

Removal of arsenic from groundwater using burnt rice straw

M.O. Faruque^{1*}, M. J. Uddin²

¹Department of Petroleum and Mining Engineering
Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh

²Department of Chemical Engineering and Polymer Science
Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh

Corresponding author: Tel. +88-01819847124

Email: faruque_pge@yahoo.com

Abstract- The ability of burnt rice straw (BRS) as a potential adsorbent for As(III) removal from ground water was studied. Batch experiments were carried out to characterize the As(III) removal capacity of BRS. The effects of various sorption parameters such as the adsorbent dose, contact time and initial arsenic concentration have been discussed. Under the experimental conditions, the optimum adsorbent dose for BRS was found to be 10 gm/l with an agitation time of 6 hours. Langmuir and Freundlich isotherm models were used to explain the phenomenon. The maximum adsorption capacity calculated using Langmuir model was 199 $\mu\text{g/gm}$ for As(III) at 28°C and P^{H} 7.0. Adsorption mechanism was explained by Pseudo-first-order (Lagergren) model and the corresponding parameters were calculated. Burnt rice straw (BRS) was found to be a good adsorbent for removing As(III) from ground water as compared to other adsorbent already used for the removal of arsenic.

Key words - Adsorption isotherms, Arsenic, Biosorption, Sorption kinetics

I. INTRODUCTION

Arsenic is a metalloid and ubiquitous natural constituent of the earth's crust, ranking 20th in abundance in relation to other elements [1]. It has been known as one of the most toxic substance in the world [2], is found in the shallow zones of groundwater of many countries like Argentina, Bangladesh, Cambodia, Canada, Chile, China, Germany, Hungary, India, Mexico, Mongolia, Myanmar, Nepal, Pakistan, Romania, Thailand, USA, Vietnam etc. in various concentrations. In different region of Bangladesh its concentration is as high as 1000 $\mu\text{g/l}$ [3]. The ultimate source of arsenic contamination is geological (natural reactions and volcanic emissions) but many industrial processes that contribute to anthropogenic arsenic contamination of water resources are mining, smelting of non-ferrous metals, use of pesticides and burning of fossil fuel [4,5]. Ground water contamination may be due to naturally occurring arsenic. In the deeper sub-surface, elevated arsenic concentrations are associated with the compaction caused by water withdrawal [6]. The toxicity of arsenic depends on its oxidation state and form (i.e. organic or inorganic). Inorganic arsenic exists in four oxidation states in the

environment, +5(arsenate), +3(arsenite), 0(arsenic), and -3(arsine). Among these, under oxidizing conditions, arsenates are the stable species and under reducing conditions arsenites are the predominant arsenic compounds. In natural water and thus in drinking water, arsenic is mostly found as As(III) and As(V) [7]. Organic arsenic species are less harmful to health, abundant in seafood and readily eliminated by the body. Among inorganic species, As(III) is 60 times more toxic than As(V) due to its greater cellular uptake [8]. Arsenic contamination in ground water to a significant extent has posed severe health problem around the world. Arsenic can have a negative impact on almost every organ system in the body. Acute, sub-acute and chronic adverse health effect of exposure to inorganic arsenic compounds includes dermatitis, chronic bronchitis of lungs, peripheral neuropathy, CNS disturbances, liver cancer, lungs cancer, blood cancer and skin cancer [9-12]. According to WHO and US EPA, the maximum allowed concentration of arsenic in drinking water is 10 $\mu\text{g/l}$ [13]. Besides, the maximum contaminant level for arsenic in countries like India, Bangladesh, Taiwan, China, Vietnam etc. is also 50 $\mu\text{g/l}$ [14]. However, arsenic concentrations, about 100 times more than the permissible limit, are found in many parts of the world. Arsenic poisoned people in India and Bangladesh alone is about more than 70 million, perhaps the largest poisoning in the world's history [15, 16, 17].

Since contamination of drinking water due to arsenic compound has a severe problem with regards to health hazards and in this connection a lot of research have

been undertaken to remove arsenic from contaminated ground water using different techniques such as solvent extraction, chemical precipitation as synthetic coagulants, lime-softening, nano-filtration, iron co-precipitation, ion-exchange and reverse osmosis, are associated with drawbacks like incomplete metal removal, high cost of reagent and energy requirements [9,11,18]. In recent years, adsorption is an economical alternative to conventional metal removal techniques and is widely applicable because of its simplicity and economic feasibility. Substantial information is available on materials having the ability to adsorb and take out arsenic from water. Many of these materials are of natural origin and others may be by products of industrial processes that are usually considered waste [19]. The present study is focused to determine the adsorption characteristics of burnt rice straw (BRS) for As(III) removal from ground water. During the study, various factors such as effect of adsorbent dose, contact time, initial arsenic concentration, adsorption kinetics and adsorption isotherm were systematically examined. The adsorption capacity of burnt rice straw (BRS) was tested and compared with other sorbents already used for the removal of arsenic.

II. MATERIALS AND METHODS

A. Preparation of adsorbent

Rice straws were collected from rural area. For laboratory use it was chopped into smaller size of 2 to 5 cm. Later, straws were washed with distilled water and subsequently dried in an oven at 105°C along 6 hours. Then, dried straws were burnt in an open furnace over a period of 5

hours. The material was ground to a fine powder in a laboratory grinder. Finally, blackish coloured coarse powdery material was obtained (adsorbent grade) and termed as burnt rice straw (BRS).

