Fabrication and Preliminary Assessment of Fixed Adsorption Column for Arsenic (As) Removal Using Local Rice Husk

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Abstract

Arsenic (*As*) being a carcinogenic element present in drinking water in the less developed areas in the deprived countries contributes to many infectious diseases. The removal of arsenic traces from water needs to have an easy and efficient way for poor countries. Concerning this, a low-cost bio-adsorbent from Rice husk is prepared to remove arsenic from groundwater. Preparation of the adsorbent is performed by crushing, sieving, washing and drying the rice husk. The Arsenic present in groundwater samples before and after treatment were tested by Arsenic kit. Batch experiments were carried out with ten contaminated samples of groundwater from Indus river origin area (Nasarpur) to investigate the influence of operating parameters such as adsorbent bed height (ABH) and initial arsenic concentration and residence time (TR) on *As* removal efficiency using locally fabricated adsorption column. Environmental parameters such as pH, temperature, TDS, and EC were also determined. It was observed that the highest optimized removal efficiency of 90% was achieved at ABH 30 cm: residence time, 60 minutes for feed arsenic concentration of 80 ppb samples. These results suggest that this bio-adsorbent can provide an easy, efficient, and economical method for removing *As* ions from effluents and water resources.

Keywords—Arsenic removal, adsorption bed column, adsorbent bed height.

1 Introduction

THE high toxicity of arsenic is observed in groundwater [1]. Arsenic mostly occurs in the inorganic form in nature. Various research outcomes highlight that arsenic is a carcinogenic element if used in excess amount in drinking water [1–4]. Arsenate is less poisonous and eager to migrate than Arsenite. It is up to 60–99% of total arsenic present in water [2][5–8]. World Health Organization's (WHO) drinkable water limit for arsenic is set to $10.0 \mu\text{g L}^{-1}$ which is not because of safe consumption of water containing less than that concentration of arsenic, but due to the difficulty of detection and removal of arsenic below that concentration.

Consumption of arsenic content water has been reported for various health issues due to its toxicity and severe damage to human body, especially in south-eastern countries including China, India, Pakistan and Bangladesh [9–11]. The health problems cannot be visible immediately as human body can absorb significant arsenic amount, which is more harmful because the health problems occur when the tolerance limit of arsenic content is attained [2][3][12]. Arsenic consumption is a major cause for Prolonged illness including cardiovascular and mental retardant in children [13]. Considering the hazardous effects of arsenic, Environmental Protection Agency (EPA), USA strongly recommends arsenic as Group-A carcinogenic that can cause multiple skin diseases and cancers. It is also observed in the literature that a huge population of the world consumes contaminated drinking water having arsenic in higher percentages than the one

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recommended by World Health Organization (WHO), i.e., 0.01 mg/L [14][15].

Trivalent and pentavalent arsenic are observed as most common inorganic traces for the contamination of water. These both molecules of arsenic are mobilization-sensitive and sustain in metalloid in either reducing or the oxidizing situation with a pH range of 7.5 ± 1 . Arsenate As(V) can form oxyanions (H_2AsO_4) and $(HAsO_4)_2$ in rich oxygen availability, however, Arsenite As (III) species are stable in inverse atmospheric conditions such as anaerobic or reducing situation and can develop H_3AsO_3 around neutral pH range. The trivalent As(III) is more toxic than the pentavalent form of As(V) and hard to remove by conventional methods such as physiochemical treatment [16]. The population of various countries like Magnolia, Mexico, Taiwan, Thailand, Bangladesh and India is exposed with acute and chronic arsenic through drinking water up to a level of 2000 $\mu g/L$ [4], [17]. In Pakistan, Punjab and Sindh provinces are highly affected with arsenic in water. Almost 24% of residents of Punjab province are in danger by 12-14 $\mu g/L$ arsenic contamination, and 3-4% people above 56-60 $\mu g/L$. About 35-46% of the population of Sindh province is prone to be affected by 12-15 $\mu g/L$, and 18-22% with 56-60 $\mu g/L$ of arsenic [18]–[20].

