A Study on Bacterial Oxidation and Fe (Iron) Based Arsenic Removal Technology with Rapid Sand Filter

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Abstract-In Bangladesh, the groundwater from which people get their drinking water has a high proportion of As. Drinking water with more than the WHO's standard (10µg/l As) affects over half of the population (80 million people). The goal of the study is to develop a combination filter that would be easily installed in Bangladesh's rural areas and reduce As concentrations to the 10µg/l level. In the study, two independent experiments are carried out at two distinct sites (location A and location B) with As concentrations of 57 and 48µg/l, respectively. One experiment used bacterial oxidation and Fe-based removal in a sand filter, which is followed by a Zero Valent Iron (ZVI) column, and another focused on bacterial oxidation of As in a plastic filter with subsequent Fe-based removal in a sand bed. It is seen that plastic can oxidize As (up to 80%) after the start of the experiment and that it was not very sensitive to the discontinuous flow of the passing water, while the oxidation rate was dropping when the anaerobic condition was occurring. The subsequent sand column is then able to remove all the adsorbed As from the water. Sand reached lower oxidation rates (up to 50%) and was more sensitive to discontinuous flows and anaerobic conditions. On the other hand ZVI columns show a removal rate of approximately 90%. Under the correct circumstances, the systems performed as planned. The system deviates from such expectations when those conditions are not satisfied.

Keywords: *Bangladesh, Arsenic, Drinking water, Oxidation, Filter, Concentration, ZVI, Aerobic, Anaerobic condition etc*

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1 INTRODUCTION

In Bangladesh, where most people rely on tube wells for drinking water, the severity of arsenic poisoning of groundwater has been noted. Recently, (Chakraborti et al., 2010) provided a comprehensive picture (Figure-1) of As poisoning in all 64 districts of Bangladesh [1]. Arsenic concentrations in drinking water should be rigorously regulated to 10 g/L, according to World Health Organization (WHO) recommendations [2]. The population exposed to As polluted water with concentrations between 10 and 50 µg/l might be as high as 36.6 million in 59 districts and 22.7 million in 5 districts. In recent decades, 35–77 million individuals in Bangladesh have been exposed to dangerous amounts of arsenic in drinking water (MArgos et al., 2010), despite the fact that the entire estimated population is around 164 million [3]. In 2001, The British Geological Survey (BGS) and the Department of Public Health and Environment (DPHE) found in 2000 that 46 percent and 27 percent of the 3,534 examined tube-wells in Bangladesh surpassed the As guideline threshold [4]. Simultaneously, according to estimates, 30 to 70 million people in Bangladesh are at risk from arsenic-contaminated water. The southeast (Meghna floodplains) and southern (coastal area of Khulna division) sections of Bangladesh are the most impacted by As polluted aquifers. Drinking water poisoned with arsenic is increasingly recognized as a global issue in many nations, particularly in Southeast Asia, including India, Bangladesh, and China. In these locations alone, almost 70 million people are affected by arsenic poisoning. This is possibly the biggest poisoning in

human history [5]. Today, in West Bengal, arsenic contamination in groundwater, and eventually in drinking water has been reported in the range of 50 to 3600µg/l in 111 blocks of 12 districts of the state (De, 2008) affecting more than 1 million people [6]. To avoid using pathogen-contaminated surface water and reduce waterborne diseases, the Bangladesh government began installing shallow wells to extract low-As groundwater in the 1970s, with assistance from international aid agencies, and, above all, to investigate low-tech, low-cost, locally fitted systems for arsenic removal from groundwater, but all of these approaches are associated with some practical problems in terms of applicability, economy, and infrastructure [7]. This is because the majority of the Bengal basin is extremely sensitive to the downward movement of high-As groundwater due to increasing irrigation withdrawals from deeper wells. Because water produced from deeper aquifers often contains lower As concentrations, obtaining such aquifers in the Bengal Basin might provide a short-term or limited supply of As-safe water for consumption. In contrast, surface water treatment entails the construction of large-scale water purification and distribution systems. On the other hand, we need to consider cost-effective distribution systems. So, The main goal of the study is to create a unit for removing arsenic from water by using used bacterial oxidation and Fe-based removal in a sand filter, which is followed by further removal in a Zero-Valent Iron (ZVI) column, and another focused on bacterial oxidation of As in a plastic filter with subsequent Fe-based removal by a sand bed which is very cost effective.

The study is made up of work done at two separate locations: **Location A and Location B.**

• Location A of this thesis first investigated if the sand filters were able to effectively host the bacterial oxidation of the inflowing As (III). The oxidizing bacteria will grow on the surface of the sand grains. Subsequently, the sand filter effluent would pass through columns containing zero-valent iron. In these iron columns, the capacity to capture the remaining arsenic from the sand effluent by readily oxidized zero-valent iron was tested.

• Location B of this thesis focuses on the capability of plastic to oxidize arsenic (III) into arsenic (V) with the help of bacteria that grow on the plastic surface. Hereafter, the removal capacity of a plastic column combined with a sand filter was investigated to conclude whether this method was efficient or not for the removal of arsenic as well as iron (Fe).
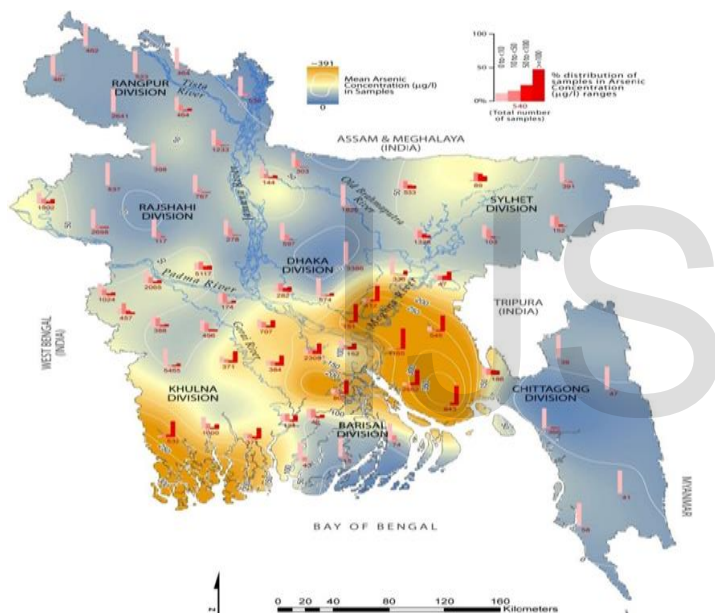

Figure 1: Arsenic (As) concentration in all 64 districts in Bangladesh. [1]

1.2 The stance of WHO

The World Health Organization (WHO) has published guidelines on arsenic in drinking water since 1958. In 1958, WHO published the first version of "International Standards for Drinking Water," which included As in the category of toxic substances and established an allowable concentration of 200 µg/l. In 1963, an updated version of the International Standards for Drinking Water came into being with a stricter concentration of 50 µg/l. Another updated document of International Standards was published in 1971, reaffirming the limit of 50 µg/l and stating that the use of As was not harmful to human health.

