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Title of Project:

Integrated Arsenic and Iron Removal from Contaminated Groundwater

File No. DST/TSG/WP/2007/14

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Assam

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4. **Date of Commencement:** 23/4/2008

5. **Planned Date of Completion:** 22/4/2011

6. **Actual Date of Completion:** 22/4/2011

7.(a) Objectives as stated in the project proposal:

The aim of the project was to develop a low-cost and easy to use integrated As-Fe removing process and design systems for domestic and community use. The main objectives of the project were:

- (1) Speciation of As in representative samples of groundwater.
- (2) Modification of the existing Fe-removal process developed earlier by the PI so that it can remove As efficiently.
- (3) Optimization of the method with respect to the As speciation results, Fe content of the groundwater, dissolved oxygen and pH.
- (4) Study of kinetics of oxidation of As(III) to As(V), the role of aeration and Mn-content of the water.
- (5) Study of co-precipitation, adsorption isotherm with varying weights of ash, the nature of binding of As with Fe-oxide, goethite or ferrihydrite and appropriate sludge disposal.
- (6) Design and fabrication of the integrated As-Fe removal systems for domestic and community use.
- (7) To check the usefulness of the units by chemical and bacteriological testing the water before and after treatment and through user trial.
- (8) Testing of as As detection kit provided by the DST vis-a vis analytical and test strip method.

7.(b) Objectives met:

(1) *Speciation of As in representative samples of groundwater:* Yes, the objective has been met. This was done with representative samples from arsenic affected areas of Assam and was found that arsenic is present mainly as arsenite as is reported for other parts of the world. We had not gone for detail speciation because we were interested mainly in the removal of arsenic rather than detailed academic study and the speciation was done by others with samples from elsewhere. The presence of about 80% arsenic as arsenite requires oxidation of the difficult-to-remove arsenite to easy-to-remove arsenate form. In addition to oxidation by natural aeration after withdrawal, we had chosen potassium permanganate (KMnO₄) for oxidizing arsenite to arsenate.

(2) *Modification of the existing Fe-removal process developed earlier by the PI so that it can remove As efficiently:* Yes, the objective has been met very well. This was the main objective of the project. This work has been carried out rigorously. The work can be divided into three parts:

i) Removal of iron by precipitation and filtration using banana ash, carbonate and bicarbonate salts of Na and K, and their 1:1 mixtures,

(ii) Removal of arsenic by precipitation and filtration using banana ash, carbonate and bicarbonate salts of Na and K, and their 1:1 mixtures and

(iii) Removal of arsenic and iron by oxidation-coagulation at controlled pH (Arsiron Nilogon) method.

i) Removal of iron by precipitation and filtration using banana ash, carbonate and bicarbonate salts of Na and K, and their 1:1 mixtures:

Recently, we developed a method of removal of iron by using banana ash which was based on an indigenous practice. The method is easy to use and of low-cost but it is not so easy to adjust the dose of ash to retain the pH of the treated water within the acceptable range for drinking. As the main active component of the ash is K₂CO₃, we thought it to be worthwhile to study the removal of iron using carbonates of K and Na and their mixtures. The study of removal of iron with the bicarbonates of K and Na were also taken up thinking them to be better choice for retaining the pH within 8.5, the maximum limit acceptable for drinking water. The present work involved a laboratory study of effectiveness of banana ash, carbonate and bicarbonate salts of Na and K, also their 1:1 mixtures in removing iron from initial concentration range of 2 to 20 mg/L. The removal has been studied with respect to the quantity of ash/salt required, residence time and the effect on the pH of water. An attempt has also been made to understand the reasons for the differences in the observed performances of the materials through analysis of the reactions in terms of kinetic considerations and characterization of the precipitates of iron using X-ray diffraction (XRD), scanning electron microscopy combined with Energy Dispersive X-ray Spectroscopy (SEM-EDX) and Fourier transform infrared spectroscopy (FTIR).