A significant number of treatment methodologies have been developed for removing arsenic traces from water, most of them emphasizing on industrial or large scale water treatment plants, however, the rural or small scale local treatment is not well established yet [12]. Different techniques including ion exchange, coagulation, membrane filtration, precipitation and adsorption have been applied for removing arsenic from groundwater of contaminated surface water, and synthetic or natural adsorbents are been developed besides lime softening technique to reduce arsenic concentrations [1][6][21], however, economic constraints for these technologies is still a big challenge [16].

Considering the afore-mentioned issues, a cost-effective technology development for the removal of arsenic and production of safe and clean drinking water would be a breakthrough for achieving the consumers' health satisfaction with the economy [20]. Adsorbents share many features for adsorbing metals such as the concentration of metal present in liquid, pH, residence or contact time, and chemical characteristics of the adsorbent [22]. Some researchers have revealed that various agricultural waste materials such as wheat husk and barn can also be utilized for this purpose can be quite effective in terms of cost [23]. In addition to that, some shells of trees and nuts, and other material such as maize, sugarcane, and some seeds have also

been found efficient for removing arsenic from water [21][24–27].

The most prominent technologies include membrane separation, precipitation–coagulation, ion-exchange and adsorption [28–30]. Among all these, the fixed bed adsorption system is simple and has a sludge-free operation and handling along with good regeneration capacity. Hence, this technology is receiving popularity for arsenic removal [31]. Considering the attraction of arsenic toward iron, various forms of irons like ores, oxides, and iron coated materials have been efficiently and intensively used in water treatment processes [8]. The main objective of this study is to investigate the potential of raw rice husk to be used as an adsorbent for arsenic removal from groundwater. The local availability of rice husk makes this adsorbent cheap and reliable for these technologies. Moreover, the effect of various operating parameters such as adsorbent bed height, initial arsenic concentration and residence time were investigated to reveal the performance of fabricated adsorption column.

2 Material & Method

The study work is mainly aimed to find out the optimized parameters for removal of arsenic from the groundwater by passing it through rice husk bed in fixed adsorption column. The main idea behind this proposed configuration is to provide arsenic molecules present in groundwater and the active sites on the surface of rice husk molecules to filter pure water at the outlet. In order to achieve such objectives, different operating parameters including the rice husk bed height, initial arsenic feed concentration in samples and residence time/contact time were investigated. The proposed model was remoulded and fabricated with respect to the model in [32] by changing its bed height inside column diameter and the omission of a pump for decreasing capital cost for poor clients in deprived areas.

2.1 Collection, Preparation and Sampling

The following sections describe the process of collection, preparation and sampling of rice husk.

2.1.1 Collection and preparation of Rice Husk

Rice husk has been collected from a rice mill situated in Hyderabad city. After collection, it was grounded with the help of grinding machine (Figure 1a) present at the Department of Chemical Engineering, MUET Jamshoro. Ground rice husk was separated by using a sieve to obtain the uniform size adsorbent, i.e., 1.18 mm, 850 micrometre, and 710 micrometres with the

help of sieve shaker (Figure 1b). Adsorbent 1.18 mm sized particles were washed with deionized water, dried in an oven (Figure 1c) at 105°C for 50 minutes. Finally, this bio-adsorbent was stored in airtight jars.

2.1.2 Sampling of Water

Ten samples were taken from the groundwater sources of Nasarpur, a historical city in Indus civilization as it has an origin of the river Indus. Nasarpur is 45 km away from the study area (Mehran UET, Jamshoro). The manner in which samples are collected has a direct impact on the quality of analytical findings. As shown in many studies, there are high chances for the sample contamination at the sample source, therefore, high priority was given to the safe and secure sample collection following the SOPs to minimize the risks of sample contamination. Groundwater is collected in plastic bottles, washed with distilled water and diluted in HCl solution. Water was collected at the well-head/spigot after allowing it to run for sufficient time, so that the water being collected has come directly from the aquifer. Bottles were filled with as little head-space as possible, but the neck of the bottles were left empty to allow for any expansion during shipment. After filling, the bottles were sealed around the cap/bottle joint to prevent exchange or loss of CO_2 from the water.