2.0 Objectives

The main goal of this research is to create a unit for removing arsenic from water.
The following are the precise goals:
1. To describe the groundwater in an arsenic-affected area.
2. Using locally accessible materials design and build two arsenic removal units.
3. To see how arsenic-oxidizing bacteria affect the RSF system.
4. To assess the effectiveness of the designed arsenic removal unit.

2.1 Study area

The study region of the work is done in Darusha, a village located 16.2 kilometers north-west of RUET, Rajshahi. The arsenic crisis has nearly wiped out this area. Almost all of the village's tube wells are red-painted, and there is no secure pipe water supply in place.
GPS Location for these households are

Household A - - - - - - - - → | 24.445343 88.550260 |

Household B - - - - - - - - → | 24.445701 88.552534 |

This study is done in two household named as Location A and Location B shown in Figure 2, and Figure 3

Figure 2. Google Map Location

Figure 3. Satellite view of two household

2.2 Instrumental and experimental setup

TABLE 1 Instrumental and experimental setup

Title	Location A	Location B
Experimental setup	Sand-Iron filtering was used at this site. For the oxidation procedure, the water was filtered through a sand filter and subsequently through a zero valent iron filter column.	At location B the setup was **Plastic- Sand** filtration. Where the water initially passed through a plastic (also known as filter bio-career) columnfilter and then it was passed through a sand column filter.
Location A-Sand column Location B- plastic column	To keep the water level in the columns at a constant level, three columns have been positioned at the bottom, top, and center of a water filter. To keep water levels maintained, an overflow pipe is located in the center of the columns. This will eventually aid in height optimization by providing insight into the oxidation rate throughout the filter bed heights.	A PVC tube with a height of 180 cm and a diameter of 15 centimeters makes up the plastic column. Three outlets are fitted within this PVC tube to tab water from the plastic filter bed. With the help of overflow pipes, the minimum supernatant water level in the plastic column will be set at a maximum of 20 centimeters.
Location A-Iron column Location B- Sand column	The quick sand filter (ZVI) is made up of a sequence of metal sheets, each measuring 24 cm in diameter and 4 cm in height. The ZVI fills these columns up to 12cm and features a filter and regulating tab on either end.	A PVC tube with a height of 180 cm and a diameter of 15 centimeters makes up the plastic column. Three outlets are fitted within this PVC tube to tab water from the plastic filter bed. With the help of overflow pipes, the minimum supernatant water level in the plastic column will be set at a maximum of 20 centimeters.
Aeration	Manganous and ferrous ions in the sand column of a sand bed were oxidized using water from an underground tank. This oxidation step's major goal was to partly oxidize arsenite (as-III) to arsenate (As-V) and manganese ions.The water fall was about 30cm high, and because the flow velocity was kept constant, air was exposed to air in the way to the sand bed.	In the way to plastics in the column from the tank's exit, water from an underground tank has been exposed to air. This oxidation step's major goal was to partly oxidize arsenite (As-III), manganous, and ferrous ions. The effluent is then fed into the sand column as an influent after completion of aeration and filtration in the plastic column.
Biological oxidation As(III)	Inside the sand filter, an oxidation zone is formed around the sand grains. According to (Gude, Rietveld, & Halem, 2017), a prokaryotic cell known as 16s rRNA was discovered within a fast sand filter that has recently been dubbed arsenic oxidizing bacterium (AsOB). Oxidation is caused by the proliferation of this bacterium or microbial population. Because the column was anoxic, bacterial growth was not feasible within the zero valent iron (ZVI) column [8].	Microbial communities form on the surface of sand grains, according to a study (Gude, Rietveld, & Halem, 2017).It was hypothesized that if we used a material with a larger surface area, the bacterial community would expand faster. Some plastic chips, as shown in Figure 3.9, are employed as filtering material in the plastic filter column based on this idea.
Adsorption by Hydrogen Ferric Oxide(HFO)	Oxidation of Fe (II) by atmospheric oxygen can simultaneously enhance the oxidation of As (III) to better absorbable As (V). Co-precipitation occurs through oxidation of Fe(II) with dissolved O_2, and adsorption on hydrous ferric oxide (HFO), iron oxide coated sand, or Zero-valent iron. The oxidation state of As is crucial for As removal as its affinities to HFO differ by a factor of 100. The relevant reactions can be summarized as follows: (1) $Fe(0) + 1/2O_2 + 2H_2O \rightarrow Fe(II) + H_2O + 2OH^-$ (2) $Fe(II) + 1/4O_2 + H_2O - (RI) \rightarrow Fe(III) + 1/2H_2O + OH^-$ (3) $As(III) + RI \rightarrow As(V)$ (4) $Fe(III) + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$	When raw water passes through these plastic chips, the As (III) is first oxidized by bacteria (AsOB), and subsequently the As (III) is oxidized with HFO via the adsorption process.

