Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering

doi:10.3233/978-1-61499-656-9-2379

Performance of arsenic removal unit installed in Bangladesh and cement solidification of arsenic sludge from the unit

Effect d'enlèvement de l'arsenic par l'instrument installé en Bangladesh et de solidification du ciment dans la boue arsénique de l'appareil

M.M. Hussainuzzaman & H. Yokota
University of Miyazaki, Miyazaki, Japan

ABSTRACT

Most of the drinking water is supplied from groundwater in Bangladesh, where the arsenic polluted groundwater has been found in 60 districts out of a total of 64 districts**.** It is estimated that about 40 million people are currently exposed to the risk of arsenic poisoning. We have been making detailed surveys and experiments with AAN (Asia Arsenic Network) in model villages in Jessore district from March 1997 to get the arsenic pollution mechanism and arsenic-free water. We have developed Pond Sand Filter (PSF), which makes drinking water from arsenic free pond water, in Bangladesh since 1999. The pond water, however, dries up at the end of dry season and the use of PSF becomes difficult. In order to utilize PSF all the year round, we attempted to put the arsenic contaminated well water into PSF. After the fundamental tests about the arsenic removal performance of gravel tanks (2000 ~2001), we installed the gravel and sand tanks, which had the same size and structure as PSF, at Marua village in December 2002. We named it as GSF (Gravel Sand Filter). The arsenic removal performance was tested from 19 December 2002 to 4 January 2003 to obtain the performance data for the initial stage of the GSF operation. And, we have now the one year performance data for the arsenic removal of GSF.

This paper first shows the arsenic removal performance of GSF. It was seen that GSF could remove arsenic very well. The arsenic concentration of groundwater decreased from 0.25mg/L to 0.01~0.05mg /L after the gravel tanks and less than 0.01mg/L after the sand tank. The co-precipitation of arsenic with ferric iron is discussed with the effect of DO, As and Fe concentration values in the tanks. The one year performance data shows that PSF can be operated through a year by using pond water in rainy season and groundwater in dry season with a periodical maintenance of GSF like drainage from the gravel tank and cut of the surface sand of sand tank. Besides, we installed a smaller GSF, used exclusively for the removal of arsenic.

Secondly, The paper shows and discusses the leaching tests of the ferric-arsenic sludge from GSF and the solidified sludge with cement. The leaching ratio of arsenic to that in the sludge were 5-9% for the former and less than 5 % for the later. This means the co-precipitation of arsenic with ferric iron forms a strong chemical bond and the treatment of the sludge may not be difficult.

RÉSUMÉ

La plupart des eaux au Bangladesh provenant des sources souterraines est atteinte d'arsenicisme (60 sur 64 arrondissements ou districts). On estime qu' environ 40 millions d'habitants risqueraient l'arsenicisme. Depuis Mars 1997, avec le réseau Arsenic Asiatique (AAN), nous avons effectué des enquêtes détaillées et des expériences dans des villages. Depuis 1999, nous avons développé le système de filtrage d'eau des lacs pour avoir de l'eau usuelle. Cependant en saison sèche, les lacs étant épuisés, le procédé PSF semble très difficile. Pour un Procédé PSF fréquent, nous avons essayé de conduire de l'eau dans un bassin de filtrage PSF. Après plusieurs expériences fondamentales sur l'efficacité du filtrage de l'eau arsenicale des bassins de sable et de cailloux (2000-2001), nous avons installé des bassins de sable et de cailloux qui ont la même dimension et la même construction que les bassins PSF dans le village Marue en Décembre 2002. Nous les appelons des bassins de filtrage GSF. Les expériences effectuées du 19 Décembre 2002 au 4 Janvier 2003 vise à obtenir des informations dans les premières étapes de fonctionnement des bassins GSF. Actuellement nous avons en main des informations d'un an de fonctionnement du bassin GSF.