B. Preparation of standards, reagents and apparatus

Double distilled water (DDW) was used throughout the research. High purity chemicals used in the study were of analytical grade and purchased from Merck (Germany). Standards for calibration were prepared from As(III) absorbance through Silver diethyl dithio carbamate (SDDC) method for various arsenic concentration solution ranging from 10 ppb to 500 ppb. As(III) stock solution (1000 ppm) was prepared by dissolving 1.320 gm of As_2O_3 in 10 ml DDW containing 4 gm NaOH and diluted with DDW upto 1000 ml. For the preparation of intermediate arsenic solution (10 ppm), 5 ml of stock solution was diluted with DDW upto 500 ml. Standard arsenic solution (1 ppm) was prepared from 10 ml of intermediate solution diluted upto 100 ml with DDW. Standard arsenic solution (1ppm) was used for the preparation of required sample solution in ppb level. For the reduction of As(V) into As(III) 5 ml of conc. HCl, 2 ml of 15% (w/v) KI solution and 0.5 ml of 40% $SnCl_2$ reagents was added to 35 ml of sample solution and allow for about 15 minutes. The concentration of the arsenic in water was determined by SDDC method with the help of UV-VIS Spectrophotometer (UV-1601, SHIMADZU, Japan) using standard working conditions.

C. Batch Experiments

To determine the optimum working conditions, batch mode experiments were performed in 250 ml conical flasks placed on a flash shaker at a agitation of 400 osc/min. To study the effect of adsorbent dose in the range (0.5-2.0 gm/100ml) 5-20 gm/l at room temperature (28°C), P^H was adjusted to 7.0 and contents were agitated for 6 hours at a agitation of 400 osc/min. Afterwards, suspensions were filtered to remove adsorbent and filtrates were analyzed spectrometrically to determine the percent removal of As(III). Subsequently, in studying the effect of contact time, adsorbent dose was selected optimally based on the previous trials, while time of contact was changed in the range of 15-360 minutes at 28°C, shaking the contents at 400 osc/min and P^H was kept at 7.0. A number of stopped conical flask (250 ml) containing known solution of arsenic of various initial concentration with adding of favourable fixed adsorbent dose for each flask were started to shake and for various predetermined time intervals, a few quantities of solutions from each flask were collected to test tubes to centrifuge. The absorbance was measured spectrometrically for those supernatant solutions based on selected arsenic determination method. After measuring the absorbance, the concentration of As(III) was determined from the prepared calibration chart for that time interval.

D. Adsorption isotherms

Various types of model have been utilized for describing sorption equilibrium for the removal of arsenic from ground water. Langmuir and Freundlich adsorption isotherm are being used for

present work. Isotherm studies were performed in five stopped conical flask (250 ml). Each flask was filled with 100 ml of As(III) solutions having different initial concentration (100- 400 ppb) and P^H was adjusted to 7.0. To each flask, 1 gm of adsorbent was added and the solutions were agitated at a speed of 400 osc/min for 6 hours at 28°C. Further, the solutions were filtered and analyzed.

D(a). Langmuir sorption isotherm

The Langmuir sorption isotherm describes that the uptake occurs on a homogeneous surface by monolayer sorption without interaction between sorbed molecules [20,21]. The linear form of the Langmuir isotherm may be represented as

$$\frac{1}{q_e} = \frac{1}{Kq_\alpha} \times \frac{1}{C_e} + \frac{1}{q_\alpha}$$

Where q_e is the amount adsorbed per unit mass of adsorbent; q_α is the maximum adsorption capacity; C_e is the equilibrium As(III) concentration and K is the adsorption equilibrium constant. The isotherm constants q_α and K were calculated from the slope and intercept between $\frac{1}{q_e}$ and $\frac{1}{C_e}$.

D(b). Freundlich sorption isotherm

The Freundlich sorption isotherm which describes the equilibrium on heterogeneous surfaces and the linear form of the isotherm can be represented as [21]

$$\text{Log}q_e = 1/n \text{Log}C_e + \text{Log}K_f$$

The isotherm constants n and K_f were calculated from the slope and intercept of the plot $\text{Log}q_e$ Vs $\text{Log}C_e$

E. Adsorption kinetics

Sorption kinetics reveals the strong dependence on the physical and/or chemical characteristics of the adsorbent material, which also influenced the sorption mechanism. Batch studies were conducted for the concentration range of 100 ppb to 400 ppb using 250 ml stopped conical flask and a flash shaker. To each flask, 1 gm of fixed adsorbent dose was added in 100 ml of adsorbate solution at P^H 7.0. The agitation speed of the shaker was 400 osc/min. The samples at different time intervals (15-360 min.) were taken and analyzed.

In order to predict the sorption kinetics model of As(III), the following Pseudo-first-order (Lagergren) model was plotted and the corresponding parameters were calculated [22].

$$\text{Log}(q_e - q_t) = \text{Log}q_e - \frac{K_{ad}t}{2.303}$$

Where

k_{ad} = The rate constant for adsorption.

q_t = The amount of As(III) adsorbed(kg/kg) at time t .

q_e = The amount of As(III) adsorbed(kg/kg) at equilibrium time.

F. Scope and limitations of this research work

This work has been done with good freedom of action. Batch experiments were employed for doing this research. Each experiment has been accomplished in a replicate way for the accuracy of data using available laboratory equipment and instrument. No problem was faced during the collection and preparation of burnt rice straw(BRS). Besides, sufficient supply of chemicals makes easy our research work.

In this study, the particle size of the prepared adsorbent was not determined due to the scarcity of the instrument. Consequently, the effect of particle size on the removal of As(III) was not examined. This work has been finished by maintaining constant P^H , temperature and speed of agitation. Therefore, the effect of these parameters on the removal of As(III) were not verified. So, this is also a shortcoming of this work.