2.2 Fabrication of Adsorbent Column Assembly

The experimental setup including the containment building, fixed adsorption column, storage tanks, sieves and fixation of the manual water flow valve is fabricated/assembled in a mechanical workshop, Mehran University of Engineering and Technology, Jamshoro, Pakistan. The experimental setup and the assembly are shown in Figure 3.

Adsorption Column (AC): Adsorption column was made up of acryl material, available in sheet, rod, and tube for use in injection mouldings, extrusion and vacuum forming. The column has O.D, 5 cm and I.D of 4 cm, whereas, the total height of the column is 150 cm. The column is divided into three sections: upper section (raw water), middle section (rice husk adsorbent bed) and a lower section (treated water). The lower section has a height of 60 cm, while upper section height changes in proportion to the bed height.

Storage tanks (ST): For adsorption, bed column experimental setup, two storage tanks having 5-litre volume capacity were fabricated at the mechanical workshop, Mehran university of engineering and technology, Jamshoro. Storage tanks, ST-1 and ST-2 were used for the distribution/

collection of raw water and treated water, respectively.

Sieve (SE): A perforated sieve made from the acrylic plastic (glass) of 0.5 mm hole diameter was used to filter the treated water from the adsorption bed. This sieve is adjusted at the top of the lower section to handle the material over it as well as to fix the bed height.

Manual Water Flow Valve (WFFV): A manual water flow valve is used to regulate, stop and control the flow towards adsorption column by opening and closing (either fully or partially).

2.3 Experimental Methods

The prime objective of this study is to investigate the operating parameters for arsenic removal. For that, we must also analyse the major water quality parameters. Beside arsenic, the water quality parameters to be examined are temperature, pH, Electric Conductivity (EC) and Total Dissolved Solids (TDS), etc. The method adopted to analyses these parameters is shown as follows. The results before and after the filtration are shown in Table 2.

2.3.1 Arsenic

Arsenic of water samples will be measured using arsenic mobile kit MERCK with a precision error of $\pm 1\%$ (Germany) (Figure 4). WHO's standard value is 0.01 mg/L and Pakistan standard for As is 0.05 mg/L. The concentration and the percentage removal of arsenic from aqueous solution were calculated using the following equation,

$$\% \text{Adsorption} = \frac{C_0 - C_f}{C_0} \times 100 \quad (1)$$

where C_0 and C_f are the initial and final arsenic concentrations in (mg/L) [32].

2.3.2 pH and Temperature

pH and temperature of the water samples before and after the filtration were measured using a portable HANNA pH meter (Figure 5). The instrument was calibrated with standard pH-7 buffer solution. the pH of water is the number of concentrations of hydrogen ion in water. It ranges from 0 to 14. Generally, water that has pH = 7 is neutral, pH $>$ 7 is basic, and pH $<$ 7 is acidic in nature. The normal pH recommended for drinking water by WHO ranges from 6.5-8.5.

2.4 Total Dissolved Solids (TDS)

Total dissolved solids in water were measured with the help of Hanna digital TDS meter. Solid contaminants

(a) Hammer mill

(b) Mechanical sieve shaker

(c) Dryer/over

Fig. 1: Different equipment used for the preparation of Rice Husk

Size Reduction

Fig. 2: Rice Husk- Size reduction from left to right

No.	Sample Name	Location	Arsenic (ppb)
1	S1	Abra Mohalla	30
2	S2	Bus Stop	40
3	S3	Dars Mohalla	50
4	S4	Pandhyani Mohalla	60
5	S5	Almani Mohalla	70
6	S6	Memon Mohalla	80
7	S7	Nasarpur Stop	85
8	S8	Ghirana Mohalla	90
9	S9	Nasarpur Petrol Pump	95
10	S10	Arain Mohalla	100

TABLE 1: Arsenic content in water before passing through adsorption bed

Fig. 3: Experimental setup and assembly

may be organic or inorganic or suspended in the water. Its unit is mg/L. TDS is an important environmental parameter whose normal range is ≤ 1000 mg/L in accordance with the WHO standards as well as Pakistan drinking water standard.