Dans cet article, d'abord sera présentée l'efficacité des bassins de filtrage des eaux arsenicales GSF. Les résultats montrent que ces bassins GSF sont très efficaces. La concentration de l'arsenic dans les eaux souterraines est réduite de 0.25 mg/L à 0.01-0.05 mg/L dans les bassins de filtrage de cailloux ou à 0.01 mg/L pour les bassins de fonctionnement montrent qu' il est possible de filtrer de l'eau des lacs en saison de pluie et de l'eau souterraine en saison sèche avec les bassins de filtrage PSF. On pourra aussi construire un bassin plus petit detinè au filtrage de l'eau arsenicale.

1 INTRODUCTION

Arsenic poisoning in the ground water of Bangladesh is the most catastrophic arsenic poisoning in the world. BGS (2001) reported that an estimated 35 million people are exposed to the risk of arsenic in drinking water exceeding concentration of 50 μgL^{-1}. The source of arsenic seems to be geologic in the land, which are basically flood plains and deltaic plain from different river systems. Many researhers suspect that this poisoning is triggered by present era agricultural practice of this region that uses large amount of groundwater and chemical fertilizers. So it is almost impossible to prevent the poisoning by stopping the activities causing it. Therefore it is necessary to come up with technologies introducing alternative sources of safe water and also technologies enabling the use of existing contaminated sources safely.

People of this region were habituated to use dug well, pond and other surface water sources for drinking in past. But as drinking of surface water without proper treatment had posed a serious risk on health, government of Bangladesh, with assistance from UNICEF, had campaigned very strongly for tube wells. It was not easy to convince the rural people switching to the tube wells. But now many of the tube wells are extracting poison (i.e. arsenic). It will put a big question mark on peoples' trust for government decisions if they forbid the people again to drink from tube wells and ask them to get back to the surface water sources. Besides this phenomenon of arsenic contamination in the much campaigned tube wells served as a lesson for the researchers and decision makers about the consequences to adopt a technology without having an environmental impact assessment (EIA).

Many government and non-government organizations are presently working on this issue to provide a solution to this problem. But no single technology could be prescribed for the solution of the problem without having a long-term performance check and without EIA. Before implementing any technology we have to be sure about its sustainability and suitability to the present socio-economic condition of the rural Bangladesh.

2 BACKGROUND

We, the research team from the university of Miyazaki, have been working on arsenic, remediation and its source in Bangladesh since 1997. This team has been working on the origin of arsenic contamination and its remedy in one of the most arsenic affected area, Jessore district, of Bangladesh. Development of Pond Sand Filter (here after referred as PSF) was a remedy to get arsenic free water. Investigation indicated that the PSF is performing well, supplying ample water to the community and removing biological contamination [Yokota et al., 2001]. The only problem was that during dry seasons it could not be operated since the pond water level becomes very low at that period, some ponds even dry. Some of the pond water has some arsenic contamination as they receive discharge from the nearby tube wells containing high arsenic contamination [Yokota et al., 2001] and therefore cannot be used for the PSF operation. Groundwater is the only source of potable water during dry season.

There was a Horizontal Roughing Filter (HRF), developed by the All Indian Institute of Hygiene and Public Health (AIIH&PH), attached to the PSF as a pretreatment unit for SSF. The HRF can work as an alternative process of coagulation-sedimentation. Therefore it was assumed that it can be used for coagulation-sedimentation process to remove arsenic from groundwater of Bangladesh, generally containing very high amount of naturally occurring iron. This vision of the research team paved the way for development of a unit that can treat turbidity and bacteria contaminated pond water as well as arsenic and iron contaminated groundwater simultaneously to resolve the problem encountered with the PSF operation during dry seasons.

Based on the tests performed at laboratory in Miyazaki University and with the PSF, a new unit has been developed, which can treat pond water as well as tube well water. The unit is named as Gravel Sand Filter: GSF. This GSF has been tested as an arsenic removal unit using only arsenic contaminated tube well water for a year. The arsenic removal performance was tested from 19 December 2002 to 4 January 2003 to obtain the performance data for the initial stage of the GSF operation (K. Hamabe et al., 2003). And, we have now the one year performance data for the arsenic removal of GSF.