The performance in precipitating iron was initially studied by mixing varying amounts of the material/salt, alone and as their 1:1 mixtures, with the iron containing water. The precipitates formed in the mixtures were then allowed to settle for ½ to 2 h and filtered subsequently. The bicarbonate salt of K alone has been found to be the most efficient candidate for Fe removal which can remove iron by 99-100% and leaves the pH of the treated water between 7.0 and 7.5,

i.e., well within the acceptable range for drinking water. The effect of varying the concentration of KHCO_3 in the range of 10-500 mg/L, on the removal of iron from different initial concentration from 2-20 mg/L in distilled water as well as prefabricated groundwater has been examined. The quantity of KHCO_3 required to bring down Fe from 2 mg/L and 20 mg/L to 0.3 mg/L, the WHO guideline value for drinking water have been found to be only 10 mg/L and 50 mg/L, respectively. The precipitate of iron was characterized by X-ray diffraction (XRD), scanning electron microscopy combined with Energy Dispersive X-ray Spectroscopy (SEM-EDX) and Fourier transform infrared spectroscopy (FTIR) and found to be largely goethite. The observed best performance of the bicarbonate salts has been attributed to formation of more goethite than ferrihydrite.

The following conclusions have been drawn from the above study:

- Banana ash and the carbonate and bicarbonate salts of potassium and sodium, and their mixtures are effective in the removal of iron to below maximum contamination level.
- Both bicarbonates, especially that of potassium, individually have been found to be very effective for removal of iron, retaining the pH in the acceptable range for drinking, in comparison to the carbonate salts and ash, and their mixtures.
- An iron removal of 98.5-100%, from initial concentration of 2-20 mg/L, can be achieved with only 0.07-0.1 g/L of potassium bicarbonate retaining the pH between 6.88 and 7.72.
- The removal rate has been found to improve with increase in the amount of the dose and residence time.
- Iron has been found to be removed by the bicarbonate salts mostly as goethite at the prevailing pH, acceptable for drinking.
- The removal becomes poor in the presence of the carbonates and the ash because of formation of ferrihydrite.
- The application of the bicarbonates is a simple which can be used by laymen. The effective, simple, safe, fast and low-cost removal of iron by the bicarbonates seems to be promising in the context of the global problem iron contamination of groundwater.

The main outcome of this work was the finding that the bicarbonates of sodium and potassium are most effective buffering agents in maintaining pH most favorable for iron removal.

(ii) Removal of Arsenic by precipitation and filtration using banana ash, carbonate and bicarbonate salts of Na and K, and their 1:1 mixtures:

In the present work, we have studied the efficiency of those salts and ash and their 1:1 mixtures on removal of arsenate ion. The removal has been studied with respect to the quantity of ash/salt required, residence time and the effect on the pH of water. Moreover the solid sludge, *i.e.*, the precipitate obtained after the treatment has been studied by X-ray Diffraction (XRD), Scanning Electron Microscopy combined with Energy Dispersive X-ray Spectroscopy (SEM-EDX) and Fourier Transform Infrared Spectroscopy (FTIR) to understand the reason for the removal of arsenate ion.

The efficiency of the ash and the salts in precipitating arsenate with iron ion were studied in terms of the effects of dose. At first, 20mg/L Fe(II) solution and 0.25mg/L As(V) solution were prepared by dissolving $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ and $\text{Na}_2\text{HAsO}_4 \cdot 7\text{H}_2\text{O}$. The arsenic removal experiments were carried out in batches by mixing varying quantities of the ash and the salts with 50 mL of Fe(II) and As(V) containing water in Erlenmeyer

flasks. The flasks were shaken manually for 1 minute and allowed to settle. The flasks were taken out one by one and the liquid and solid phases were separated after 2 hour of residence time by filtration using Whatman grade 2 filter paper. After that the residual iron and arsenate ion concentrations in the filtrates were determined. The principle applied in the present study has been oxidation of iron by aeration and at high pH by adding ash and the bicarbonate and carbonate salts of Na or K.

