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Water Management
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Arsenic removal from drinking water using wood charcoal

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ABSTRACT

Arsenic contamination of drinking water is threatening the health of millions of people of Bangladesh. Lack of appropriate arsenic removal technology has complicated and inhibited the mitigation initiatives. The effectiveness of wood charcoal for removal of arsenic from tubewell water was evaluated in this study. Arsenic contaminated water sample was passed through a pitcher having a small hole at its bottom contained wood charcoal at a controlled flow rate of 30 mL min^{-1} with different thickness of wood charcoal (7.5, 10, 12.5, 15, 17.5, 20 and 22.5 cm) and at different flow rates (10, 30, 50, 70, 90, 110 and 130 mL min^{-1}) with 20 cm fixed thickness of wood charcoal. Results revealed that with the increased of flow rate the removal of arsenic percentage decreased. Maximum arsenic removal efficiency (93.68%) was obtained at a flow rate of 10 mL min^{-1} with 20 cm of charcoal thickness. In addition, it was also observed that both flow rate and charcoal thickness are critically important in achieving higher arsenic removal efficiency. Therefore, water flow rate of 50 mL min^{-1} with charcoal thickness of 15 cm could be used to remove arsenic from contaminated tube well water (arsenic concentration after filtration was 30 μg L^{-1} which is below the allowable arsenic concentration standard i.e. 50 μg L^{-1}).

Keywords: Drinking water, arsenic, wood charcoal, filtration

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1 Introduction

Safe drinking water is still an important issue in Bangladesh. In the past, most drinking water was harnessed from rivers, ponds, dug well with little or no arsenic but with contamination of pathogens transmitting various diseases such as cholera, diarrhea, dysentery, hepatitis and typhoid. In order to control these diseases, program for safe drinking water initiated the use of tubewells to harness groundwater. Although it succeeded in achieving its goal of supplying water free of pathogens, but after a couple of decades since its inception, an unexpected side effect i.e. arsenic contamination on human health has been noticed. Intake of arsenic associated with food is a common phenomenon for human beings but this arsenic is less toxic than inorganic arsenic. Nevertheless, drinking water yielded from underground sources contains arsenic in inorganic form, which is of higher toxicity and a significant hazard for human health. Prolonged use of arsenic-rich water for drinking purpose is unsafe and most commonly reported symptoms of chronic arsenic exposure are black pigmentation, dermatitis, keratosis of the skin, skin and lung cancer, hepatic dysfunction and diabetes (Chen and Ahsan, 2004; Wu et al., 2015). Cardiovascular and neurological diseases have also been found to be linked to arsenic contamination (Saha, 1998; WHO, 1999).

Groundwater is available in shallow aquifers in adequate quantity in the flood plains for development of tubewell based water supply to scattered rural population. Bangladesh achieved remarkable successes by providing drinking water at low-cost to the rural population through sinking of shallow tubewells in flood plain aquifers. Among 10 million shallow tubewells installed in Bangladesh, 30-40% has been estimated to contain arsenic at levels exceeding standard value i.e. 50 μg L^{-1} (WHO, 1999). As a consequence about 22 million people in Bangladesh are exposed to arsenic concentration through drinking water was above 50 μg L^{-1} and above 5.6 million are exposed to arsenic concentration above 200 μg L^{-1} (BBS/UNICEF, 2009).

Arsenic toxicity has no effective medicine for treatment, but drinking of arsenic free water can help the arsenic affected people to get rid of the symptoms of arsenic toxicity. Hence, provision of arsenic free water is urgently needed to mitigate arsenic toxicity and protection of health and well-being of rural people living in acute arsenic contaminated areas of Bangladesh and India. The alternative options available for water supply in the arsenic affected areas include treatment of arsenic contaminated ground water. Treatment of surface waters by low-cost methods, rain water harvesting and water from deep aquifers would be potential sources of water supply to avoid arsenic ingestion through shallow tubewell water.

Several arsenic removal technologies such as oxidation, coagulation, flocculation, precipitation, ion exchange, membrane filtration, lime treatment and adsorption are most commonly used for removing arsenic from contaminated groundwater in worldwide (Liu et al., 2012). Among the above mentioned arsenic removal technologies, adsorption has been reported as the most widely used technique for arsenic removal due to its several advantages i.e. relatively high arsenic removal efficiencies, easy operation and handling, cost-effectiveness and sludge production (Singh and Pant, 2004; Mohan and Pittman Jr, 2007; Jang et al., 2008; Anjum et al., 2011). A wide variety of absorbents such as activated carbon, coal, red mud, fly ash, chicken feathers, kaolinite, montmorillonite, goethite, zeolites, activated alumina, titanium dioxide, iron hydroxide, zero-valent iron, chitosan and cation-exchange resins has been studied for removal of arsenic from water (Nicomel et al., 2015). Since the effectiveness of adsorption primarily depends on the characteristics of the adsorbent, arsenic concentration and pH of water sample, there has been considerable interest in identifying the proper adsorbents for arsenic removal.