Besides, tests have also been performed to check out arsenic leaching characteristics of the sludge that is being discharged from the GSF during periodical maintenance. The sludge has been mixed with cement, and after setting, tests have been performed to check the arsenic leaching characteristics of cement sludge mixture. This test results will serve as the basic data for the future sludge disposal methodology development.

3 THE GRAVEL SAND FILTER

The GSF was constructed in Marua village of Chougacha upazilla at Jessore district in Bangladesh. Figure 1 represents schematic diagram of the GSF. It consists of four basic units i.e. inlet, gravel tanks, sand tank and reservoir. Water flows diagonally bottom to the surface and then diagonally surface to bottom directions through the successive gravel tanks and then flows bottom to surface in the outlet chamber and spills into the SSF (slow sand filter) chamber. Dimensions of the gravel and sand chambers are 1.45m×0.77m×1.10m (L×W×D) and 2.90m×0.77m×0.60m respectively, which is same as that of the medium sized PSF built previously in some villages. The gravel chambers and the outlet have been filled totally with 5 mm gravels except that larger gravels are placed at bottom layers, near the water holes and the drainage pipe to facilitate drainage and easy water flow through them.

In January 2004 we mixed some small (12 mm in diameter, 25 mm in length) cut pieces of PVC pipe with the larger gravels at the bottom layers to increase the void in this part, so that it can hold much sludge (Hussainuzzaman et al. 2004).

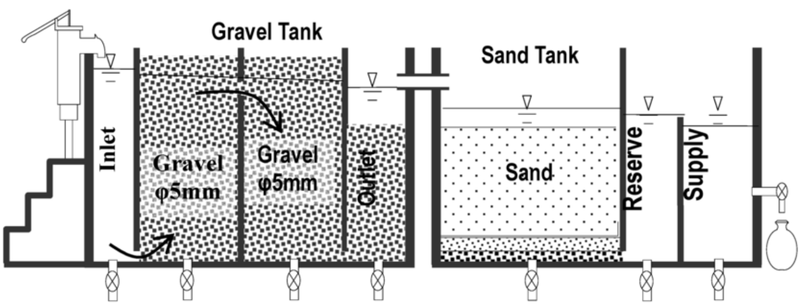
3.1 *Principle of arsenic removal*

When water is being poured into the unit through the inlet, it gets aeration for oxidizing Fe^{+2} and As^{+3} to Fe^{+3} and As^{+5} respectively. Naturally occurring iron in the groundwater (in concentrations of several mg/L) is being utilized to remove arsenic here. Arsenic is being adsorbed on the iron oxide particulates' surface and then those insoluble particulate iron hydroxide undergo coagulation-flocculation process and then being precipitated into the inter-particular spaces of the gravels. Thus arsenic is filtered out with the iron along the gravel tanks, acting as horizontal roughing filter (HRF).

3.2 *Operation and maintenance*

In the process of removing arsenic, this unit produces arsenic rich iron sludge. The sludge is accumulated in the gravel chamber, thus clogging the inter-particular spaces of the gravels, reducing the flow rate with time. Gradually this leads to very low flow through the gravel chamber. This is visible by looking at the water level in the inlet chamber, when a small amount of pumping tends to overflow the inlet chamber.

We successfully have increased the sludge holding capacity of the bottom drainage section of the gravel tank. But it is not enough to hold all the sludge produced with time. So, periodical maintenance of the unit is done by opening the drain valves of the gravel tanks once in every ten days of operation. Those valves are located at the bottom of the chambers of the unit. By this process arsenic rich sludge is washed out and goes to a large underground settling tank through a surface drain. The supernatant water of the surface drain is then flown to a natural pond. We collect samples of the settled sludge once a month



from that settling tank, which is located just beside the GSF.

Majority of the arsenic rich sludge is thus removed in the gravel chambers but some of them flows to the SSF and then mechanically filtered out and accumulate on the sand surface. This results lower flow in the sand filter and eventually decreases the performance (Hussainuzzman et al. 2004). Therefore, the sand surface is maintained by cutting the surface by 1 cm every month.