III. RESULTS AND DISCUSSION

A. *Effect of adsorbent dose on the removal of As(III)*

The removal of As(III) by adsorption on burnt rice straw (BRS) are shown in Fig. 1. This figure shows the percentage removal of As(III) with the increase in concentration of adsorbent dose (0.5 - 2.0 gm/100 ml) 5-20 gm/l for each initial concentration of As(III) solution (250 ppb-1000ppb). It is evident that there was an initial quick increase in percentage removal of As(III) for each initial As(III) concentration with increase of adsorbent dose. At lower adsorbent dose, the increase in percentage removal of As(III) due to the increase in adsorbent dose is very high. However, at higher adsorbent dose the increase in percentage removal of As(III) due to the increase in adsorbent dose is negligible. Beyond the adsorbent dose of 10 gm/l (1 gm in 100 ml), the increase in the percentage removal of As(III) with increase in adsorbent dose is very less. Hence, the optimum removal of arsenic can be obtained by using 10 gm/l for each initial concentration. At this optimum adsorbent dose, the percentage removal of As(III) was 87.88%, 88.13%, 79.90%. 69.82% for the initial

concentration of 250 ppb, 400 ppb, 500 ppb and 1000 ppb respectively. With the increase in adsorbent dose the number of active sites in unit volume of solution increases, which leads to the increase in the percentage removal of arsenic. However, after the adsorbent of 10 gm/l, this increase in percentage removal is less or not significant. The reason may be due to the agglomeration of adsorbent particles at higher adsorbent concentration. Such aggregation would lead to decrease in total surface of adsorbent particles available to As(III) adsorption and increase in diffusional path length. Ultimately, a stage was reached when there was no more adsorption with the further addition of adsorbent and at that time, equilibrium was attained.

B. *Effect of contact time and initial arsenic concentration*

The effect of contact time and different initial arsenic concentration on the uptake of arsenic with fixed adsorbent dosage are shown in Fig.2. It was found that the time required to attain equilibrium for As(III) sorption on burnt rice straw (BRS) was 6 Hours. It is also mentionable from the results that in all the systems, the saturation time is almost independent of concentration of the adsorbate solution. The adsorbed amount of As(III) was found to increase as the initial arsenic concentration increased. It was because the number of ions adsorbed from solutions of higher concentrations is more than that removed from less concentrated solutions. It was also noteworthy that the removal of As(III) was rapid in the initial stages of contact time and gradually decrease with the lapse of time until equilibrium in each case. It may be due to the two stages of

arsenic adsorption (i.e. fast formation of monolayer followed by slow plateau stage) [23]. The curves thus obtained are single, smooth and continuous leading to equilibrium.

C. Adsorption isotherms

Relevant adsorption equilibrium is one of the vital information and also necessary for proper analysis and design of adsorption. Equilibrium concentration of adsorbate and adsorbent are a function of temperature. Thus, the adsorption equilibrium relationship at a given temperature is referred to an adsorption isotherm. Langmuir and Freundlich isotherm models were used to explain the phenomenon from several adsorption isotherms.

A plot of $\frac{1}{q_e}$ Vs $\frac{1}{c_e}$ yielded a good fitted straight line (Fig.3) confirming the applicability of the Langmuir adsorption isotherm. The correlation coefficient (R^2) of value 0.989 implies a very good mathematical fit. The Langmuir isotherm constants q_a ($\mu\text{g/gm}$) the maximum adsorption capacity and K ($1/\mu\text{g}$) a constant related to the free energy of adsorption were calculated from the slope and intercept of the plot. The maximum adsorption capacity of burnt rice straw (BRS) was found to be $199 \mu\text{g/gm}$ for As(III) at 28°C and P^{H} 7.0. The value of K was found to be $4.24 \times 10^{-9} \text{ l}/\mu\text{g}$, indicates the favourability of the process.

Freundlich isotherm constants n and K_f were calculated from the slope and intercept of Fig.4. The sorption capacity K_f was found to be 0.383. The values of n (intensity of sorption) between 1 to 10 (i.e. $1/n$ less than 1) represents a favourable

sorption. For the present study the value of $n=1.067$ also indicate the same trend representing a beneficial sorption.

D. Adsorption kinetics

The adsorption of As(III) from liquid to solid phase can be considered as a reversible reaction with an equilibrium established between two phases. For the pseudo-first-order (Lagergren) adsorption rate constant, a plot of $\text{Log}(q_e - q_t)$ against time (Fig.5) was analyzed for different initial concentration. A straight line plot yielded by each system confirms the applicability of first order rate expression of Lagergren. The adsorption rate constant for various initial concentration are shown in Table: 5.1. From this table, it is observed that the rate constant K_{ad} is a function of initial concentration and decreases with increasing initial concentration. So, K_{ad} is valid only for given experiment.

E. Burnt rice straw (BRS) as a biosorbent for As(III) removal

From the above studies we can say that burnt rice straw (BRS) is a potential biosorbent for the removal of As(III) from ground water. When it was compared (Table 6) with other sorbents already used for the arsenic removal purpose, it was found that BRS was much better. It was shown promising adsorption capacity of As(III) from ground water and was found to be $199 \mu\text{g/gm}$. BRS is accompanied with easy processes, cheap, and locally available agricultural residue and need no pretreatment like treatment with acid or alkali or any type of coating. It is well able to remove a sufficient quantity of arsenic from even low initial concentration

solution as compared to other sorbents and meet required drinking water standard.

IV. CONCLUSION

The sorption of trivalent arsenic onto burnt rice straw (BRS) has been studied in detail. The removal of arsenic was found to increase with increase in initial arsenic concentration for fixed adsorbent dose. Equilibrium sorption data showed good fit to Langmuir and Freundlich isotherm model. The maximum sorption capacity of the sorbent was found to be 199 $\mu\text{g/gm}$ for As(III) at 25°C and P^{H} 7.0. It was concluded that burnt rice straw (BRS) can be a good adsorbent for removing As(III) from ground water owing to the fine adsorption capacity. It may be recommendation for further work based on this research work-

i) Column studies can be done for full scale adsorption process of burnt rice straw (BRS) using continuous-flow fixed-bed columns.

ii) Effect of P^{H} , temperature and speed of agitation on the removal of As(III) may be examined.

iii) The effect of particle size on the removal of As(III) can be experimented after determining the particle size of the adsorbent.

iv) Environmental management should take in consideration for the disposal of arsenic containing adsorbent.