2.3 Materials

TABLE 2 materials

LOCATION A	LOCATION B
1. A 1HP pump 2. One overhead water tank (300L) 3. Three Rapid Sand Filters 4. Three Iron Columns 5. Connector tubes and 6. Backwashing materials.	1. A 1HP pump 2. One overhead water tank (300L) 3. Two Plastic filled columns 4. Two sand filled columns 5. Connector tubes and 6. Backwashing materials

2.4 Methodology

2.4.0 As removal process at location A

Raw groundwater was extracted and filled the tank with some flexible tube; the water was supplied from the tank to sand filters and Iron Columns. Sand filter was built with PVC pipe which has a dia of 15cm and a height of 150cm and the Iron Column was half filled with zero-valent iron. In order to have a secure and dependable result and experiment, we used these three filters so that we can check if the result was same in the filters or not.
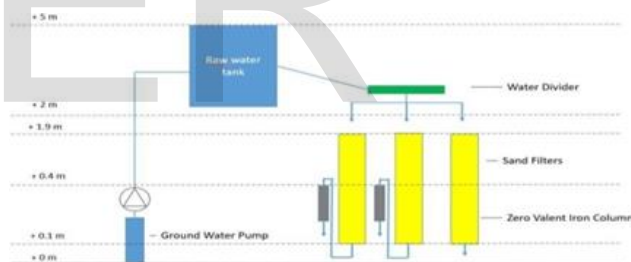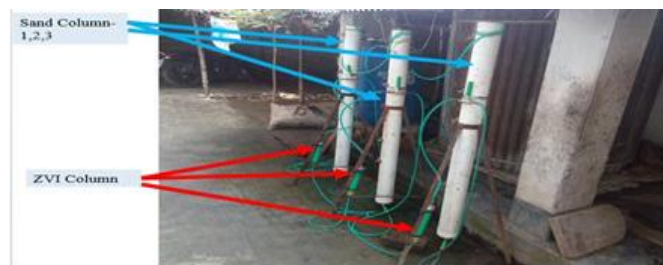

Figure-4. As removal process at location A

Figure-5 Filters at location A

2.4.1 As removal process at location B

The pump is connected to the tube-well at site "B" to draw subsurface raw water. The water is then kept in a roof-mounted 300-liter water tank. The filtering system receives water from this tank. Water is first sent to the plastic-filled

column, and then the effluent water is delivered to the sand column after passing through the plastics. The aeration was increased in this setup because the water falls on the plastic column from a height of 20cm above the plastic bed and then passes through the plastics before falling on the sand bed in the sand column. As a result, there was a greater possibility for the water to reach the air and get aerated. For the oxidation of water at the top level of the filter bed, varied amounts of supernatant water level were preserved in both the sand and plastic columns.
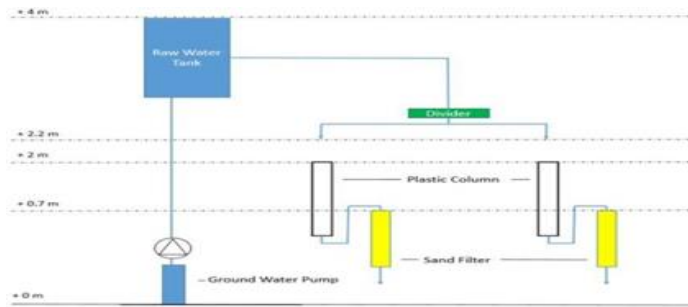
Figure-6. As removal process at location B

Figure-7. Column set up at location B

3.0 Result

3.1 Location A

TABLE 3 Averaged results of water quality of location "A

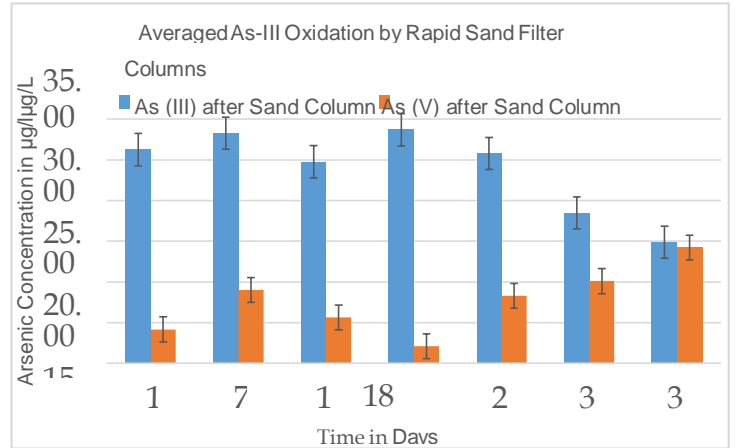| As (Total)	57.0 µg/l
As(III)	57.0 µg/l
As(V)	0.00 µg/l
Fe	4271 µg/l
Dissolved Oxygen	0.24 mµg/l
pH	7.03
Oxygen Reduction Potential	-96.95 mV
Electric Conductivity	800.35 µS/cm

Figure 7. Arsenic oxidation by Rapid sand filter

Figure 7 shows HFO flocs are adsorbed with As (V), which are retained in the sand filter. There is a modest drop in As (III) concentration from day 1 to day 39. During this time, the overall As concentration drops from 58 to 29 µg/l. During this time, steps were made to prevent rapid blockage and a spike in DO.

Figure 8 Overview of [As (III)] & [As (V)] of column A1, A-2 & A-3

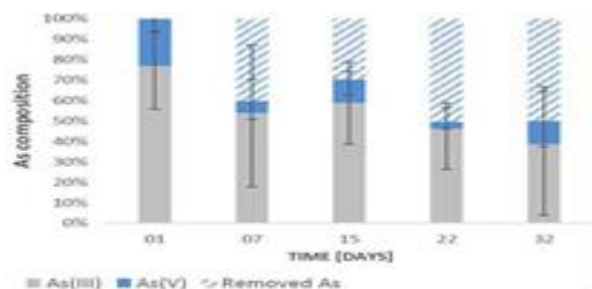### Removal of Fe by the rapid sand filters

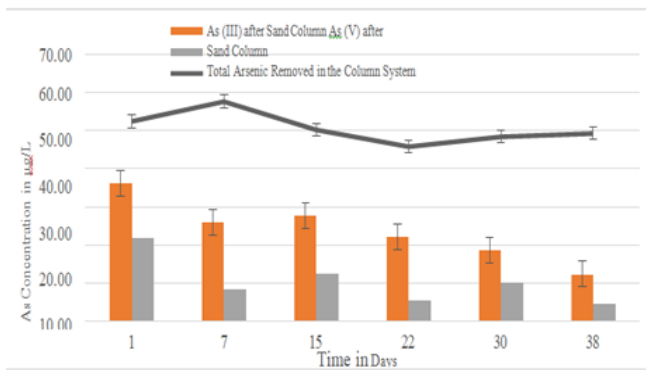Figure 9. Average removed [As], [As-III] & [As-V]

Figure 10. Average removed [As-III], removed [As-V] & Removal rate

Figure 10 show on day 32, 86 percent of Column A1 was removed. Up until day 22, columns A2 and A3 indicate the same removal progress as column A1. This emphasizes the relevance of As oxidation in the elimination process. On day 7, the removed As concentration peaked at 56.6 µg/l. At this location, this is approximately the same as raw water As concentration. Although As (III) adsorption by HFO occurs, it is clear that the rate of As removal is strongly dependent on the rate of As removal (V).