Besides, the gravels of the gravel chambers are taken out of the chamber and again set into it after being washed thoroughly once in every 3 months.

4 PERFORMANCE OF GSF

Initial performance test was performed just after finishing construction of the unit in December 2002. Another performance test was performed in January 2004, which was the performance test after one year of operation. In both of these performance tests we observed that the arsenic removal performance of the unit is very good, and it brings down the arsenic concentration of the raw water (0.2~0.3 mg/L) below the Bangladesh standard for arsenic in drinking water (0.05 mg/L) effectively.

Besides measuring iron and arsenic by spectrophotometer and field kit respectively, on site measurements of dissolved oxygen (DO), oxidation-reduction potential (ORP), electrical conductivity (EC), pH and temperature of water were done tank (3 points at different depths), two gravel tanks (9 points in each tank, in 3 rows; each row containing pipes of different depth), outlet tank (3 points), storage tank after SSF and supply tap.

Figure 2 shows the initial arsenic removal performance of the GSF. Test results for ferrous iron and DO also showed change pattern indicating the proper changes for arsenic removal in the gravel chambers. The change of ORP along the flow path of the water through the gravel chambers also showed a shifting trend from reducing to oxidizing condition, which confirms the arsenic removal by oxidation-flocculation-co-precipitation process (Hussainuzzaman et al. 2004).

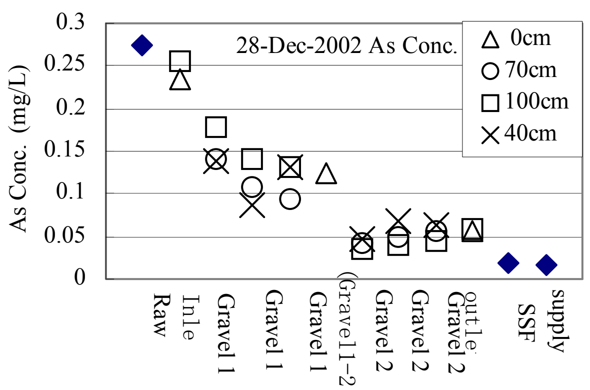


Figure 2. Arsenic removal by GSF during initial performance test.

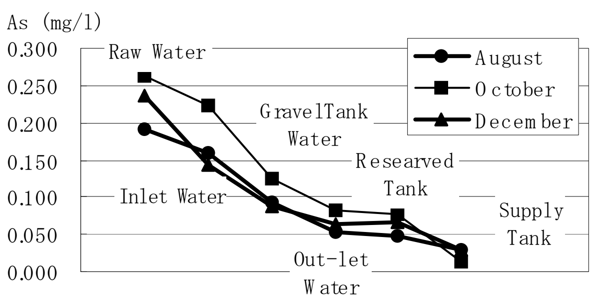


Figure 3. Long term performance monitoring result of GSF

4.1 *Long term monitoring results*

Continuous monitoring is going on to follow the performance of the unit with time. Samples are being collected twice a month from six locations along the flow path of water inside the GSF. Those samples are being checked for arsenic with atomic absorption spectrophotometer (AAS). Some results, from the year 2003, for the long term monitoring are presented in figure 3. There were problems reported by the users of the unit, which have been solved by taking appropriate countermeasures. Those countermeasures include the maintenance program by back-washing out the sludge in every ten days, cleaning the gravels in every three months and cutting the sand surface.

5 CEMENT SOLIDIFICATION OF ARSENIC SLUDGE

We have constructed an underground reservoir for settling of the sludge that is being washed out during the periodical maintenance of the unit. Precipitated arsenic sludge has been collected periodically from the bottom of the sludge reservoir for experiments. Sludge was also collected from another GSF (GSF #2), which has been constructed in the same village, having a slightly modified design, with an aim to work solely as a perfect arsenic removal unit.

We performed the tests to check out the possibility to dispose this sludge directly to nature. In this regard, we have checked the leaching out of arsenic from the sludge following Japanese standard testing procedure. Then we compared that result with the total arsenic, contained in the sludge.