According to Gupta et al. (2012), there is a strong affinity between inorganic arsenic species and iron. As a consequence, iron-based adsorption became an emerging technique for the treatment of arsenic-contaminated water. Iron can remove arsenic from water either by acting as a sorbent, co-precipitant or contaminant-immobilizing agent or by behaving as a reluctant (Mondal et al., 2013). Though iron oxides have shown high arsenic absorption affinity, but it is difficult to separate them from water after adsorption which exceeds the maximum concentration level of iron in drinking water (Liu et al., 2012; Hesami et al., 2013). In addition, an iron oxide based adsorption technique is costly and rural people could not afford it. Therefore, it is necessary to develop a low cost arsenic removal technology for rural household uses.

In this research, a low cost arsenic removal technology based on wood charcoal was used to reduce the arsenic from contaminated tube well water. Due to high adsorption characteristic, carbon filters are employed in commercial home water treatment systems as well as in large-scale municipal treatment facilities. In addition, wood charcoal shows the characteristics similar to the carbon. Furthermore, previous research reported that wood charcoal combined with sand could remove arsenic from arsenic-contaminated water up to 90% (Singh, 2004).

2 Materials and Methods

2.1 Study area

Arsenic contamination of tubewell water has been detected all over Bangladesh by GO and NGOs. This study was conducted at the Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh. The sample of arsenic contaminated tubewell water was collected from the village Ijarapara at Sarishabari upazilla of Jamalpur district. According to the identification by GO and NGOs, eighty percent tubewells of selected village were contaminated by arsenic (arsenic concentration was ranges from 70 to 95 μg L^{-1}). About 30% of the total population of selected village was affected by arsenic through drinking water.

2.2 Sample collection

The water sample was collected from the most affected tube well in two containers each of forty liters capacity. A severely contaminated tube well (arsenic concentration was 95 μg L^{-1}) was selected with the help of the people in the study area. Before collection of water sample, the containers were washed out with HCl (0.5N) and distilled water to avoid any kind of chemical contamination.

2.3 Charcoal preparation

Sixty kilogram mango wood was purchased from sawmill for the purpose of making charcoal. The collected wood was chopped into small pieces (6.5 cm in

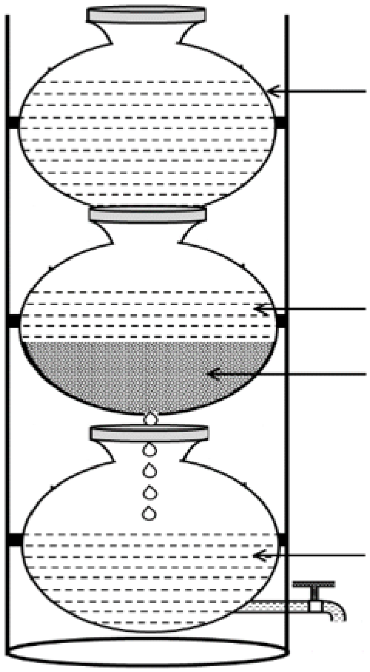

Figure 1. Filtration setup

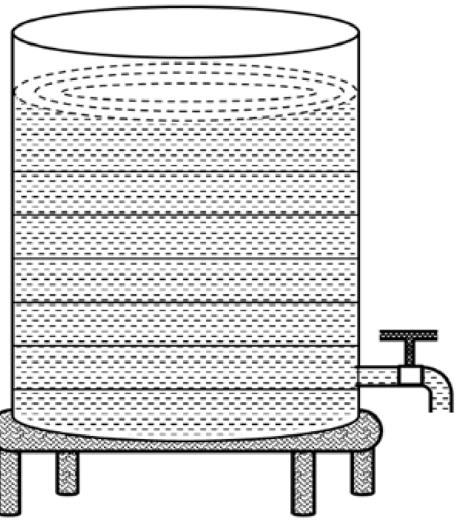

Figure 2. Natural sedimentation setup

Table 1. Arsenic removal from contaminated tubewell water by charcoal filtration method at different charcoal thickness with constant flow rate

No.	Thickness (cm)	Initial pH	Flow rate (mL min^{-1})	As content (μg L^{-1})		As removal (%)
				Before filtration	After filtration	
1	7.5	6.9	30	95	58	38.95
2	10.0	6.9	30	95	50	47.37
3	12.5	6.9	30	95	44	53.68
4	15.0	6.9	30	95	30	68.42
5	17.5	6.9	30	95	18	81.05
6	20.0	6.9	30	95	10	89.47
7	22.5	6.9	30	95	5	94.74

Table 2. Arsenic removal from contaminated tubewell water by charcoal filtration method at different flow rate with fixed thickness of charcoal

No.	Flow rate (mL min^{-1})	Initial pH	Thickness (cm)	As content (μg L^{-1})		As removal (%)
				Before filtration	After filtration	
1	10	6.9	20	95	6	93.68
2	30	6.9	20	95	9	90.53
3	50	6.9	20	95	14	85.26
4	70	6.9	20	95	22	76.84
5	90	6.9	20	95	32	66.32
6	110	6.9	20	95	44	53.68
7	130	6.9	20	95	55	42.11

diameter and 45 cm in length) and dried at the yard of engineering workshop belong to the Department of Farm Power and Machinery for 20 d to reduce the moisture content of the wood in the range of 20 to 25%. Moisture content of the wood sample was determined following standard oven dried method at Agricultural Process Engineering lab. After drying of wood, charcoal was prepared from the dried wood. Among several charcoal preparation methods open air burning method was used for preparation of charcoal in this research.