2.4.1 Electric Conductivity (EC)

Electrical conductivity is related to the measure of the concentration of dissolved ions in the water and measured in $\mu S/cm$. WHO's recommended limit of EC in groundwater is up to $400 \mu S/cm$. The electric

conductivity of the water will be measured with help of Hanna digital TDS meter. After the verification of the environmental parameters recommended by WHO, the experiments were performed on physical parameters such as Adsorbent Bed Height (ABH), initial arsenic concentration and the residence time (TR).

3 Results & Discussion

For the removal of arsenic from groundwater, it was passed through the adsorption bed column. Arsenic was tested with the help of arsenic kit method. Modified adsorption bed has shown remarkable importance of rice husk in the removal of arsenic from groundwater of Nasarpur. Along with arsenic removal, it has also affected the environmental parameters of water. Different experiments were conducted for 10 different samples (Table 1) obtained from Nasarpur by varying their inlet concentration with constant bed height of 30 cm, particle size (rice husk) of 1.18 mm, and flow rate of 20.94 ml/min. Experimental results are shown in Table 2.

3.1 Determination of Environmental Parameters

Different environmental parameters like TDS, EC, pH and temperature were analysed for the sake of

Fig. 4: Experimental observation while performing arsenic test by colorimetric method. (a) arsenic Kit, (b) sample and reaction bottles, and (c) comparison of strips with standards)

Sample	pH		TDS (mg/l)		EC ($\mu\text{S}/\text{cm}$)		T ($^{\circ}\text{C}$)	
	Before	After	Before	After	Before	After	Before	After
S1	8.3	7.37	570	550	740	380	30.6	30.6
S2	7.25	7.85	670	650	840	440	30.8	30.8
S3	7.4	8.1	340	330	680	380	31.1	31.1
S4	7.6	7.35	310	310	620	320	31.9	31.9
S5	7.25	7.05	430	410	860	460	29.3	29.3
S6	7.57	7.27	290	270	580	280	30.8	30.8
S7	7.7	7.1	280	310	560	360	29.3	29.3
S8	7.1	7.6	790	730	580	380	29.5	29.5
S9	7.3	7.1	350	330	700	290	31	31
S10	8.05	7.35	360	340	720	320	32.1	32.1

TABLE 2: Environmental parameters before and after treatment

Fig. 5: Environmental parameters test for Water (TDS, EC, pH and Temperature)

monitoring the quality of groundwater. Samples were tested with the help of Hanna pH, EC, TDS meter and thermometer for calculating the pH, EC, TDS and temperature values, respectively. TDS and pH values lie in the allowable limit of WHO standards. Values of environmental parameters are given in Table 2.

3.2 Adsorbent Bed Height (ABH)

Adsorbent bed height is defined as the total vertical distance filled up with the rice husk in a glass column. Different adsorbent bed heights were tested to remove arsenic from a wide range of contaminated groundwater samples. As shown in Figure 6, different adsorbent bed height, i.e., 25 cm, 30 cm and 35 cm were tested by keeping the flow rate (20.94 mL/min) and residence time (30 min) constant. The experiments were repeated twice for the feed arsenic concentrations varying from 30 to 100 ppb.

The maximum average removal of 87.4% was achieved in 35 cm ABH. Besides, the arsenic removal difference between ABH values of 30 cm and 35 cm is not significant. Hence for economics and optimized parametric study point of view, the ABH=30 cm can be recommended for the household applicability of the adsorbent column. The increment in the removal efficiency by increasing the ABH is mainly due to increase of the contact areas between contaminated solution and rice husk particles, allowing arsenic particles to be better adsorbed at offered active sites of the adsorbents. This phenomenon has permitted arsenic to diffuse in the molecular level into the rice

husk. Consequently, the percentage of arsenic removal increased when the ABH was increased. Whereas, increasing ABH showed no prominent change in the removal efficiency of arsenic for all feed arsenic concentrated samples. ABH= 30 cm was optimized for further experiments, because this bed gives an overall high removal efficiency (Figure 8).