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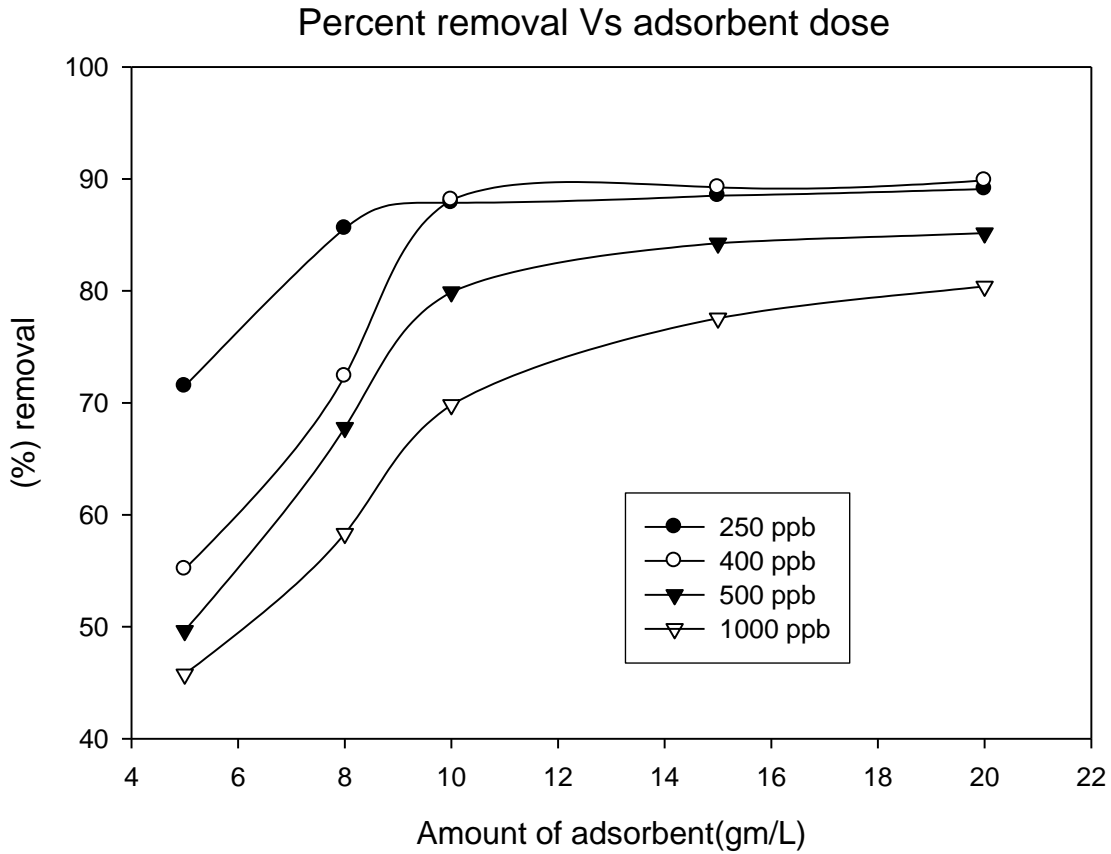


Fig.1: Effect of adsorbent dose on the percentage removal of As(III) for different initial concentration. [Adsorbent dose range = 5-20 gm/L, Initial concentration range = 250-1000 ppb, $P^H = 7$, Temperature = 28°C, Speed of agitation = 400 osc/min, Time of contact = 6 hours]

