Research Article

Hydrodynamic Studies in a Packed Bed Column for the Removal of Zinc Ions from Aqueous Solution

P. Muthusamy*, Britto and S. Murugan

Department of Biotechnology, Karunya University, Coimbatore, Tamilnadu, India.

ABSTRACT

This paper reports the results of study on the performance of low cost adsorbent such as maize cob in removing the heavy metal Zn (II) from 0.01M $ZnSO_4$ solution. The biosorption is carried out in a self-designed packed bed column. The columns with Dc/Dp < 10 have been proved to have lesser efficiency due to increased wall effect. This column aims to improve the efficiency by maintaining the Dc/Dp ratio greater than 10. Biosorption studies were carried out at various flow rates. The contact time was maintained at 30 minutes for all the flow rates. The metal removal capacity of maize cob increased from 43.5% to 58.5% and then dropped to 17.8% as the cycles progressed. Out of the total 5 cycles, the highest metal removal was obtained for the third cycle which is from the 60^{th} to 90^{th} minute at an increased 58.5%. The volumetric flow rate for this cycle was 1.25×10^{-5} m^3/s and the velocity was 3.78×10^{-3} m/s. The %metal removal for the total process duration of 180 min was 92.7%. Such a high efficiency is obtained due to the reduced wall effect which was obtained by maintaining the Dc/Dp ratio to a value greater than 10. Reynolds number was calculated and varied from 60 to 3000. This shows that both laminar and turbulent flow can be obtained in the setup. Thus, study of the column yielded better results suitable for scaling up to industrial applications. Hence, a bigger column (by scaling up the existing column) can be developed for waste water treatment at the industrial level. The existing setup can be used for waste water treatment at a small scale level. This setup can also be used in a gas-solid system and can be applied for air pollution control.

Keywords: Biosorption, Zinc, Packed bed column, Reynold's number, Wall effect.

INTRODUCTION

Heavy metals enter into the environment mainly through the effluent discharge from many of the industries such as dyeing industries, battery industries, chemical industries, metal plating industries, leather tanning industries, etc. The heavy metals such as zinc, lead, chromium, mercury, etc., are left invariably in the effluents from these industries and thus, enter into the eco system. The discharge of heavy metals such as lead, chromium, mercury, uranium, selenium, zinc, arsenic, cadmium, copper, nickel, etc., into the aquatic ecosystems constitute severe health hazard mainly due to their non-degradability and toxicity[1]. For zinc and chromium, the major application is in fertilizer and leather tanning, respectively. Even if they are present in dilute and undetectable quantities, their recalcitrance and consequent persistence in water bodies imply that through natural process such as biomagnifications, concentration may become elevated to such an extent that they begin exhibiting toxic characteristics[2].

There are numerous methods currently employed to remove and recover the metals from our environment and many physico-chemical methods have been proposed for their removal from wastewater. These methods differ in their effectiveness and cost. They include ion-exchange resin, solvent extraction, electrolytic and precipitation processes, along with electro dialysis and membrane technology. Other conventional technologies which have also been used range from granular activated carbon to reverse osmosis. These techniques are not only expensive but also exhibit incomplete removal, consuming huge quantities of reagents, energy requirements and generation of toxic sludge[3]. Bio-removal has the potential to achieve this goal. The major advantages of biosorption over conventional treatment methods include low cost, high efficiency, minimization of biological and chemical sludge. Moreover, many of the agricultural wastes are potential bio adsorbents. Thus, they are available in plenty and are inexpensive also. Due to their low cost, after these materials have been expended, they can be disposed of without

expensive regeneration[4]. Metal recovery is also possible[5].
This work evaluates the performance of maize cob as a bio adsorbent. It is easily available at free of cost in Tamil Nadu. The maize cob needs to be activated by doing acid-base treatment before even beginning the treatment process. The objective of the study was to investigate the feasibility of using maize cob as a bio adsorbent in a self designed packed bed column with Dc/Dp>10. In this study, increased heavy metal removal has been achieved in the column due to reduced wall effect. The study thus, shows that maize cob can be used as an effective bio adsorbent and the designed column can also be scaled up for waste water treatment at the industrial level.

MATERIALS AND METHODS

Synthetic Waste Water

15 lit of 0.01M $ZnSO_4$ solution is prepared by dissolving 43.05 g of $ZnSO_4$ powder in 15 lit of double distilled water. It is checked to ensure complete dissolution.

Bio sorbent collection and activation

Maize cob is collected from the agricultural fields in and around Coimbatore. The collected maize cob is washed with double distilled water. The maize cob is dried in the hot air oven at 100°C for 24 hours. It is then taken out, crushed and put into a mechanical sieve shaker to separate the particles, based on their size. The samples which are similar in size, are separated and washed with distilled water thoroughly. It is then, filtered using ordinary filter paper. The washed and dried samples are then drenched in 1N conc. nitric acid solution for 12 hours. After 12 hours, the drenched samples are again washed with double distilled water until the soluble and coloured components are removed. The washed samples are dried under the sun for a few hours. The samples are then soaked in 1N NaOH for 12 hours. Samples are then washed with de-ionized water and oven dried for 12 hours at 100˚C. The maize cobs are now activated and ready to be loaded into the column as the packing material.

