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Enhanced Removal of Arsenic from water using *Bombax ceiba* flower *as* a new adsorbent: An Eco-friendly and Sustainable Approach

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ABSTRACT

Exposure to this pollutant is a serious concern, associated with to numerous health issues, including disruptions of the respiratory, nervous, and digestive systems, peripheral neuropathy, sleep disorders, impaired memory, bladder cancer, and dyspepsia. The mitigation of As(V) from water becomes crucial concern to combat the problem. The goals of this study is to find and create economical, non-toxic, easily and abundantly available adsorbent to remove As(V). In this work, we evaluated the potential of fallen *Bombax ceiba* (red silk cotton tree) flowers as an adsorbent for mitigating arsenic from water. This study investigated the impact of key operating parameters—contact time (60 min), adsorbent dosage (40 g/L), and initial arsenic concentration (50 mg/L) on the adsorption process. Our results indicate that fallen *Bombax ceiba* flowers (BCF) exhibit potential bioadsorbent for the mitigation of arsenic from water, with significant Langmuir saturation capacity of BCF observed under specific optimum conditions, which is 1.55 mg/g.

Keywords: Arsenic, *Bombax ceiba* (red silk cotton tree), adsorption, isotherm and kinetics

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INTRODUCTION

The soil level concentration of arsenic ranging between 5 to 13 mg/Kg makes it the 20th among the most abundantly found elements in the earth's crust [1]. The several different oxidation states in which Arsenic exists are: +V (arsenate), +III (arsenite), 0 (arsenic) and -III (arsine) [2,3]. Arsenic (As) commonly occurs as contaminant in metal ores. It finds presence in the soil, water, and living organisms. It is also produced for use in wood preservatives, agricultural chemicals, metal alloys, applications in the mining and pesticides [4,5].

Depending on how much oxygen is available in the ground water, arsenic can exist in both the As (III) and As (V) forms in normal ground water conditions. In shallower aquifers with higher oxygen concentrations, arsenic typically occurs as arsenate, As (V). In deeper ground waters, where conditions are anaerobic, arsenic usually occurs as arsenite, As (III) [6]. The species of arsenite which are soluble are H_3AsO_3, $H_2AsO_3^-$, $HAsO_3^{2-}$ and AsO_3^{3-} and those of soluble arsenate are H_3AsO_4, $H_2AsO_4^-$, $HAsO_4^{2-}$ and AsO_4^{3-}. Arsenic found in drinking water above maximum permissible limits (10 ppb) could be the cause of liver, lung, kidney, bladder and skin cancers according to one study [7]. It has been reported to impact the human's vascular system and can also lead to diabetes [6,8], neurological problems and hypertension [9]. Skin thickening and discoloration, gut pain, vomiting, hand and feet numbness, blindness and partial paralysis are some of the symptoms of arsenic poisoning [10]. As a result of withdrawal of excessive amounts of ground water, problems of contamination of iron, fluoride and arsenic have been reported in different regions of India [11-13]. As observed in some of our studies, quite a few ground water samples in the Budhi Gandak river belt in Muzaffarpur town of Bihar state of India have arsenic contamination, going beyond the maximum permissible limit of 10 ppb [14]

Several methods for removing arsenic from waste and drinking water have been documented. Commercial technologies for removing arsenic like precipitation, membrane filtration, coagulation-flocculation, and ion exchange are often relatively expensive, energy-intensive, and not fitting for function on large scales [15]. Adsorption techniques are most promising for pollutants'/ arsenic removal because these involve no byproducts, and are inexpensive, most easy in operation, highly efficient, and suitable to waste management [16]. Besides, adsorption method has attracted much attention for the abatement of chemical and biological sludge, dispensation of additional nutrient and regeneration of biosorbent [17].

Biosorption of pollutants from aqueous solution using biosorbent has attracted attention in the recent past because of quite a number of functional groups found on the surface of agro-waste as adsorbent and their unique chemical composition. The use of agro-waste materials further enhances its value for it requires renewable, abundant and cheap wastes biomass. Various agro-waste materials used currently for the removal of toxic metal ions and dyes from aqueous media are date palm fiber [18], coconut [19], chestnut and water melon peels [20], rice husks, tea, and agricultural wastes which are some examples of inexpensive adsorbents used for the purpose [21]. This work has been taken up to develop a low cost, easily operated method of water treatment with special focus on in the rural areas.