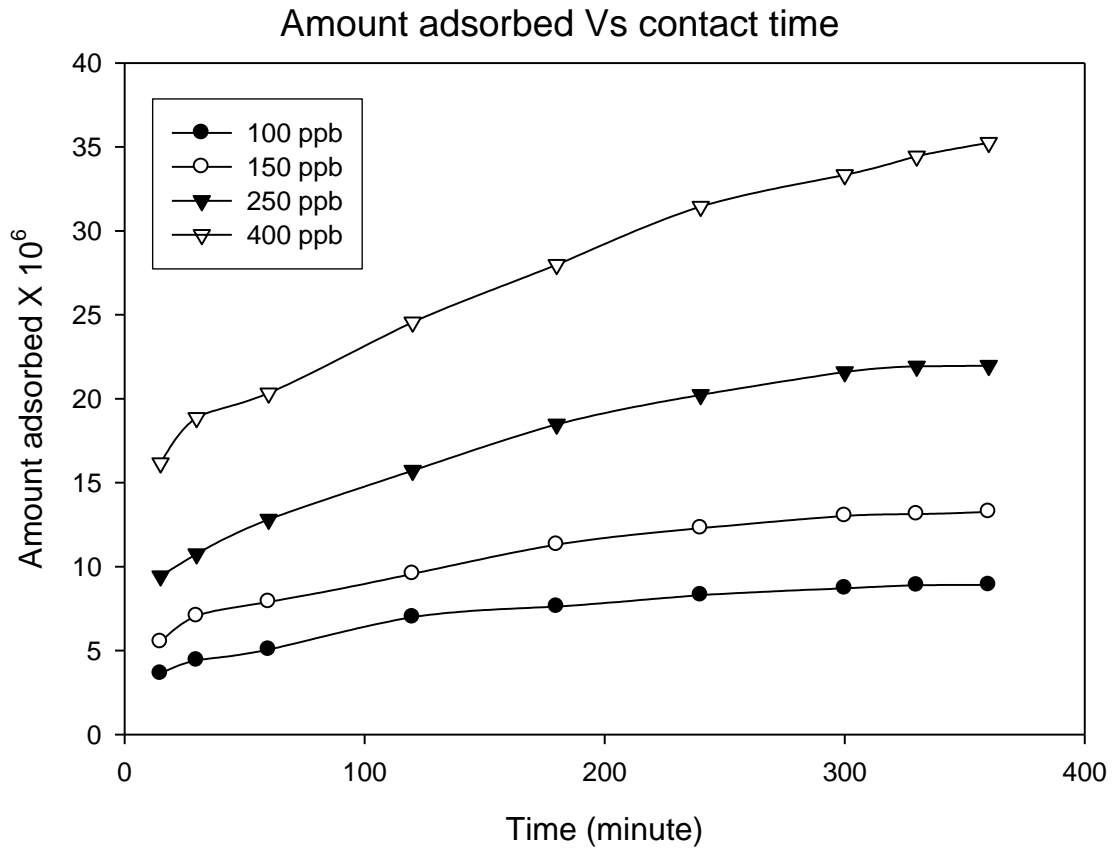


Fig. 2: Effect of contact time and initial arsenic concentration on the removal of As(III). [$P^H = 7$, Adsorbent dose = 10 gm/L, Temperature = 28°C, Initial concentration range = 100-400 ppb, Speed of agitation = 400 osc/min]

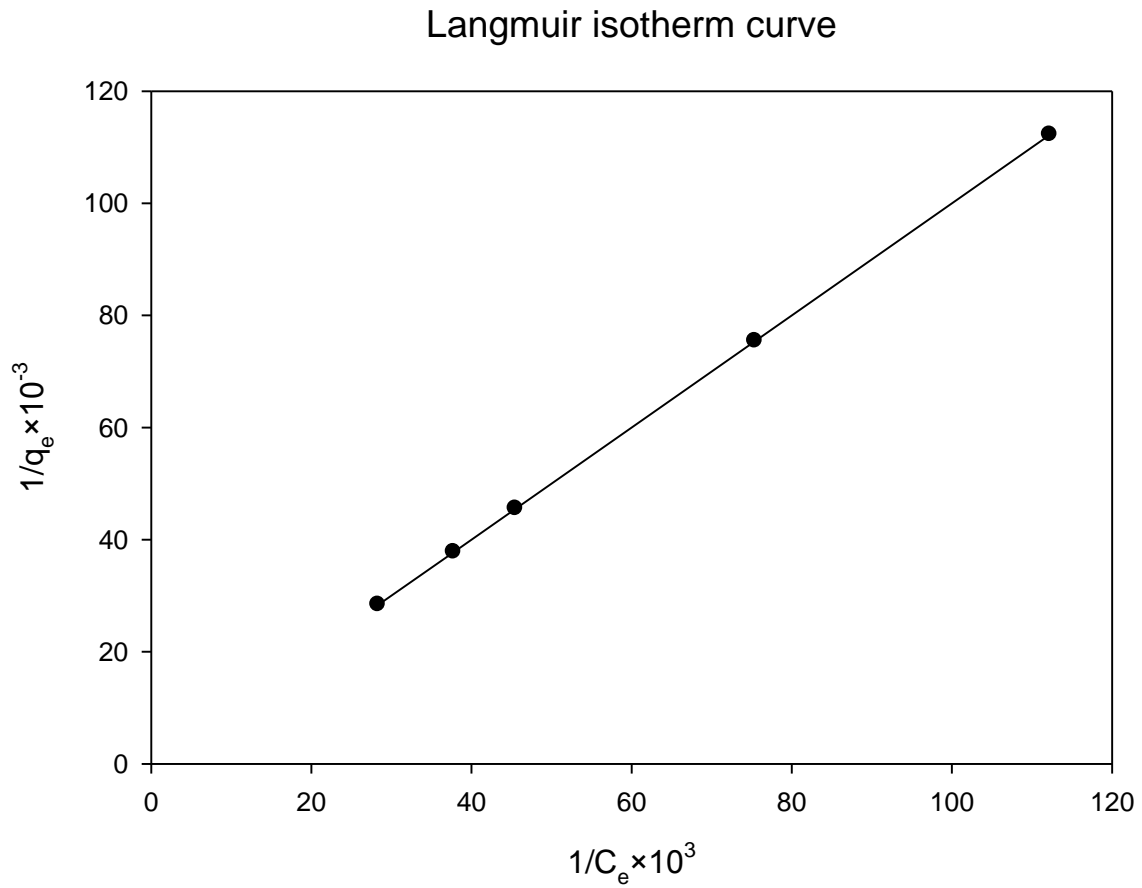


Fig.3: Langmuir isotherm plot for As(III) removal. [$P^H = 7$, Adsorbent dose = 10 gm/L, Temperature = 28°C, Initial concentration range = 100-400 ppb, Speed of agitation = 400 osc/min, Contact time = 6 hours]