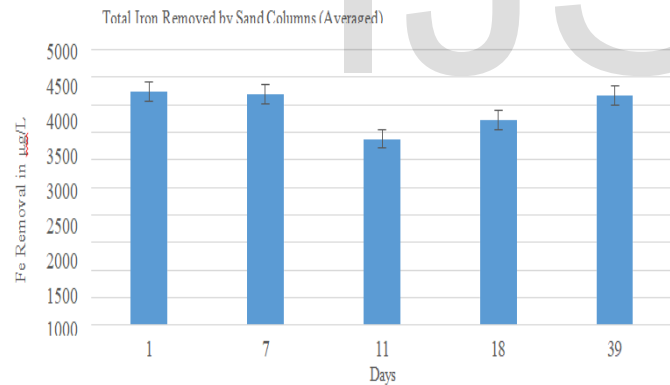## Removal of Fe by the rapid sand filters

Figure 11. Total iron (Fe) removed in sand columns

Figure 11 shows the removal of Fe from the atmosphere over time has been shown to be dependent on the oxidation and removal of As, as well as the concentration of Fe in the atmosphere. It can be observed that on average the removal of Fe is increasing over time, except for day 7 and 11, when Fe levels decrease due to anaerobic conditions in column.
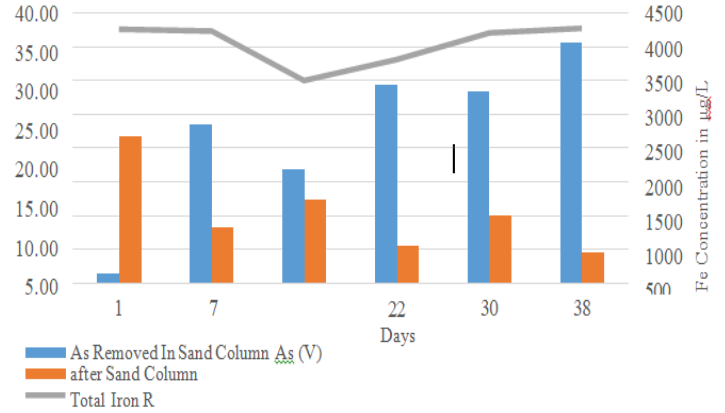

Figure 12. As Removed, As (V) & Total iron removed

Figure 12 shows, When Fe (II) oxidizes to Fe (III), HFO is produced, which adsorbs (oxidized) As. The columns were overflowing by day 22 to 30, with no removal of As and low removal of Fe. Fe removal rises from day 15 to day 30, whereas As removal increases from 43.2 to 49.2 µg/l, a total removal of 86 percent, and the As (V) concentration increases from 0 to 6 µg/l. Only 6 µg/l of As was removed, whereas the quantity of residual HFO rose by 1312 µg/l. Both As and Fe levels increased after backwashing on day 15. This might imply that the organism is transitioning from a reducing to an oxidizing state as a result of the anaerobic circumstances. This resulted in an 85 percent elimination of As, which can only be accomplished by the oxidation of As.

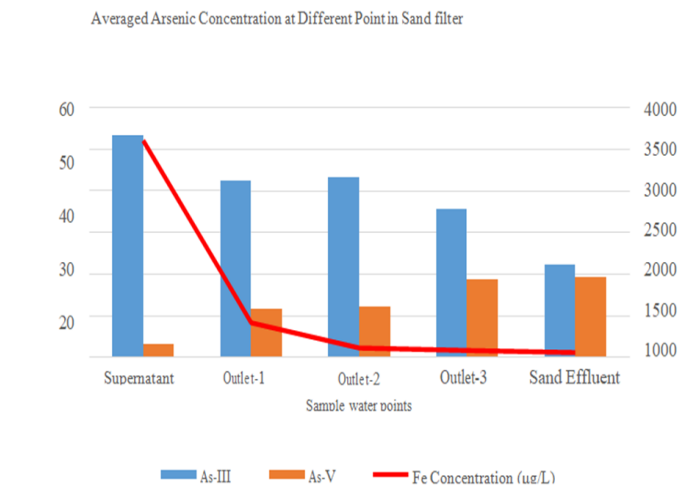## Oxidation and removal of as and Fe over the height of the sand filter bed

Figure 13. The removal of As and Fe over the height of column

Figure 13 depicts the concentration variations throughout the height of the columns in weeks 2 and 3. When As is removed from the equation, the Fe concentration drops. Due to adsorption by the newly formed HFO flocs both As (III) and As (V) decrease.

There is still a minor removal of Fe from stopper1 to stopper 2, but the removal of As is considerable. Under aerobic circumstances with a reduced supernatant water level, graph 5 illustrates the Fe, As (III), and As (V) concentrations across the height of column A3. It can be observed that on the upper layer, fewer HFO flocs occur, resulting in less removal. The oxidizing trend progressively resumes from stopper 3 to the effluent tab as seen in Figure13

Removal and oxidation of as by the zvi columns

The elimination rate of ZVI columns varies between 60 and 75 percent on average. Between column 1 and column 2, the removal rate differs somewhat. This might imply that the removal is dependent on the As concentrations in the quick sand filter effluent. The adsorption of As (III) onto HFO flocs is highly likely to play a substantial part in the overall removal of As. The As will be absorbed more efficiently by the HFO in a shorter reaction period when the As (V) concentration is larger. When the As (V): As (III) ratio is high, the elimination rate is likewise high, according to the average results.
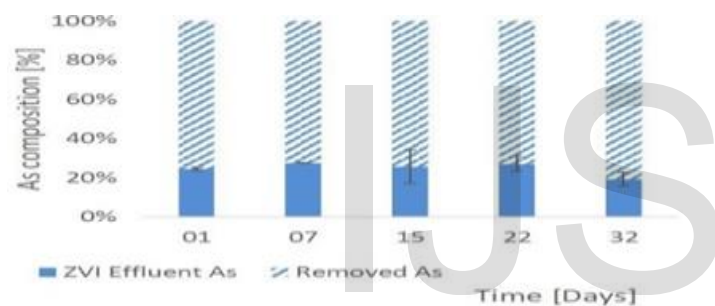