The results of the batch studies with different salts showed that the ash and the carbonate and bicarbonate salts and their mixtures are effective in the removal of iron as well as arsenic to below maximum contamination level without affecting the taste and colour. Also the pH of treated water remains within the acceptable range for drinking i.e. the method is efficient in removal of arsenate under neutral pH. So, there is no need of pH adjustment unless the $\text{pH} > 8$. The high removal capacity of the salts and ash may result from both co-precipitation of As(V) with the Fe hydroxides (i.e., ferrihydrite (FeOOH), goethite ($\alpha\text{-FeOOH}$) or ferric hydroxide [$\text{Fe}(\text{OH})_3$]) forming during the reaction and subsequent adsorption of As on these fresh Fe hydroxide minerals. When comparing the removal mechanism of the present study with other studies, the main advantages are the method has a considerable promise as a low-cost technique, simple and versatile. The principal finding of this study was that the arsenate as well as iron ion removal is far better with both of the bicarbonates of sodium and potassium than their corresponding carbonate salts. On the other hand, the final pHs obtained with the bicarbonate salts were lower than that of the carbonate salts of Na and K. In case of NaHCO_3 , 200 mg/L of the salt can remove iron ion to below MCL level, with a $\text{pH} > 8$ and residual arsenate ion of 10 $\mu\text{g/L}$. In case of KHCO_3 , 80 mg/L of the salt can remove both the arsenate and iron ion to below the MCL at the pH value of 7.49 and about 100 mg/L of KHCO_3 , both the ions were removed to an undetectable level with a final pH within the acceptable limit, i.e. within 6.5 to 8.5. Thus, KHCO_3 and NaHCO_3 show best removal efficiency among all the four salts and banana ash for integrated removal of arsenate and iron ion retaining the pH within acceptable range for drinking.

(iii) Removal of arsenic and iron by oxidation-coagulation at controlled pH (Arsiron Nilogon) method:

We have chosen sodium bicarbonate over potassium bicarbonate even though the latter was found to be more efficient in arsenic and iron removal from water as described above, because of more familiarity of common people with the former as baking soda. Moreover, sodium bicarbonate does not impart unpleasant taste to water unlike potassium bicarbonate. Since arsenic is present in the groundwater mostly as difficult-to-remove arsenite, we have used potassium permanganate for oxidizing the arsenite to easy-to-remove arsenate state. Finally, we have used a coagulant for faster removal of arsenic and iron from water. We have preferred ferric chloride over alum because of better efficiency and cost of the former than that of the later.

(3) Optimization of the method with respect to As speciation results, Fe-content of the groundwater and dissolved oxygen and pH:

The doses of the three chemicals, viz., baking soda, potassium permanganate and ferric chloride were decided from the results of a series of experiments carried out with varying concentrations of each of the chemicals keeping all other parameters constant. It was found that the effect of

dissolved oxygen is insignificant on the arsenic and iron removal by the present method. The treatment is done in open air so that aerial oxidation can decrease the dose of potassium permanganate. As we use a buffering agent, viz., baking soda, the effect of initial pH of the groundwater also is insignificant. The final doses thus decided have been shown in Table 1.

Table 1. The doses of the chemicals in mg/L, used in the Arsiron Nilogon technique, for iron-free and iron containing water having iron concentration up to 5 mg/L*.

Groundwater type	(NaHCO ₃) mg/L	(KMnO ₄) mg/L	(FeCl ₃) mg/L
Iron-free	100 mg	0.5 mg	25 mg
containing up to 5 mg/L Iron*	100 mg	4 mg	25 mg

*For higher concentrations of iron, the dose of KMnO₄ is increased to that much which is sufficient to oxidise all ferrous iron and arsenite but just less than the quantity that leaves the colour of KMnO₄ in the water.

The three chemicals viz., baking soda, Potassium permanganate and ferric chloride are added to the water in the specified doses with subsequent stirring for a while after addition of each chemical. The detail procedure is included in Annexure. The water after one hour from the treatment appears as shown in Fig. 1. The clear water from the top can be decanted into any filter, preferably sand-gravel.