However, we also have tried to stabilize the arsenic sludge using different concentrations of cement (2% and 10%). We allowed it to set for 28 days in room temperature with an initial water solid ratio of 20. After that we crushed the cemented solid and performed the elution test again with those samples. Table 1 and 2 show the results of those tests. Figure 4 also helps us to compare the effect of cement stabilization with no stabilization situation.

5.1 *Results and discussions*

Table 1 shows the total arsenic content in the sludge of GSF#1 and GSF#2. It can be seen that the total arsenic contained in the sludge for GSF#1 was about 60 mg/kg, and for GSF #2 it was about 15 mg/kg. On the other hand in the soil of that locality most of the arsenic is contained in a clay layer, where the highest arsenic concentration is about 20 mg/kg (Tanabe et al., 2001). Therefore, delivering this arsenic bearing iron sludge ($FeAsO_4$) to the surrounding soil may not be a good option of disposal.

Table 1. Arsenic content test result for sludge

Sample ID	Source GSF No.	Collection Date	pH	Arsenic content mg/kg
1-6	GSF#1	28-Jun-2003	6.9	66.47
1-7	GSF#1	27-Jul-2003	6.7	48.16
1-8	GSF#1	30-Aug-2003	6.8	68.49
2-6	GSF#2	28-Jun-2003	7.0	10.19
2-7	GSF#2	27-Jul-2003	7.1	11.80
2-8	GSF#2	30-Aug-2003	6.9	18.97

Table 2. Elution test result for arsenic sludge

Sample ID	Arsenic Leaching							
	Sludge		Sludge + 2% Cement			Sludge + 10% Cement		
	mg/kg	%	pH	mg/kg	%	pH	mg/kg	%
1-6	2.04	3.08	10.5	1.09	1.64	11.8	0.80	1.20
1-7	2.04	4.28	10.7	0.93	1.94	11.8	0.82	1.71
1-8	2.72	3.97	10.7	1.25	1.83	11.8	0.86	1.25
2-6	0.91	8.92	10.9	0.59	5.83	11.8	0.35	3.42
2-7	1.51	12.82	10.8	0.51	4.30	11.9	0.41	3.45
2-8	1.18	6.21	10.9	0.78	4.09	11.8	0.44	2.31

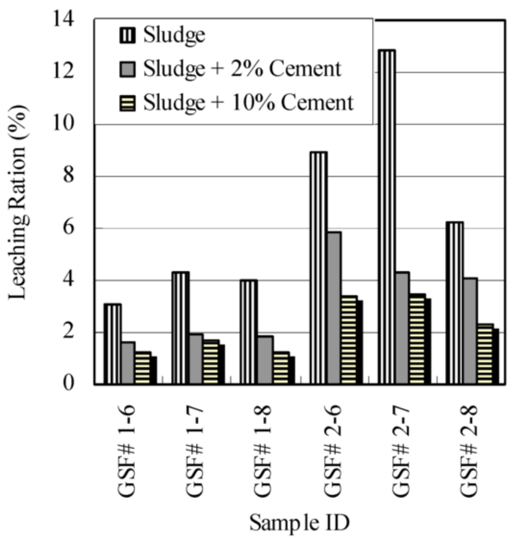


Figure 4. Comparison among arsenic leaching in different conditions

Elution test results for sludge (Table 2) shows that 3.8% to 9.3% of the arsenic leaches out of the sludge. Therefore, 90~95% of the arsenic is confined into the sludge. The leaching figures, ranging from 0.12 mg/L to 0.27 mg/L, meet the criteria for industrial sludge disposal site in Japan but exceed the WHO guideline value for leaching (0.01 mg/L) by a wide margin.

On the other tests the addition of cement led to higher pH to the solution but it is seen that adding cement reduced the leaching over 50% (Table 2 and Figure 4). The decreasing tendency of arsenic leaching with increasing amount of cement (Figure 4) associates higher pH. In this condition calcium (source = Portland cement) arsenate solids may have formed, which are stable under this condition and hence prevent the release of arsenic (Khoe et al., 1997).