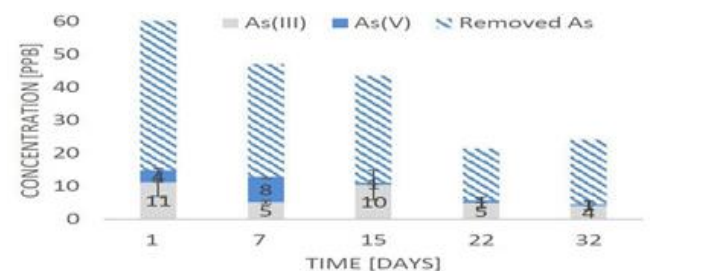Figure 14. Removal rate of As at Figure

Figure 15. Averaged removed As, As(V):As(III) ratio

This relationship isn't obvious on day 32 because the ZVI columns were back-washed, resulting in an incorrect measurement. When Graph 15 is compared to Graph 14, it can be observed that when the inflowing total As concentration is high and the influent's As (V): As (III) ratio is low; there is more As (V) in the ZVI column effluent. It suggests that oxidation occurred, but that there was inadequate contact time between the oxidized As and the HFO flocs as a result of the low As (V): As (III) ratio. Because of the huge adsorption area, removed As was identified by As (III) adsorption in the ZVI column.
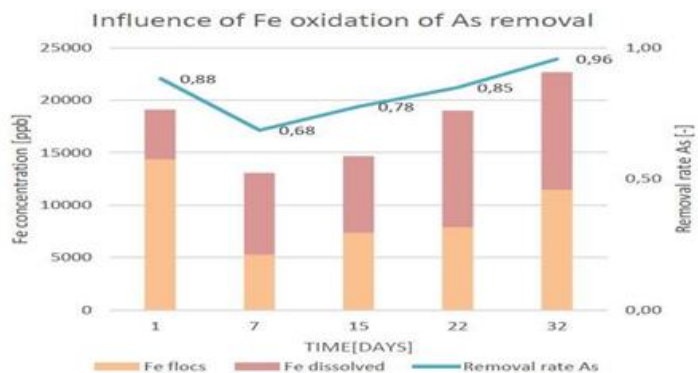

Figure 16. Fe (floc) & Fe (dissolved) concentration vs As removal rate of ZVI

Figure 16: ZVI As removal rate against Fe (floc) & Fe (dissolved) concentrations. The concentration of HFO flocs indicates that ZVI oxidizes into Fe (II) and then maybe into Fe (III). Because more adsorption sites are produced as a result of increased oxidation, larger removal rates can be detected.
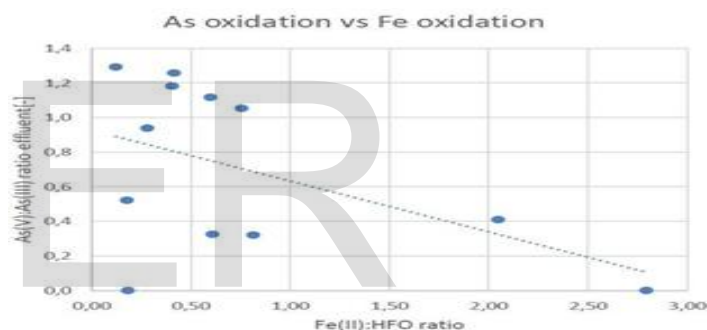

Figure 17. Ratio As (V): As (III) vs Fe (II): HFO ratio of ZVI colum

The Fe (II): HFO ratio in the effluent of the ZVI columns falls as the As (V): As (III) ratio rises. When there is more As (V) in the effluent than As (III), there are also more HFO flocs in the effluent. It reveals that the ZVI oxidizes to Fe (II) and then to Fe (III), whereas As (V) is produced in the process. Poor contact time, on the other hand, leads to low As (V) adsorption and elimination. A high Fe (II) concentration, on the other hand, is associated with a high As (III) concentration, signifying that little oxidation has occurred.

TABLE 4 -Oxidation rate with aerobic conditions vs anaerobic conditions

Day	DO [µg/l]	Initial As[µg/l]	∆As [µg/l]	∆Fe [µg/l]	As(V)/Fe [µg]	HFO [µg/l]	Re-tained As(V) [µg/l]	As(V)[µg/l]	Total As(V)[µg/l]
32	0.9	57	15.4	2.3	5.1	1.3	11.7	6.6	18.3
42	3.2	57	34.4	2.1	14.8	1.6	31	23	54

TABLE 5- Influence of Continuous (C) and Discontinuous (D) flow on As and Fe concentrations

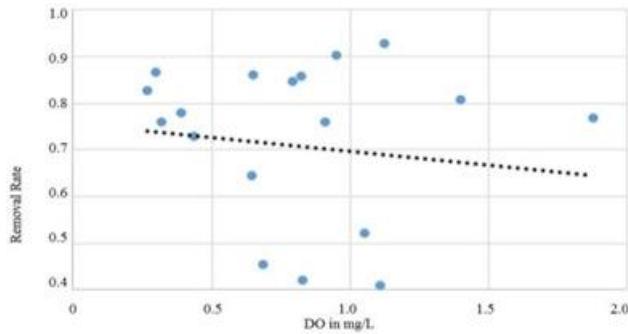| Column	Day	Flow	As(III) [μg/l]	As(V) [μg/l]	Total As removed [μμg/l]	Fe removed [μg/l]	As(III) removed [μg/l]	Total As(V) [μg/l]
A1	18	C	14.9	0.6	42.2	3365	5.2	37.6
A1	21	D	9.4	37.4	10.2	3174	4.9	42.7
A2	18	C	33.1	0	23.9	3320	5.2	18.7
A2	21	D	9.6	43.3	4.1	2298	3.6	43.8

Figure 18. DO vs Removal rate of As of ZVI

The Dissolution of Organic Matter (DO) in the ZVI column of the HFO flocs has been shown to have no effect on the removal rate of As (III) from the effluent. This means that anaerobic circumstances do not affect the performance of the Zvi column. The relationship between DO and Z VI column removal rate is seen in graph 18, which shows that the removal rates of both are unaffected by the DO.