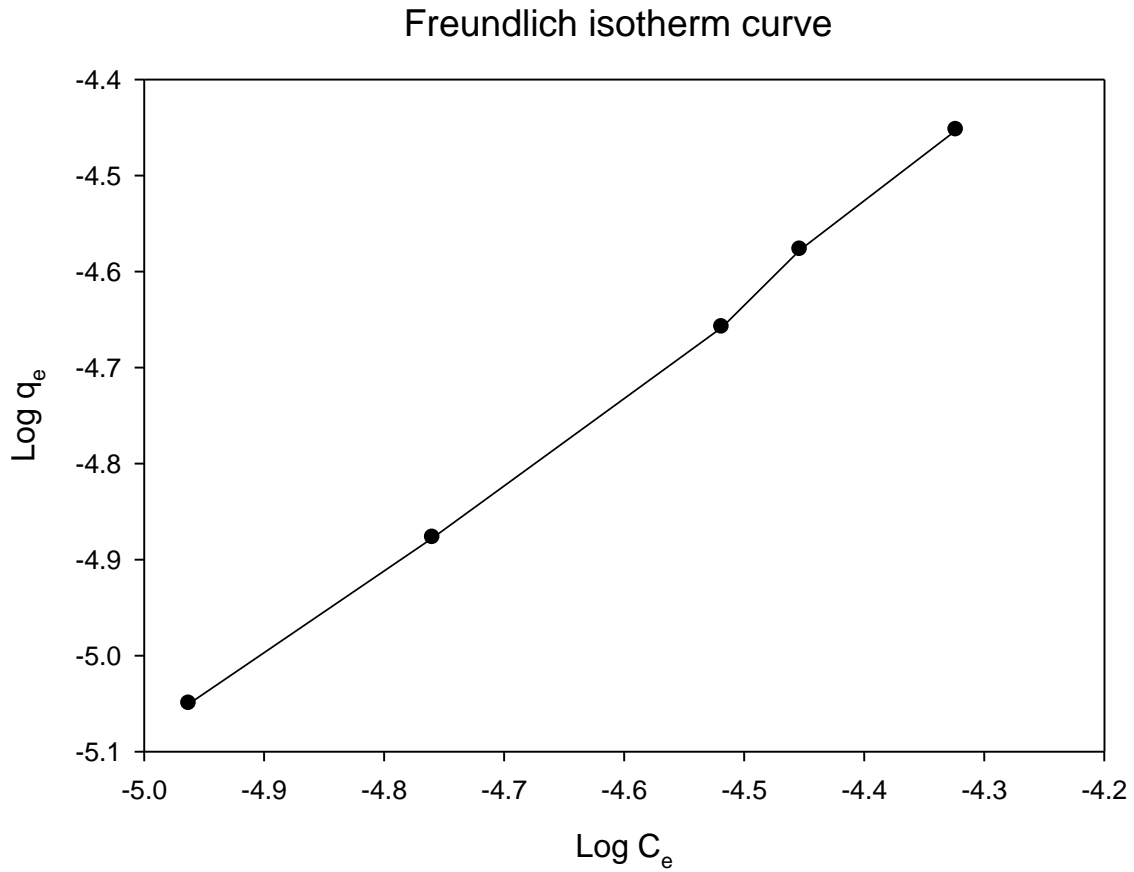


Fig.4: Freundlich isotherm plot for As(III) removal. [P^H = 7, Adsorbent dose = 10 gm/L, Temperature = 28°C, Initial concentration range = 100-400 ppb, Speed of agitation = 400 osc/min, Contact time = 6 hours

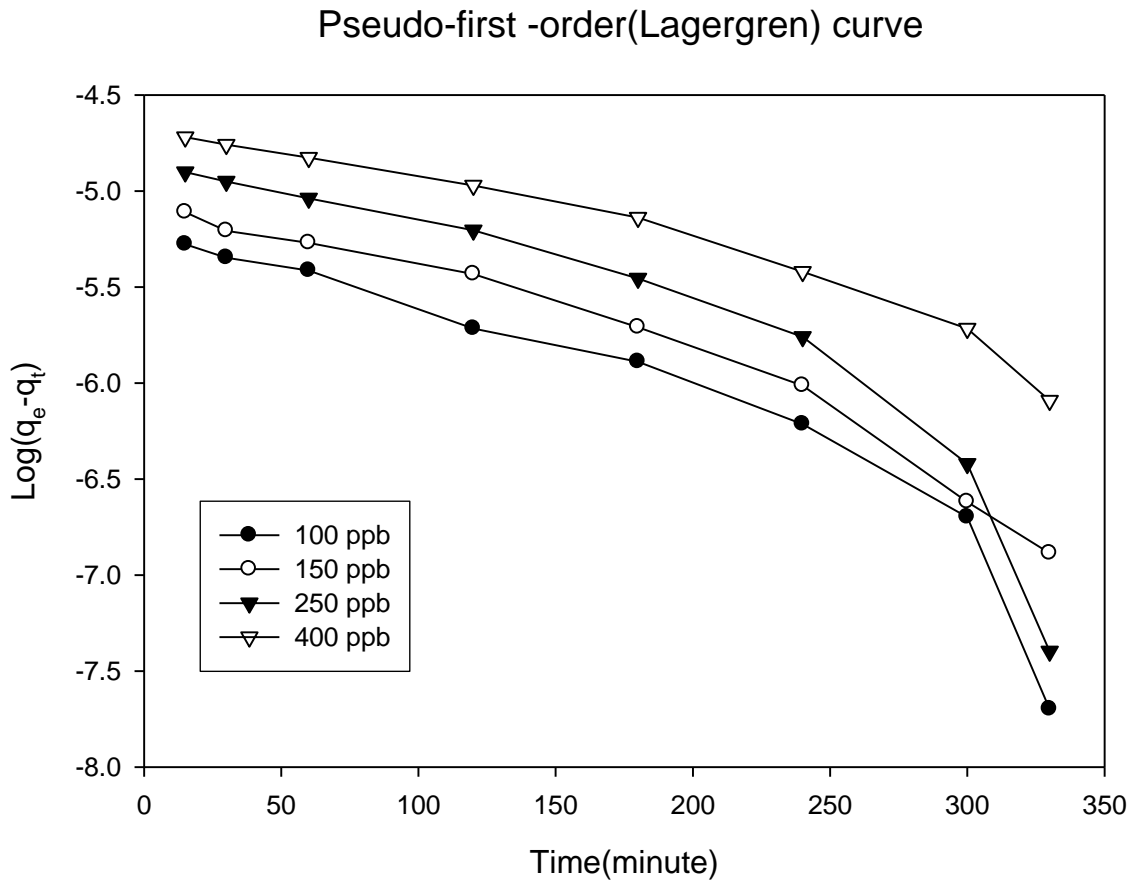


Fig.5: Pseudo-first-order (Lagergren) plot for As(III) removal. [[P^H = 7, Adsorbent dose = 10 gm/L, Temperature = 28°C, Initial concentration range = 100-400 ppb, Speed of agitation = 400 osc/min]