Fallen flowers of *Bombax ceiba* (red silk cotton tree) commonly cultivated in India is abundant and an easily accessible agricultural waste biomass. Fallen flowers of *Bombax ceiba* (red silk cotton tree) powder could be potential adsorbent for the removal of toxic pollutants. Fallen flowers of *Bombax ceiba* has so far not been utilized for the treatment of arsenic laden aqueous effluents.

In this study, fallen flowers of *Bombax ceiba* (red silk cotton tree) were applied for the adsorptive mitigation of Arsenic from water. The purpose of this study is to find and evolve cost effective, non-toxic, easily and abundantly available adsorbent to remove As. We have investigated the impacts of parameters for operations, such as contact time, BCF dosage, and initial arsenic concentration on the adsorption process. Results suggest that fallen flowers of *Bombax ceiba* could prove to be bioadsorbent of choice as it has been found to remove significant quantities of arsenic from water.

MATERIALS AND METHOD

Materials and reagents:

Every reagent was analytical quality and used exactly as it was purchased. All glassware was acid-washed, and all solutions were made with double-distilled water.

Preparation of adsorbent

Fallen flowers of *Bombax ceiba* (red silk cotton tree) were collected from local sources within the Muzaffarpur area. The flowers were thoroughly cleaned with tap water and then rinsed with double-distilled water to remove any surface contaminants. The washed flowers were initially dried under direct sunlight for several days, with a final dehydration step at 70°C for 2 hours in a laboratory oven. The completely dried floral material was mechanically ground into a powder. Subsequently, the powder was sieved to obtain particle sizes (less than 75 µm) and stored in airtight containers.

Preparation of metal solutions

A 100 mg/L arsenic standard solution was prepared by solubilizing the calculated amount of sodium arsenate heptahydrate ($Na_2HAsO_4 \cdot 7H_2O$) in double-distilled water. Color development for spectrophotometric analysis involved adding 10 mL of ammonium molybdate ($(NH_4)_6Mo_7O_{24} \cdot 4H_2O$) solution) and 2.0 mL stannous chloride ($SnCl_2 \cdot 2H_2O$) solution upto a 500 mL aliquot of the arsenic solution, which led to the development of arseno-molybdate complex that absorbed at 840 nm [22-24].

Batch sorption analysis

Batch adsorption analysis were performed by taking different doses of adsorbent (10–50 g/L) with 50 mL of arsenic solution. The arsenic concentration in water was varied from 25 to 100 mg/L. The solutions with sorbent were stirred by at room temperature for different contact lengths of time, at 10 to 100 min for the As(V) solutions. After separation of the sorbent by centrifugation for 5 min, the concentration of the anion remaining was established colorimetrically. The amount of As(V) metal uptaken by the BCF was calculated by applying the equation:

$$q_e = \left[\frac{(C_o - C_e)}{W} \times V \right] \qquad (1)$$

$$\% \text{ removal} = \left[\frac{(C_o - C_e)}{C_o} \times 100 \right] \qquad (2)$$

where C_0 and C_e represent the starting and final arsenic concentrations (mg/L), W represents the amount of adsorbent (g/L), V represents the volume of arsenic concentration (L), and q_e represents the amount of As(V) adsorbed by the sorbent (mg/g).

The kinetic studies were performed out by stirring 50 mL of Arsenic solution with calculated amount of BCF at room temperature, and the remaining As(V) concentrations were found out at 10 min time intervals. Similarly, isotherm experiments were also done under optimized conditions of parameters. All experiments were tree times performed, and mean values are used.