3.2 Location B

Table 6 Averaged results of water quality of location "B

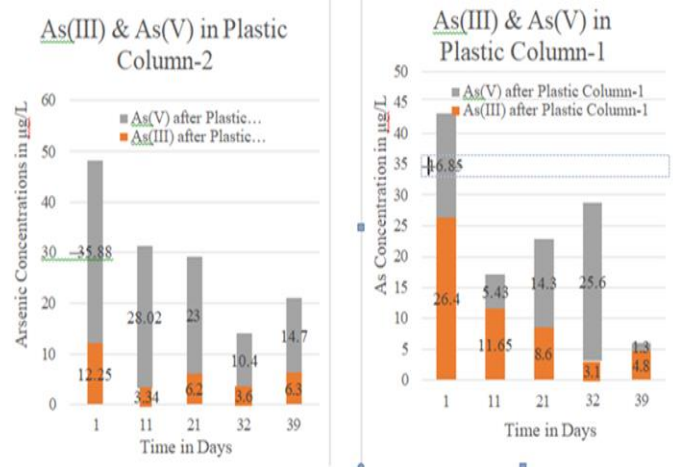| As (Total)	47.8 μg/l
As(III)	47.8 μg/l
As(V)	0.00 μg/l
Fe	6671 μg/l
Dissolved Oxygen	0.1 mμg/l
pH	7.03
Oxygen Reduction Potential	-59.16 mV
Electric Conductivity	706.41 μS/cm
Temperature	26°C

Figure 19. As Oxidation in Plastic Column1 and 2

Figure 19 shows In groundwater, there is a high concentration of arsenic and a high concentration of iron. The presence of these elements demonstrates that ground water is unfit for human consumption and irrigation. Other water quality metrics indicate that the water is drinkable at a modest level. The amount of dissolved oxygen in the groundwater was excellent. The electric conductivity of water is a measure of its salinity. The pH was slightly higher than 7, which is good for drinking and other tasks.

Oxidation in plastic column

For ease of analysis, the average of these two columns was used, as shown in Figure 20. The difference between retained As and As was retained As (V) (III). The total soluble As (III) concentration declines with time, as shown in graph 20, dropping from 45 μg/lto 6 μg/l after two weeks. The overall As (III) concentration declines from 100% to 21% in percentage terms, indicating that oxidation is taking place in the plastic column.
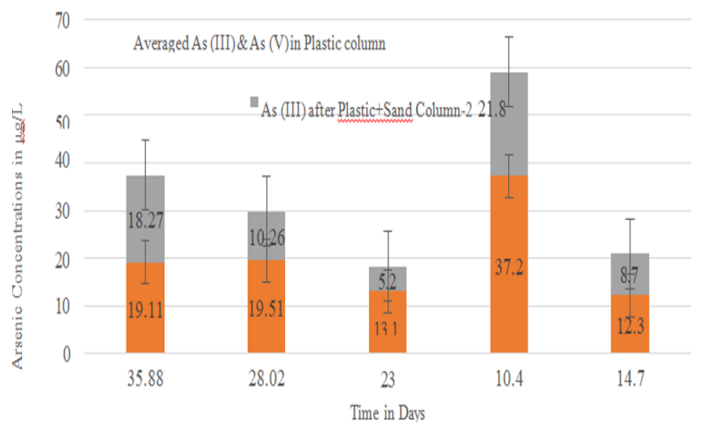

Figure 20. As (III) and As (V) concentrations formed in plastic column (retained and effluent)

Figure 21 shows Fe removal in the plastic filter is accompanied by a drop in Fe content. The rate of Fe elimination does not remain con-

stant over time and reaches a limit. The adsorption capacity of the plastic cylinders explains this maximum. This diagram shows how HFO is attached to the cylinders. When looking at the average graph, one can observe that Fe has risen in recent days. HFO flocs build up in the plastic column, and if the flow rate is changed slightly, the flocs may detach and end up in the filter effluent. As a result, the Fe concentration rises, and the As linked to the HFO causes the Fe Fe concentration to rise to a level greater than that of raw water at the time. This explains the rise in Fe from day 5 to day 14. Adsorption of As (V) or As (III) by HFO that detaches from the plastic cylinders results in significant As elimination.

Figure 21. As and Fe concentrations of effluent plastic filter.

Figure 22. Composition of removed As in plastic column.

Removal in sand column

Figure 23 Averaged As composition and Fe concentrations of sand effluent.

Removal in sand column HFO adsorbs As (III) ions, which are then filtered out of the water. After two weeks, an 80 percent clearance rate is obtained, leaving 5% of the As (V) in the effluent unaffected. While the soluble As (III) concentration swings about 20 µg/l throughout the filter, the adsorbed As concentration decreases dramatically along with the Fe concentration. The mean absolute As and Fe concentrations in the two sand columns are shown in Figure 23. It clearly reveals that when Fe is filtered out, adsorbed As is also filtered out.

This means that HFO adsorbs the majority of the As (V) and a lesser portion of the As (III) ions, which are then filtered out of the water. After two weeks, an 80 percent clearance rate is obtained, leaving 5% of the As (V) in the effluent unaffected. With a larger Fe concentration, both As (V) and adsorbed As (III) concentrations rise, demonstrating that when Fe is filtered out, adsorbed As is filtered out as well.

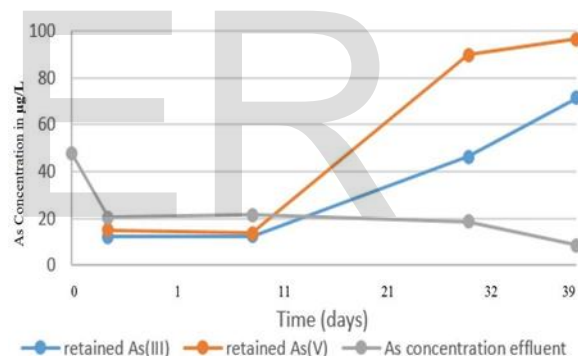## As (iii) versus as (v) removal over total filter

Figure 24. concentration of effluent & removal fracti ons As (III) and As (V).