Design of Packed Bed Column

Height of column- 65 cm

Diameter of column (Dc) - 6.5 cm

Diameter of particles (Dp) - 0.65 cm or lesser

Dc/Dp = 6.5/.6 = 10.83 (ratio greater than 10)

Fig. 1: Packed Bed Column with Maize Cob as Packing Material

Working

The activated maize cobs are cut into small pieces of diameter approximately 0.65 cm. This is done to maintain the Dc/Dp ratio to a value greater than 10. Next, the activated and uniformly cut maize cobs are packed into the column. It should be packed to the entire column length. Next, the synthetically prepared heavy metal water is run through the column by turning on the pump. The flow rate of the input water is maintained using a ball valve placed near the inlet. Different flow rates can be attained by maintaining the inlet ball valve at different levels. The water after passing through the column comes out through the outlet and is collected in a tank and again recycled back into the column. Before running the column, some water is collected which gives the initial heavy metal concentration. Next, the column is run at different flow rates for a period of half an hour (30 min) each and water is collected at the end of each of these cycles. The water samples collected are filtered and sent for Atomic Absorption Spectrophotometer (AAS) which would quantify the heavy metals present in the samples.

Analysis of Metal Ions

The initial heavy metal Zinc concentration was quantitatively assessed using AAS. The final concentration of the Zinc ion was determined by AAS[6].

RESULTS AND DISCUSSION

Characterization of the Bio Sorbent

The activated maize cob was sent for SEM analysis and the results showed the pore size to be around 10µm. The XRD results showed the various components present in the sample as peaks in the graph which indicates cellulose, hemicelluloses, lignin, phenolic compounds etc. Out of these, cellulose and lignin are the components which are mainly responsible for the adsorption capacity of the maize cob. Thus a higher presence of these two components results in an increased adsorption capacity.

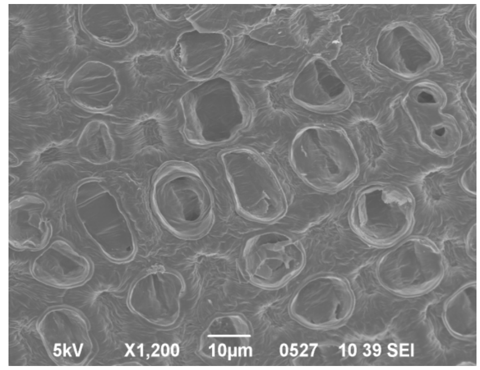

Fig. 2: SEM Image of Maize Cob

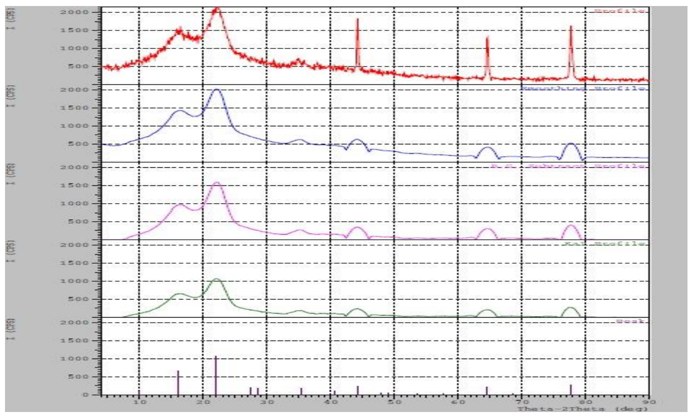

Fig. 3: XRD Graph of Maize Cob

Table 1: Hydrodynamic Studies in a Packed Bed Column

Manometer reading 'h1' (cm)	Manometer reading 'h2' (cm)	ΔH (h2-h1) (cm)	Volume (ml)	Time Taken (s)	Volumetric Flow Rate 'Q' (m^3/s)	Velocity V_o'=Q/A (m/s)	Reynolds number	ΔH/L
19.5	24	4.5	100	50	2×10^{-6}	6.06×10^{-4}	60.96	0.07
18	25.5	7.5	100	40	2.5×10^{-6}	7.57×10^{-4}	76.15	0.11
15.5	28	12.5	100	15	6.67×10^{-6}	2.02×10^{-3}	203.2	0.19
13.5	30	16.5	100	8	1.25×10^{-5}	3.78×10^{-3}	380.25	0.25
11	32.5	21.5	100	1.5	6.67×10^{-5}	2×10^{-2}	2011.90	0.33
9	34.5	25.5	100	1.25	8×10^{-5}	2.4×10^{-2}	2414.28	0.39
8	35.5	27.5	100	1	1×10^{-4}	3×10^{-2}	3017.86	0.42