FINDINGS AND DISCUSSION

Optimization of process parameters

Effect of contact time

The percentage adsorptive removal of As(V) was investigated at different time intervals (10-100 min.), with 50 mg/L arsenic concentration, BCF dose of 40 g/L at room temperature and the findings are depicted in Figure 1. The adsorption process was rapid, reaching maximum removal within 50 minutes and plateauing thereafter, gradually reaching equilibrium after 60 minutes suggesting the saturation of all active sites. The time data 60 min. was used for more investigation.

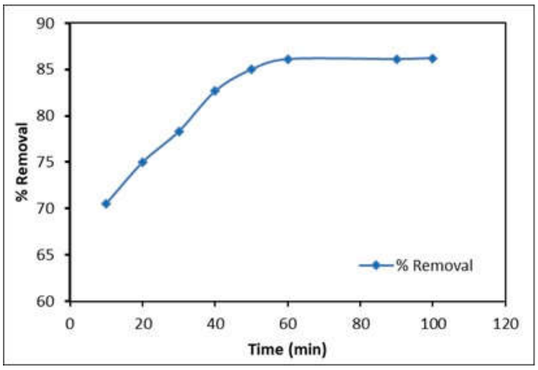

Figure 1: Effect of contact time of BCF with As(V)

The impact of adsorbent dose

The impact of the BCF dose on the As(V) concentration of 50 mg/L was investigated at an optimum contact period of 60 min and temperature (305 K) (Fig. 2). The percentage of arsenic removal increases from 73.00 to 86.50% with rise in the BCF amount from 10 to 50 g/L. This enhancement is likely ascribed to the greater accessibility of free unbounded sites at greater As(V) concentrations. However, the subsequent gradual decrease in the rate of removal may be due to a less favorable ratio of arsenic ions to active sites or a reduction in the effective surface area caused by adsorbent agglomeration. Based on these observations, BCF amount of 40 g/L was chooses for subsequent studies.

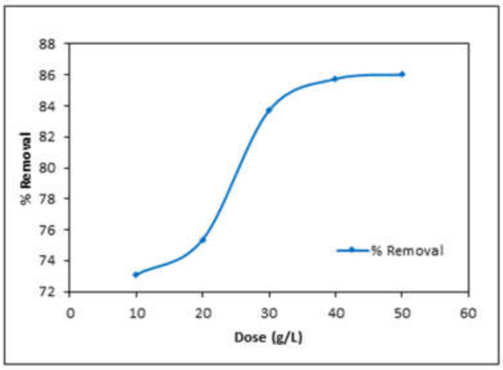

Figure 2: Effect of BCF dose with As(V)

Impact of initial As(V) concentration

The initial As(V) concentration was studied by ranging from 25 to 100 mg/L at constant BCF dose of 40 g/L, contact time 60 min and temperature 303K. With rise in initial As(V) concentration, it was found that the percent removal decreased from 90 to 30 (Fig. 3).

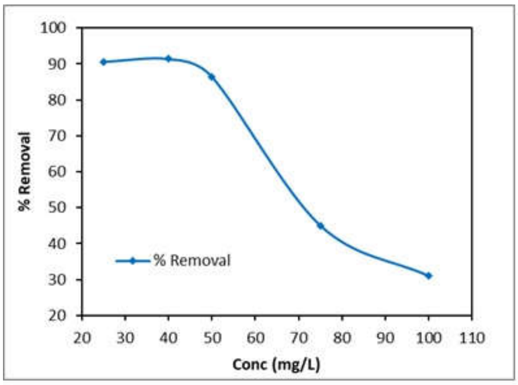

Figure 3: Effect of As(V) concentration with BCF.

Isotherm modeling

The mechanism of the mitigation method was examined by fitting investigational data obtained at various concentrations at 303 K to different linear adsorption isotherm models. The goal was to identify the best-fit isotherm to describe the adsorption behavior.

Langmuir isotherm is applied when (a) all sites are the similar, (b) each active site of BCF holds single As(V) ion, (c) there is no involvement of adjacent active sites and every site is independent, forming energetically consistent single layer surface. Freundlich isotherm suggest multi-layer, reversible, non-linear diverse adsorption. This isotherm considers indirect adsorbate–adsorbent interactions [25].