Figure 24 is used to explore the role of As oxidation in the elimination of As. It depicts the effluent's overall As concentration as well as the As (III) and As (IV) removal percentages (V). As can be seen, the inclusion of As (V) results in a minimum increase of 50% to the overall removal. This extra removal increases to 100% later in the process, implying that two times more As (V) is eliminated than As (V) (III). This suggests that oxidation of As (III) accelerates As removal from groundwater.
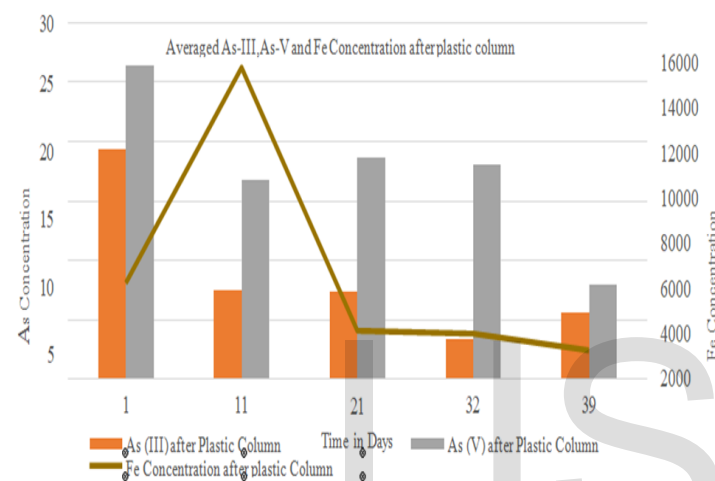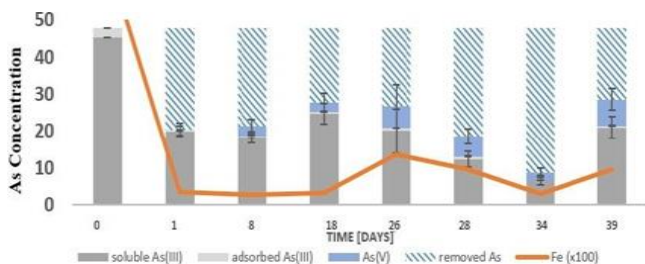
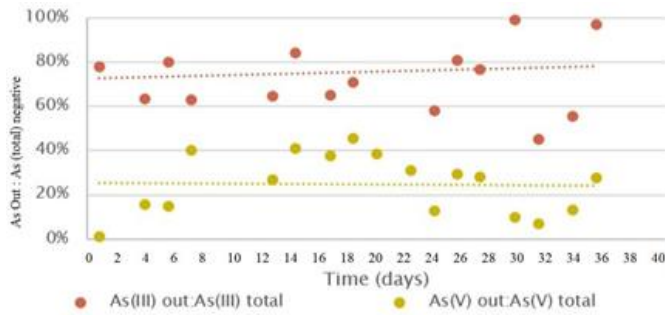Figure 25. As-X out: As-X total ratio over the total filter

Figure 25 shows a smaller ratio implies that the As ion may be extracted from water more easily by adsorption on HFO. The linear trend line of the As (V) ratio is approximately 25%, whereas that of the As (III) ratio is around 75%. When compared to As (V), this is around a factor of three lower (III). As (V) can be considered to be three times as easy to remove as As (III).

As adsorption by HFO

TABLE 7 Fraction of total As that is adsorbed by HFO

Day	As[µµg/l]	Adsorbed As effluent [µµg/l]	Percentage adsorbed [%]
32	21	11	53%
42	27	13	50%
44	44	28	60%

Table 7 shows the adsorption of As (V) by HFO was measured by filtering the samples of the effluent of the plastic columns with a 0.45 µm filter and test them on As concentration. The filter is able to filter out the HFO from the samples and the attached As ions with them. This experiment shows to what extend the As ions attach themselves to HFO in a rapid flow filter.
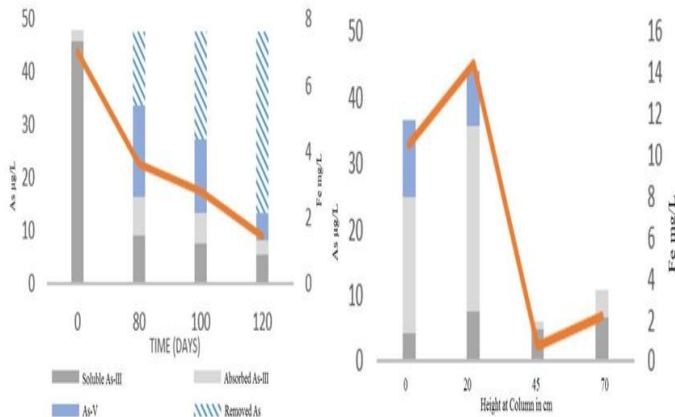

Figure 26. As and Fe concentrations over height plastic (A) and sand (B) filter.

Operational challenges in anaerobic condition

Figure 27 shows, The As/Fe removal gradient indicates how

much As is adsorption by Fe and provides information on the oxidation rate. With rising DO, there is a definite upward trend, indicating that increased O2 concentrations result in higher As (V) concentrations and therefore more As removal. Aside from oxidation, a greater DO causes more removal in the plastic filter, while the changes are minor. To investigate the effect of O_2 in the system, two days with high and low O2 concentrations were chosen.
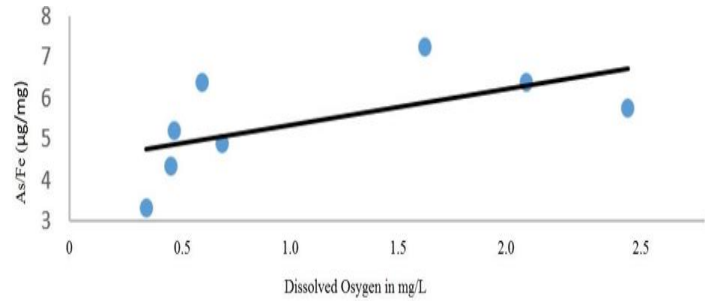

Figure 27: As/Fe over plastic filter versus DO of effluent

Table 8: Oxidation rate of 2 effluents of plastic column with high and low DO Sand column

Day	DO [µg/l]	Initial As[µg/l]	∆As[µg/l]	∆Fe [µg/l]	As(V)/Fe[µg/mg]	HFO[mµg/l]	Retaind As(V)[µg/l]	As(V) [µg/l]	Total As(V)µg/l
32	1.8	48	19	2987	4.45	3.5	13	16	29
42	0.6	48	14	2831	2.95	3.5	8	10	18

Following that, the adsorbed As (V) in the sand column should be removed. On day 32, the As concentration is 11 µg/l, whereas on day 42, it is 14 µg/l. Taking into consideration the adsorbed As (III) concentrations (8.5 and 7.6 µg/l), the estimated values for both situations fit well with the observed data, with a little variance in both. The oxidation As and Fe are not important in this column since sand is only used to filter the HFO with adsorbed As generated in the plastic column. As a result, O2 concentrations have little impact on this column.