3.3 Feed Arsenic Concentration (ppb)

All contaminated samples of groundwater were found having different arsenic content. WHO standard value is 0.01 mg/L or 10 ppb and Pakistan standard for arsenic is 0.05 mg/L or 50 ppb. Arsenic values ranged from 30 ppb to 100 ppb in the referenced samples (Table 1). The effect of initial arsenic concentration was studied on a column by varying feed arsenic concentrations of 30-100 ppb. The adsorbent bed height (30 cm), the diameter of the column (4 cm), residence time (30 min) and flow rate (20.94 mL/min) were kept constant. It was observed that with low arsenic concentration samples, the treated quantity was higher. However, for the high arsenic concentration samples, the adsorption capacity also increased. This was due to the rise in the driving force of the concentration gradient. On the other hand, for low arsenic concentration samples, the driving force of adsorbent is smaller due to lower gradients. Figure 6(b) shows that the highest removal was 82 ppb and lowest removal was 19 ppb for S1 and S10, respectively. On the contrary, higher concentration samples have high driving force for the As ions to surmount the liquid phase mass transfer resistance. The removal efficiency for the lowest concentration to the highest concentration was in the range of 63-83%.

3.4 ABH Results Comparison

When water was passed through the column at adsorbent bed height of 25 cm, the removal efficiency was in the range of 30-48%, which showed that the arsenic concentrations were still higher and non-recommendable for the household use even. When the water was passed through the bed height of 30 cm, it reduces the arsenic content in water with a removal efficiency between 63-83%, and finally 66-87% (Figure 8). Hence it was concluded that for this assembly, a 30 cm ABH can be fixed for another parametric study such as the residence time.

3.5 Residence time (T_R)

For residence time study, the contaminated samples were passed through the adsorbent bed for 30 and 60 minutes. Parameters fixed were adsorbent bed height

(a)

(b)

(c)

Fig. 6: Effect of Adsorbent bed height on Arsenic concentration (a) 25 cm (b) 30 cm and (c) 35 cm

30 cm, and column diameter 4 cm, however, the flow rate was varied between 20.94 and 10.5 ml/min to reduce or increase the residence time. Samples were recovered after 30 and 60 min and were tested. Arsenic was reduced from all samples nearly to WHO's allowable limit in case of 60 minutes residence time, whereas, for 30 min time for those which were still slightly higher than WHO's limit. Results for arsenic concentrations before and after treatment and the

Fig. 7: Comparison of different Absorbent Bed Heights(ABHs)

Fig. 8: Effect of adsorbent bed height on removal efficiency

Fig. 9: Effect of residence time on arsenic concentration

Fig. 10: Effect of residence time on removal efficiency

arsenic removal efficiency are presented in Figure 9 and 10 respectively.

4 Conclusion

The fabricated fixed adsorbent bed column treatment system due to its easy operation, maintenance and cheap adsorbent media is a suitable domestic approach for arsenic removal for poor community areas. Rice Husk being bio-material, cheap and locally available has proven to be effective in underprivileged areas. In this study, a fixed adsorption bed column was fabricated from glass column and rice husk (as adsorbent material). The geometry of the column was taken into consideration including constant inside column diameter and constant column height in accordance with recent research work with some modifications to reduce the capital cost. Experiments were carried out at three different bed heights: 25 cm, 30 cm and 35 cm, and a wide range of feed arsenic concentrations, and two residence times. Each ABH has given different removal efficiency, however, 30 cm bed height resulted in optimal results. This ABH was used for 60 minutes that gave the removal efficiency of 80-90%. Regarding the use of this contaminated rice husk material, it can be recommended to use as a binding material with Portland cement. Besides, this consumed biomass can be used as an insulating agent for cement/insulation panels and roof sheets. Whereas, Computational Fluid Dynamics (CFD) studies are highly recommended to investigate other factors in adsorption column such as porosity, different adsorbing materials and variable geometries.

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