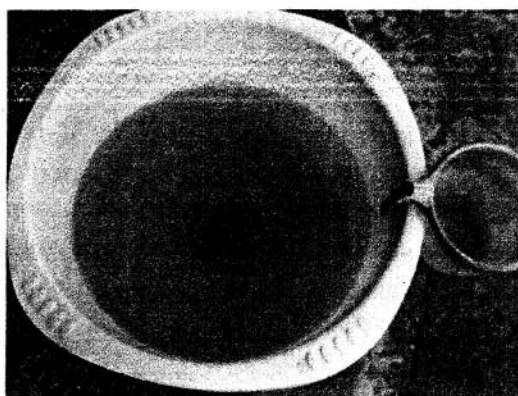


Fig.1. The settling of the precipitate after treatment.

The Arsiron Nilogon Technique:

Arsiron Nilogon is a simple, low-cost, safe and environment-friendly chemical technique for removal of arsenic from groundwater to less than 5 ppb which also removes iron to less than 0.1 ppm if present in water.

Principle: The technology is based on removal of arsenic and iron by Oxidation-Coagulation at Optimized pH (OCOP). Here the arsenic and the iron present in groundwater are oxidised from As(III) (arsenite) and Fe(II) (ferrous) states to As(V) (arsenate) and Fe(III) (ferric), respectively by using an oxidizing agent, viz., potassium permanganate (KMnO₄) and then coagulated using a coagulant, viz. ferric chloride (FeCl₃) at an optimized pH range controlled by adding sodium bicarbonate (baking soda or cooking soda, NaHCO₃) before

oxidation and coagulation. Aeration of the water reduces the required quantity of KMnO_4 . The water is then filtered using any filter, preferably a sand-gravel filter fitted with a filtration assisting device. The process removed arsenic as well as iron from contaminated water. Arsenic can be removed to below 5 ppb ($\mu\text{g/L}$) from up to 500 ppb initial concentration. Similarly, iron can be removed to below 0.1 ppm (mg/L) from up to 20 ppm initial concentration.

The Process: The method needs small quantities of some common chemicals, *viz.*, NaHCO_3 , KMnO_4 and FeCl_3 . The treatment can be done in any container. The method involves a three-step chemical treatment and subsequent filtration.

The chemical treatment for water with arsenic but without iron: The three chemicals are added in the three steps as follows:

Step 1. A specified quantity of NaHCO_3 as shown in Table 1 is added to a certain quantity of arsenic containing water in a bucket or container and thoroughly mixed by stirring with a stick. It mixes immediately. It controls the pH of the water in an optimum range where the chemicals added in the subsequent steps work as desired. The pH after addition of baking soda is about 8.3.

Step 2. A specified quantity of KMnO_4 as shown in Table 1 is added to the water and with thorough mixing by stirring. It mixes immediately. At the prevailing pH, KMnO_4 oxidizes arsenite to more easily removable arsenate form while reducing manganese from Mn(VII) to Mn(IV) state, *i.e.*, to MnO_2 and not to Mn(II) state. Mn(II) is soluble in water and is unwanted in drinking water whereas MnO_2 is an insoluble solid and is removed in the process. The presence of carbonate also accelerates oxidation of arsenite to easily adsorbed arsenate.

Step 3. A specified quantity of FeCl_3 as shown in Table 1 is then added to the water with thorough mixing by stirring for at least a minute. FeCl_3 is the most popular coagulating agent used in water treatment worldwide as alum is avoided as the residual aluminium is suspected of causing Alzheimer's disease. FeCl_3 is acidic and corrosive in aqueous solution but is safe in alkaline solution, *e.g.*, in the presence of the specified quantity of baking soda. Ferric chloride coagulates sufficiently in the presence of the specified quantity of baking soda.

Coagulation in the form of reddish brown particles will be visible within minutes as shown in Fig.1. The water is then allowed to settle for at least an hour. It can be decanted and filtered through any kind of water filter, preferably a sand-gravel filter.