6 CONCLUSION

The initial objective of the development of GSF was to solve the low-flow problem encountered by the PSFs during the dry season. Initial testing of GSF clearly shows that, PSF can be run with ground water during dry season supplying arsenic free safe water.

Problem associated with the GSF was disposal option for the arsenic rich sludge produced in this process. But tests show that cement solidification of that sludge eliminates the risk of further pollution of environment with leached arsenic. Besides, the amount of sludge produced by this process is small. So, it would not be impossible for the users to stabilize that sludge after the dry season use of PSF as GSF.

So far the GSF has been run with only one source of groundwater. It performed excellently to accommodate the seasonal variation of the groundwater quality. But groundwater quality also varies spatially. So, we need to test its effectiveness for different compositions of groundwater before suggesting it as a generalized solution for arsenic removal.

Safe ponds for construction of PSF are not always available easily. There are places in Bangladesh where it would be very difficult to find a pond for this purpose as the villagers use those ponds for fish culture. Therefore, we are now trying to improve the unit as an effective, low-cost arsenic removal unit so that it can be operated with minimum maintenance. We are now analyzing the performance data for another one year, which corresponds to some changes and adjustments in the structure of GSF, we made, to improve its performance. We are also planning to improve it, so that it can be utilized for small scale piped water supply system, where it will be operated with a continuous flow of groundwater, in the rural Bangladesh.

ACKNOWLEDGEMENTS

Some data in this paper have been taken from the Masters thesis of three students of the University of Miyazaki, Mr. Kazuki Ueno, Mr. Kazuhide Owaki and Mr. Kazuto Kudo. This research has received financial assistance from the scientific research fellowship grant, Japan. Moreover, AAN (NGO, Asia Arsenic Network) and the Bangladesh Marua village arsenic committee helped us a lot during the course of research. We want to thank all of them for their co-operation.

REFERENCES

British Geological Survey (BGS)*, Arsenic contamination of groundwater in Bangladesh, Vol.1:Summary,* February 2001

H.Yokota, K.Tanabe,et.al, Arsenic Contamination in Groundwater of Samta Village, Bangladesh, *Water Science and Technology, IWA,Vol.46*, No.11-12, pp.375-380,2002.

H.Yokota, M.Sezaki, K.Tanabe and Y.Akiyoshi, et al. Arsenic contamination of ground and pond water and water purification system using pond water in Bangladesh, *Journal of Engineering Geology, 60, Elsevier*, pp.323-331, 2001.

Hussainuzzaman M.M., Setoyama Y., Kataoka D. and Yokota H., Performance and maintenance of arsenic removal unit installed at Bangladesh, In proceedings of ISLT2004, September 1-3, 2004, Bangkok.

Hussainuzzaman M.M., Setoyama Y., Kataoka D. and Yokota H., Arsenic removal performance analysis of the gravel sand filter, In proceedings of Vietnam-Japan joint seminar on geotechnics and geoenviorонment engineering, November 27-28, 2004, Hanoi.

K. Hamabe, K. Tanabe, H.Yokota, et al., Arsenic Contamination of Groundwater and Arsenic-free Water Supply System in Bangladesh, Intern. Symp. on Groundwater Problems related to Geo-Environment, Okayama, Japan, Intern. Workshop on Safe & Sustainable Exploitation of Soil 6 Groundwater Resources in Asia, May, 2003.

Khoe G.H., Zaw, M., and Emett, M.T. : Immobilisation of Arsenic and Stability of the Solid Waste. In: Proceedings WISMUT 97 Workshop 'Water Treatment and Residues Management - Conventional and Innovative Solutions' WISMUT-haus, Kirchoffstrasse ,34-36,Chemnitz,septembe, 24-26, 1997.

Tanabe K., Yokota H., Hironaka H., Tsushima S. and Kubota Y. (2001). *Arsenic pollution of groundwater in Bangladesh*. Applied Organometal Chemistry 2001; 15: 241-251.