Theoretical $$\frac{\Delta P}{L} = \frac{150 \mu V_o (1-\varepsilon)^2}{\varepsilon^3 D_p^2 \varphi_s^2} + \frac{1.75 \int V_o^2 (1-\varepsilon)}{\varepsilon^3 D_p \varphi_s} \quad \text{For } 1 < N_{Re} < 1000 \qquad (1)$$

Theoretical $$\frac{\Delta P}{L} = \frac{1.75 \int V_o^2 (1-\varepsilon)}{\varepsilon^3 D_p \varphi_s} \quad \text{For } N_{Re} > 1000 \qquad (2)$$

Experimental $$\frac{\Delta P}{L} = \frac{\int g \Delta H}{L} \quad \text{For } N_{Re} > 1000 \qquad (3)$$

where V_o – Velocity (m/s)
$\int_W$ – Density of water = 1300 Kg/m^3
µ – Viscosity of water = 0.00084 Kg/m.s
L_o – Bed height = 0.65 m
φ_s – Sphericity (Assume 1)
Ɛ – Porosity = $(1 - \varepsilon_o) = (1 - 0.48) = 0.52$
ε_o – Initial porosity = $\frac{\text{Void volume}}{\text{Total volume}} = \frac{650}{1350} = 0.48$

Table 2: Theoretical and Experimental values for ΔP/L

$\Delta P/L_{Theoretical}$	$\Delta P/L_{Experimental}$
3.53	-
4.55	-
15.26	-
36.67	-
75.64	-
487.68	4204.2
702.25	4968.6
1097.28	5350.8

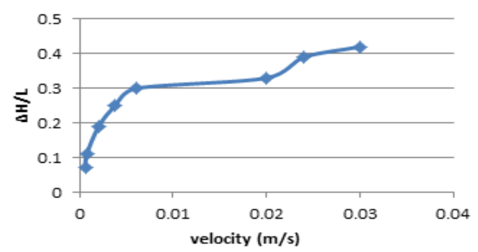

Fig. 2 Velocity Vs. ΔH/L graph

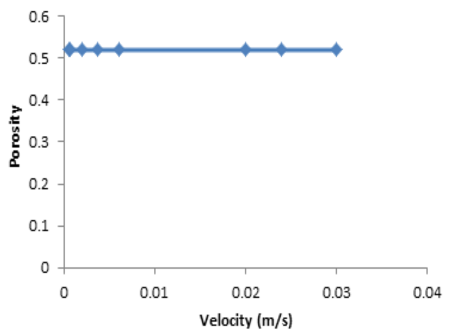

Fig. 1 Porosity versus Velocity Graph

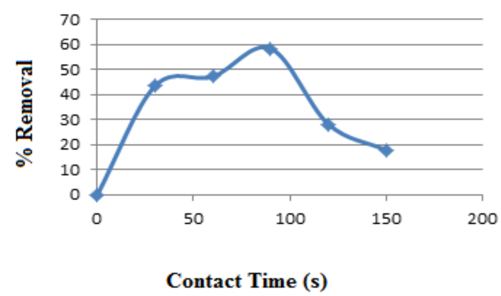

Fig. 3 % Removal Vs Contact Time

Table 2: Absorbance and %Metal Removal

S.No.	Sample taken after Time (min)	Absorbance	Heavy metal Concentration in the sample (ppm)	Percentage Metal Remova
1	0	0.325	31.5	0
2	30	0.192	17.8	43.5
3	60	0.108	9.4	47.2
4	90	0.053	3.9	58.5
5	120	0.042	2.8	28.2
6	150	0.038	2.3	17.8

$$\textbf{Percentage metal removal} = \frac{\text{Initial concentration} - \text{Final concentration}}{\text{Initial concentration}} \times 100$$

$$\text{Metal removal after 150 minutes} = \frac{31.5 - 2.3}{31.5} \times 100 = 92.7\%$$

CONCLUSIONS

The present study clearly shows that maize cob can be used as an effective adsorbent for the removal of Zn (II) from industrial effluents. The result of the study also proves that the packed bed column is also suitable for scaling up and very high efficiency of metal removal is obtained using this self-designed column. This is possible due to the reduced wall effect in the column which is achieved by maintaining the Dc/Dp ratio to a value greater than 10. Highest metal removal is obtained for the third cycle where the removal percentage is 58.2%. The removal percentage for the whole process of duration 180 min is found to be 92.7%. Such a high removal efficiency has been achieved in this study. The existing setup can be used for waste water treatment at a small scale level. This setup can also be used in gas-solid systems and can be applied in air pollution control. As the setup showed results suitable for scale up, a bigger column (by scaling up the existing column) can be developed for waste water treatment at the industrial level. Thus, maize cob as an agricultural waste, has been proved to be an efficient adsorbent when activated. Also, the self-designed column has been proved to be suitable for scale up.

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