2.4 Arsenic removal by charcoal filtration

In this method, three pitchers (11 liters each) were placed one above another vertically in a bamboo-tripod (Fig. 1). The top most pitcher having a small hole at its bottom contained arsenic contaminated tubewell water. The middle one contained wood charcoal had a small orifice at its bottom covered with a screen to prevent leaking of any fine charcoal through the orifice except water. The bottom pitcher acted as a collector. In the first case, water was allowed to pass through the middle pitcher at a controlled flow rate of 30 mL min^{-1} with different thickness of wood charcoal (7.5, 10, 12.5, 15, 17.5, 20 and 22.5 cm), respectively (Fig. 2). In later case, water was allowed to passes through the middle pitcher at different flow rates (10, 30, 50, 70, 90, 110 and 130 mL min^{-1}) with a fixed thickness of wood charcoal of 20 cm.

2.5 Water quality evaluation

Water quality parameters i.e. pH, arsenic concentration, electrical conductivity (EC) and total dissolved solids (TDS) was considered for evaluating the performance of selected arsenic removal techniques. The OAKTON PCD 650 multi-parameter handheld meter (OAKTON Instruments, USA) was used to measure the pH, EC and TDS of raw and treated arsenic contaminated tubewell water. All readings given by OAKTON PCD 650 multi-parameter handheld meter were recorded only when the displayed results became steady (wait for 2-3 minutes as recommended). The arsenic content of water samples were measured with Perkin-Elmer (Model: 2380) Atomic Absorption Spectrophotometer (equipped with MHS-10 hydride generator assembly, Perkin-Elmer EDL power supply, electrode less discharge, arsenic lamp and printer). Required amount of water sample was injected with a syringe in the hydride generator and reading of arsenic content was printed.

3 Results and Discussion

Charcoal is a well-known organic adsorbent which has a large surface area to adsorb different chemicals. During this study, charcoal was used as an absorbent of arsenic. The charcoal filtration experiment was carried out in two conditions i.e. at fixed flow rate but varying charcoal thickness and at fixed charcoal thickness but varying flow rate. Five replications for each condition were carried out and found no significant differences in results. Therefore, in the rest of this section only single replication results are represented and discussed. In the first case, arsenic contaminated tube well water was allowed to flow at a flow rate of 30 mL min^{-1} through charcoal of thickness range from 7.5 to 22.5 cm.

The results obtained from this experiment are shown in Table 1. It is observed that with the increased of charcoal thickness the removal of arsenic percentage increased. Maximum arsenic removal efficiency was obtained at a flow rate of 30 mL min^{-1} with 22.5 cm of charcoal thickness. In the second case, arsenic contaminated tube well water was allowed to flow through charcoal of thickness 20 cm at different flow rate ranges from 10 to 130 mL min^{-1}. The results obtained from this experiment are shown in Table 2. It is also observed that with the increased of flow rate the removal of arsenic percentage decreased. This results is similar to the results obtained by Hussain et al. (2007).

The higher arsenic removal efficiency was obtained at a flow rate of 10 mL min^{-1} with 20 cm of charcoal thickness. From this experimental findings it is reveal that both flow rate and charcoal thickness are critically important in achieving higher arsenic removal efficiency. Finally, from experimental results shown in Tables 1 and 2, water flow rate of 50 mL min^{-1} with charcoal thickness of 15 cm could be used to remove arsenic from contaminated tube well water (arsenic content 30 μg L^{-1} which is below standard 50 μg L^{-1}).

4 Conclusions

Removal of arsenic from drinking water is critically important to save millions of people from arsenic poisoning. An attempt was undertaken to develop user friendly and cost effective arsenic removal process using wood charcoal for the rural household uses in Bangladesh. Experimental results showed that developed wood charcoal based arsenic removal technology could remove arsenic from arsenic-contaminated tubewell water up to 94%. However, both flow rate and charcoal thickness are critically important in achieving optimum arsenic removal efficiency. It was observed that with the increased of charcoal thickness the removal of arsenic percentage increased. On the other hand, higher flow rate decreased the removal of arsenic percentage. Optimum arsenic removal efficiency was obtained at a flow rate of 50 mL min^{-1} with charcoal thickness of 15 cm i.e. arsenic concentration reduced from 95 μg L^{-1} to 30 μg L^{-1} which is below the allowable arsenic concentration standard

($\leq$50 μg L^{-1}). Therefore, developed technology could be adopted as cheaper and simple technology for removal of arsenic from drinking water.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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