 130 min) is as follows: percent removal of lead increases with an increase in adsorbent dosage and reached 100% at 500 mg/50 cm^3 (figure 9). The adsorbent dosage required for wastewater proved to be very high compared with that for synthetic solution, which may be due to the presence of other dissolved ions. Similar results were reported by SHANMUGAVALLI et al. [5].

Table 3

Characteristics of radiator-manufacturing industry wastewater

Parameter	Value
pH	3.1
Total dissolved solids (mg/dm^3)	6010
Total solids (mg/dm^3)	7150
Sodium (mg/dm^3)	2850
Potassium (mg/dm^3)	11.0
Calcium (mg/dm^3)	250
Chloride (mg/dm^3)	312
Sulphate (mg/dm^3)	38.0
Pb(II) (mg/dm^3)	155

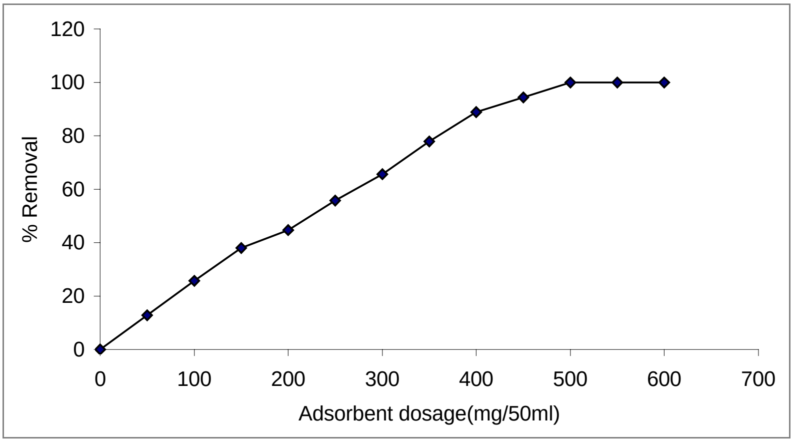

Fig. 9. Effect of carbon dosage on lead removal from industrial wastewater (adsorbent dosage: 50–600 mg/50 cm^3, Pb(II) concentration: 30 mg/dm^3)

4. CONCLUSION

The current investigation shows that *Ricinus communis* pericarp carbon is very effective adsorbent of Pb(II) ions that should be removed from aqueous solution. An increase in the adsorbent dosage and agitation time increases Pb(II) ion removal at the optimum pH 5±0.2. The adsorption followed both Langmuir and Freundlich isotherm models. Desorption studies reveal that the recovery of Pb(II) ions from adsorbent is possible. Removal of lead from wastewater produced by radiator-manufacturing industry confirms the validity of the results obtained in batch mode studies.

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