DATA TABLE FOR FIG. 1**Table1: Effect of adsorbent dose on the percentage removal of As(III) for different initial concentration.**

Adsorbent dose (gm/l)	Initial concentration (ppb)	Final concentration (ppb)	Amount adsorbed $q \times 10^6$ (Kg/kg)	% Removal (R)
5	250	71.30	17.87	71.48
8		36.05	21.39	85.58
10		30.30	21.97	87.88
15		28.72	22.18	88.51
20		27.52	22.24	89.10

Adsorbent dose (gm/l)	Initial concentration (ppb)	Final concentration (ppb)	Amount adsorbed $q \times 10^6$ (Kg/kg)	% Removal (R)
5	400	179.44	22.05	55.14
8		110.48	28.95	72.38
10		47.50	35.25	88.13
15		43.00	35.70	89.25
20		40.56	35.94	89.86

DATA TABLE FOR FIG. 1 (Continued)**Table1: Effect of adsorbent dose on the percentage removal of As(III) for different initial concentration.**

Adsorbent dose (gm/l)	Initial concentration (ppb)	Final concentration (ppb)	Amount adsorbed $q \times 10^6$ (Kg/kg)	% Removal (R)
5	500	251.80	24.82	49.64
8		161.10	33.89	67.78
10		100.50	39.95	79.90
15		78.70	42.13	84.26
20		74.20	42.58	85.16

Adsorbent dose (gm/l)	Initial concentration (ppb)	Final concentration (ppb)	Amount adsorbed $q \times 10^6$ (Kg/kg)	% Removal (R)
5	1000	542.40	45.76	45.76
8		416.80	58.32	58.32
10		301.80	69.82	69.82
15		224.40	77.56	77.56
20		196.00	80.40	80.40

Experimental variables:

Volume of solution	= 100 ml
Speed of the shaker	= 400 osc/min
Contact time	= 6 hours
p ^H	= 7
Initial concentration	= 250,400,500 &1000 ppb
Temperature	= 28 ⁰ C

DATA TABLE FOR FIG. 2**Table 2: Effect of contact time and initial arsenic concentration on the removal of As(III)**

Contact time (minute)	Concentration (ppb)		Amount adsorbed $q \times 10^6$ (Kg/kg)	% Removal (R)
	Initial	Final		
15	100	63.70	3.63	36.30
30		55.75	4.42	44.25
60		49.35	5.06	50.65
120		30.10	6.99	69.90
180		23.75	7.62	76.25
240		16.95	8.30	83.05
300		12.90	8.71	87.10
330		11.10	8.89	88.90
360		10.90	8.91	89.10

DATA TABLE FOR FIG. 2(continued)**Table 2: Effect of contact time and initial arsenic concentration on the removal of As(III)**

Contact time (minute)	Concentration (ppb)		Amount adsorbed $q \times 10^6$ Kg/kg	% Removal (R)
	Initial	Final		
15	150	94.90	5.51	36.73
30		79.40	7.06	47.07
60		71.00	7.90	52.67
120		54.30	9.57	63.83
180		36.90	11.31	75.40
240		27.05	12.29	81.97
300		19.98	13.02	86.80
330		18.65	13.13	87.57
360		17.40	13.26	88.40

DATA TABLE FOR FIG. 2(continued)**Table 2: Effect of contact time and initial arsenic concentration on the removal of As(III)**

Contact time (minute)	Concentration (ppb)		Amount adsorbed $q \times 10^6$ Kg/kg	% Removal (R)
	Initial	Final		
15	250	155.70	9.43	37.72
30		142.50	10.75	43.00
60		121.90	12.81	51.24
120		92.80	15.72	62.88
180		65.30	18.47	73.88
240		47.70	20.23	80.92
300		34.10	21.59	86.36
330		30.70	21.93	87.72
360		30.30	21.97	87.88

DATA TABLE FOR FIG. 2(continued)**Table 2: Effect of contact time and initial arsenic concentration on the removal of As(III)**

Contact time (minute)	Concentration (ppb)		Amount adsorbed $q \times 10^6$ (Kg/kg)	% Removal (R)
	Initial	Final		
15	400	238.33	16.17	40.42
30		211.40	18.86	47.15
60		203.33	20.33	50.83
120		154.40	24.56	61.40
180		120.20	27.98	69.95
240		85.45	31.45	78.63
300		66.65	33.33	83.34
330		55.55	34.44	86.11
360		47.50	35.25	88.13

Experimental variables:

Amount of adsorbent = 10 gm/l
 Volume of solution = 100 ml
 Speed of the shaker = 400 osc/min
 Contact time = 6 hours
 p^H = 7
 Initial concentration = 100, 150, 250 & 400 ppb
 Temperature = 28⁰C

DATA TABLE FOR FIG. 3**Table 3: Langmuir isotherm plot data for As(III) removal**