Langmuir isotherm

The Langmuir isotherm equation (3) is given below [26]:

$$\frac{C_e}{q_e} = \frac{1}{bQ^o} + \left(\frac{1}{Q^o}\right)C_e \qquad (3)$$

where Q^o is the Langmuir saturation capacity (mg/g), C_e is the supernatant concentration at the equilibrium (mg/L), and b is the Langmuir binding constant (L/mol).

The values of Langmure isotherm parameter were calculate form linear plot of C_e vs C_e/q_e (Fig. 4). The Q^o and R^2 values were evaluated 1.55 mg/g and 0.997, respectively.

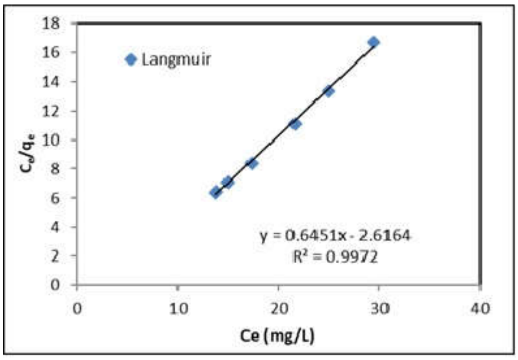

Figure 4: Langmuir model with BCF with As(V)

The dimensionless parameter (R_L) was calculated by using equation (4) [27]. The value of R_L was 0.226, which is between zero to one suggesting that the process of adsorption is favorable.

$$R_L = \frac{1}{1 + bC_e} \qquad (4)$$

Freundlich isotherm

Freundlich equation (5) is given below [28]:

$$q_e = K_f C_e^{nf} \qquad (5)$$

where K_f is the Freundlich constant correspond to sorption capacity (L/g) and n_f is the Freundlich exponent (dimensionless). The K_f and n_f value were computed from the plot of C_e vs q_e (Fig. 5) and tabulated in Table 1.

The R^2 values were used to predict the well fitted data. The higher R^2 values 0.997. Langmuir isotherm confirmed that, this isotherm best correlated with the experimental data pointing out the adsorbent process to be energetically homogeneous [29].

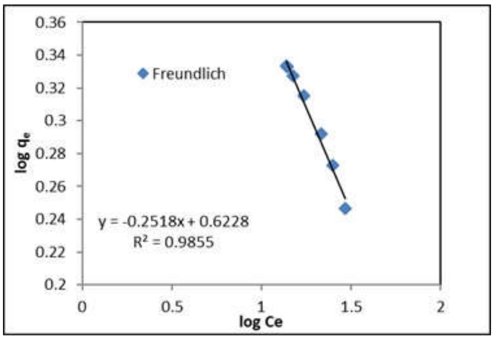

Figure 5: Freundlich model with BCF with As(V)

Table 1: Langmuir and Freundlich sorption isotherm values.

Langmuir	Q_o (mg/g)	1.55
	b(L/ mg)	0.246
	R_L	0.226
	R^2	**0.997**
Freundlich	K_f(mg/g)	4.16
	n_f	3.98
	R^2	0.985

Table 2: Assessment of Q^o(mg/g) for As(V) with various other published adsorbents

S. No.	Adsorbents	Q^o(mg/g)	Isotherms	kinetics	References
1.	MnO_2 loaded red mud	31.57	-	-	[30]
2.	ZnO nanoparticles coated rice husk	28.23	Langmuir	Pseudo first order	[31]
3.	MnO_2	18.90	-	-	[30]
4.	Citric acid functionalized PVOH hydrogels	14.1	-	-	[32]
5.	Red mud	11.29	-	-	[30]
6.	Fallen flowers of *Bombax ceiba*	1.55	Langmuir	Pseudo second order	**(This work)**

7.	Zirconium oxide coated marine sand	0.27	Langmuir	Pseudo second order	[22]
8.	Fe(III)–Sn(IV) mixed binary oxide-coated sand	0.227	Langmuir	Pseudo second order	[33]
9.	Rice husk	0.225	Langmuir	-	[34]
10.	Iron-coated cork granulates (ICG)	4.2	Langmuir	-	[35]

Adsorption kinetic study

Kinetic studies were carried out to know the adsorption mechanism at various stages of the migration of As(V) ions from the bulk solution onto the BCF surface. The movement of the As(V) ions onto the surface of BCF can occur via external surface boundary diffusion, pore diffusion, or both.