4.0 Discontinuous flow

The effects of discontinuous flow were investigated by removing one of the total filters from service. The results from the last time the column was used were compared to the results from the first time the column was used. To test the effect of no running water through the system, samples were obtained immediately after the instant when water began to flow down the column again. The filter had been out of commission for two days in total. Table 9 shows the As, eliminated As, and Fe concentrations in the effluent of both columns.

TABLE 9 As composition of plastic and sand effluent and removal after flow stop

	Plastic Column				Sand Column		
Day	As	∆As	Fe	∆Fe	As	∆As	Fe
37	21	27	1494	5177	17	4	1548
39	6	42	151	6520	8	0	878

5.0 Discussion and Conclusion

By answering the question, whether a filter can be developed based on bacterial oxidation and Fe based As removal that is easily applicable and meets the WHO requirements ([As] < 10 µg/l). This thesis works on different methods (Location A and Location B) with different As concentrations (57 and 48 µg/l) for developing an easily applicable and efficient As removing a filter by experiments in rural Bangladesh.

The oxidation of As into As(V) improved day by day, which was seen in the rapidly decreasing As(III) concentrations. The top layers (the top 50 cm) of the filter bed remove the majority of the As and Fe. There is a clear relation between Fe removal and As removal. Fe oxidizes, HFO flocs are formed, which are retained in the filter bed and are able to adsorb mainly As(V). The oxidation of As however, develops from the bottom layers of the filter bed. Lowering the supernatant water level allows the HFO flocs to settle better over the height of the filter, resulting in more contact time with As(V) and As removal. Oxidation of As also increased with the lowering of the inflow velocity of the column. The oxidation and removal by the rapid sand filters, however, are very sensitive to anaerobic conditions and discontinuous flow. It can be seen that when either of the situations occurs, the removal of As drops. Consequently, the ZVI columns have been shown to be able to reach As removal rates of up to 90% within a short reaction time. ZVI can oxidize inflowing As (III) via Fenton reactions, which involve the oxidation of Fe. As a result of the large total surface area for adsorption, both As and As (V) can be effectively removed through adsorption onto HFO flocs. it can be seen that the more Fe is added to the effluent of the ZVI columns, the more As is removed, implying that there is a high adsorption capacity. It's also interesting that the removal performance of the ZVI columns isn't affected by anaerobic conditions or discontinuous flow.

Location B results show that, despite the fact that As (V) adsorption was far more efficient than As (III) adsorption onto HFO, As (III) was still removed in this manner. As (III): HFO removal rate was found to be around 1.95 g/mg, which removed As (III) concentrations of 30 g/l when possible. Aside from As (III) removal, biotic oxidation is taking place in a plastic filter. As is oxidized within a few days of implementation, resulting in a faster As and HFO ratio removal rate than As (III).The importance of As (III) oxidation was best seen in the percentage of As (V) that was removed compared to the total As(V) concentration formed in the column. In addition to oxi-

dation, As removal was observed in a plastic filter column. The removal was hand in hand with Fe removal, which had a certain upper limit when there was no attachment area left on the plastic cylinders for HFO. Shutting down the system for a while and restarting it resulted in a higher As removal in the plastic filter compared to the situation where a continuous supply of As and O_2 containing groundwater was available, which was possibly due to detached HFO from the cylinders, leaving more contact area for the new HFO with adsorbed As.In the study, day by day, oxidation of As into As (V) improved, as seen by progressively declining As (III) concentrations. There is a definite link between the removal of Fe and the removal of As. The subsequent sand filters are able to filter out the As that was attached to HFO. A high percentage of As removal was achieved (80%). Oxidation in the sand filter was not seen, which was possibly due to the pre-treatment plastic filter. All bacteria were already on the plastic surface before entering the sand. Fe removal in the sand filter occurred only in the top layer up to 45 cm, which indicates that HFO is rapidly filtered out of the water.

Considering everything, we may conclude that the removed As and Fe ratios increased with a higher O_2 concentration in the effluent of the plastic filter. The same holds for the absolute removal of As. With a higher O_2 concentration, the plastic filter is removed more As. The oxidation was found to be lower in the case of a low O_2 concentration, and the oxidized As was already filtered out in the plastic filter.

6.0 Ackowledgement

7.0 References

[1] Chakraborti, D., Rahman, M., & Das, M. Status of groundwater arsenic contamination in Bangladesh: A 14-year study report. Water Res. 2010; Nov; 44(19):5789-802.

[2] WHO Guidelines for Drinking Water Quality; 2004 and 2011.

[3] Maria Argos 1 , Tara Kalra, Paul J Rathouz, Yu Chen, Brandon Pierce, Faruque Parvez, Tariqul Is-lam, Alauddin Ahmed, Muhammad Rakibuz-Zaman,

Rabiul Hasan, Golam Sarwar, Vesna Slavkovich, Alexander van Geen, Joseph Graziano, Habibul Ahsan. Arsenic exposure from drinking water, and all-cause and chronic-disease mortalities in Bangladesh (HEALS): A prospective cohort study; 2010 Jul 24; Lancet 376(9737):252-8

[4] BGS and DPHE. Arsenic contamination of groundwater in Bangladesh. Kinniburgh, D G and Smedley, P L (Editors). British Geological Survey Technical Report; 2001 WC/00/19.

[5] S. Nigam, K. Gopal, P. S. VankarBiosorption of arsenic in drinking water by submerged plant: Hydrilla verticilata. Environmental Science and Pollution Research. 2013; DOI: 10.1007/s11356-012-1342-x Corpus ID: 5080094.

[6] A.K. De, Environmental chemistry 8th eddition. New Delhi: New Age International; 2008.

[7] Ahmed, M. F. An Overview of arsenic removal technologies in Bangladesh and India. ITN. 2001; 251-269.

[8] Gude, J., Rietveld, L., & Halem, D. v. (2017). Biological As (III) oxidation in rapid sand filters. Journal of Water Process Engineering,2018;21:107–115. doi:https://doi.org/10.1016/j.jwpe.2017.12.003.

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