Initial concentration C_0 (ppb)	Equilibrium Concentration C_e (ppb)	Amount adsorbed q_e $\times 10^6$ (Kg/kg)	$1/C_e \times 10^3$	$1/q_e \times 10^{-3}$
100	10.90	8.91	91.74	112.23
150	17.40	13.26	57.47	75.41
250	30.30	21.97	33.01	45.52
300	35.21	26.47	28.40	37.78
400	47.50	35.25	21.05	28.36

Experimental variables:

Amount of adsorbent = 10 gm/l
 Volume of solution = 100 ml
 Speed of the shaker = 400 osc/min
 Contact time = 6 hours
 p^H = 7
 Temperature = 28⁰C

DATA TABLE FOR FIG. 4**Table 4: Freundlich isotherm plot data for As(III) removal**

Initial concentration C_0 (ppb)	Equilibrium Concentration $C_e \times 10^6$ (gm/l)	Amount adsorbed $q_e \times 10^6$ (Kg/kg)	Log C_e	Log q_e
100	10.90	8.91	-4.9625	-5.0501
150	17.40	13.26	-4.7594	-4.8774
250	13.30	21.97	-4.5185	-4.6581
300	35.21	26.47	-4.4533	-4.5772
400	47.50	35.25	-4.3233	-4.4528

Experimental variables:

Amount of adsorbent = 10 gm/l
 Volume of solution = 100 ml
 Speed of the shaker = 400 osc/min
 Contact time = 6 hours
 pH = 7
 Temperature = 28⁰C

DATA TABLE FOR FIG. 5**Table 5: Pseudo-first-order (Lagergren) plot data for As(III) removal (initial concentration=100 ppb)**

Time (minute)	Amount adsorbed at equilibrium, $q_e \times 10^6$ (kg/kg)	Amount adsorbed, $q \times 10^6$ (kg/kg)	Log ($q_e - q_t$)
15	8.91	3.63	-5.2773
30		4.42	-5.3477
60		5.06	-5.4145
120		6.99	-5.7166
180		7.62	-5.8894
240		8.30	-6.2146
300		8.71	-6.6989
330		8.89	-7.6989

DATA TABLE FOR FIG. 5 (continued)**Table 5: Pseudo-first-order (Lagergren) plot data for As(III) removal (initial concentration=150 ppb)**

Time (minute)	Amount adsorbed at equilibrium, $q_e \times 10^6$ (kg/kg)	Amount adsorbed, $q \times 10^6$ (kg/kg)	Log ($q_e - q_t$)
15	13.26	5.51	-5.1106
30		7.06	-5.2076
60		7.90	-5.2708
120		9.57	-5.4329
180		11.31	-5.7099
240		12.29	-6.0132
300		13.02	-6.6197
330		13.13	-6.8860

DATA TABLE FOR FIG. 5 (continued)**Table 5: Pseudo-first-order (Lagergren) plot data for As(III) removal (initial concentration=250 ppb)**

Time (minute)	Amount adsorbed at equilibrium, $q_e \times 10^6$ (kg/kg)	Amount adsorbed, $q \times 10^6$ (kg/kg)	Log ($q_e - q_t$)
15	21.97	9.43	-4.9017
30		10.75	-4.9500
60		12.81	-5.0381
120		15.72	-5.2041
180		18.47	-5.4559
240		20.23	-5.7594
300		21.59	-6.4202
330		21.93	-7.3979

DATA TABLE FOR FIG. 5 (continued)**Table 5: Pseudo-first-order (Lagergren) plot data for As(III) removal (initial concentration=400 ppb)**

Time (minute)	Amount adsorbed at equilibrium, $q_e \times 10^6$ (kg/kg)	Amount adsorbed, $q \times 10^6$ (kg/kg)	Log ($q_e - q_t$)
15	35.25	16.17	-4.7194
30		18.86	-4.7854
60		20.33	-4.8262
120		24.56	-4.9710
180		27.98	-5.1384
240		31.45	-5.4202
300		33.33	-5.7166
330		34.44	-6.0915

Experimental variables:

Amount of adsorbent = 10 gm/l
 Volume of solution = 100 ml
 Speed of the shaker = 400 osc/min
 p^H = 7
 Initial concentration = 100,150,250 & 400 ppb
 Temperature = 28⁰C

Table 5.1: Adsorption rate constant for various initial concentrations

Initial concentrations (ppb)	Adsorption rate constant, $k_{ad} \text{ min}^{-1}$
100	0.01450
150	0.01220
250	0.01519
400	0.00898

Experimental variables:

Amount of adsorbent = 10 gm/l
 Volume of solution = 100 ml
 Speed of the shaker = 400 osc/min
 pH = 7
 Initial concentration = 100,150,250 &400 ppb
 Temperature = 28⁰C

Table 6: Comparison of sorption capacities of the burnt rice straw (BRS) for the removal of arsenic with those of other adsorbents [17].

Sl. No.	Adsorbent	P ^H	Concentration range	Temperature (°C)	Sorption capacities (mg/g)	
					As(III)	As(V)
1	Burnt rice straw(BRS), present study	7.0	100-400 µg/l	28	0.199	-
2	Iron oxide coated sand IOCS	-	100 µg/l	22±2	0.136	-
3	Atlantic Cod fish scale	4.0	-	-	0.02667	0.02475
4	<i>L. nigrescens</i>	2.5	50–600mg/L	25	-	45.2
5	Tea fungal biomass	7.2	1.3mg/L for As(III) and 0.9mg/L for As(V)	30	1.11	4.95
6	Fresh biomass	6.0	50–2500mg/L	30	128.1	-
7	Iron oxide coated cement IOCC	~7.0	0.5–10.0mg/L	35	3.98	
8	Iron oxide coated cement IOCC	7.0	0.7–3.5mg/L	35	0.67	-
9	<i>Penicillium purpurogenum</i>	5.0	10–750mg/L	20	35.6	-