Lagergren pseudo first-order equation

The mathematical expression of Lagergren pseudo first-order is given below in equation (5)[36]:

$$\log(q_e - q_t) = \log q_e - \frac{K_1}{2.303}t \qquad (5)$$

where, q_e is the As(V) adsorbed in equilibrium (mg/g) and q_t is the amount of As(V) adsorbed at time t (mg/g), and K_1 (l/min) is the rate constant of pseudo first order**.** The rate constant (K_1) and q_e were determined from $\log(q_e - q_t)$ *vs. t* plots (Fig. 6) and are reported in Table 3.

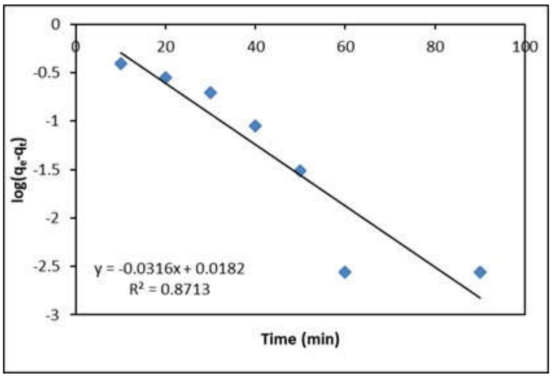

Figure 6: Pseudo-first order model with BCF with As(V)

Pseudo-second order kinetics

Eq. 6 given below in the linear pseudo-second order kinetic equation [37]:

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^{\ 2}} + \left(\frac{1}{q_e}\right)t \qquad (6)$$

where, K_2 (g/mg/min) is the rate constant of pseudo second order.

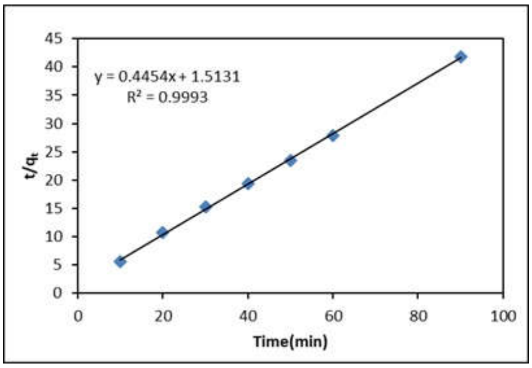

Figure 7: Pseudo-second order model with BCF with As(V)

The K_2 and q_e calculated were obtained from the t/q_t *vs. t* plots (Fig. 7) accompanied by R^2 and tabulated in Table 3.

The calculated value of q_e obtained from experiments are in a good agreement with the theoretic values obtained values form model equation recommended that kinetic model of pseudo-second order is best fitted for the removal of As(V) with BCF.

Table 3: Pseudo-first, pseudo-second order and R^2 values

Pseudo-first order	K_1(1/min)	7.40×10^{-2}
	q_e(mg/g)	1.042
	R^2	0.871
Experimental	**Q_e(mg/g)**	**2.15**
Pseudo-second order	K_2(g/(mg/min)	13.0×10^{-2}
	q_e(mg/g)	2.25
	R^2	**0.999**

CONCLUSIONS

In the present study, BCF was employed as a new adsorbent for the mitigation of As(V) from aqueous media. The maximum removal was found at contact time (60 min), initial As(V) concentration (50 mg/L), adsorbent dose (40 g/L) and temperature (305 K). The isotherm data was best fitted with Langmuir isotherm and Langmuir saturation capacity was 1.55 mg/g with high R^2 value suggesting single layer adsorption. The pseudo-second order model was found well fitted for explaining the investigational data. From the above results this is concluded that BCF is an efficient adsorbent for As(V) removal.

Conflicts of Interest: The authors declared no conflicts of interest.

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