The chemical treatment for water with arsenic and iron: The method has to be modified if the water already contains appreciable concentration of iron. The ferrous iron present has also to be oxidised along with oxidation of arsenite by addition of more KMnO_4 before coagulation. Otherwise, the added KMnO_4 will be used up for oxidation of ferrous iron and will not be available for oxidation of arsenite. An additional quantity of KMnO_4 has been used to oxidise the ferrous iron. For 5 mg/L iron present in the water the dose of KMnO_4 is 4 mg/L. For higher concentrations of iron, the dose of KMnO_4 is increased to that much which is sufficient to oxidise all ferrous iron and arsenite but just less than the quantity that leaves the colour of KMnO_4 in the water.

- (4) **Study of kinetics of oxidation of As(III) to As(V), the role of aeration and Mn-content of water:** The inorganic reaction of oxidation of As(III) to As(V) was found to be almost instantaneous and hence the kinetics should not affect the practical application of the oxidation.

Aeration has been found to reduce the quantity of potassium permanganate required for oxidation of arsenite and ferrous iron. So, it has been recommended that the treatment of the water be carried out in open condition with aeration of the water before treatment where possible.

The presence of the bicarbonate controls the oxidation by the permanganate ion and restricts reduction of the Mn(VII) ion to insoluble MnO₂ in Mn(IV) state instead of reduction to soluble manganous (Mn²⁺) ion in Mn(II) state. Because of this no Mn²⁺ ion remains in the treated water.

- (5) **Study of co-precipitation, adsorption isotherm with varying weights of ash, the nature of binding As with Fe-oxide, goethite or ferrihydrite and appropriate sludge disposal:**

From our experiments we have found that sodium and potassium bicarbonate are much more effective in iron and arsenic removal than ash. Therefore, rather than doing arsenic adsorption studies on ash we have carried out detailed study of iron and arsenic removal by the carbonate and bicarbonate salts of sodium and potassium and their mixtures.

It has been found from our study that the bicarbonates are more efficient in iron and arsenic removal than the corresponding carbonates. The reason has been found to be formation of insoluble goethite (FeOOH) from iron in the presence of the bicarbonates. In the presence of the carbonates, ferric hydroxide (Fe(OH)₃), which is sparingly soluble, is formed leaving some dissolved iron in the water. On the other hand, at higher pH provided by the carbonates, the adsorption of arsenic to solid iron is decreased due to competition of the arsenate ions with OH⁻ ions for the same adsorption sites.

Waste disposal: Disposal of wastes from arsenic removal plants still remains as a challenge worldwide. Portland cement has been successfully used to stabilise As-rich sludges and it may be suitable for treating the sludge generated from precipitative removal units. Arsenical ferrihydrite or goethite is a preferred form of arsenic sludge in metallurgical industries due to its high stability and slow leaching. The arsenic containing solid ferrihydrite or goethite formed in Arsiron Nilogon is a suitable form of arsenic sludge for disposal. However, during disposal, proper care must be taken so that the arsenic leaching out from the sludge does not go back to groundwater or is absorbed by paddy or vegetables. The binding between arsenic and goethite is quite strong and hence there is very little possibility of arsenic leaching from the sludge. We have seen that in our present method of arsenic and iron removal, the arsenic containing sludge can be filtered in a separate filter (e.g., sand-gravel) where the small quantities of sludge can be collected. The water filtered out from this filter is also free from arsenic.

- (6) **Design and fabrication of Integrated As-Fe removal systems for domestic and community use:**

There is no limitation in the technology with respect to quantity of water to be treated. The system can be custom designed to meet the requirements of a household or a community. Some of the models designed and fabricated are presented below.

The Household Arsiron Nilogon System (Models: HAN): A household Arsiron Nilogon system with a sand-gravel filter on a stand has been shown in Fig 2. It requires a bucket



Fig.2: A household Arsiron Nilogon system with sand-gravel filter alone (HAN).

(strong enough to withstand the weight of the sand and the gravels) of 25-30 L capacity as a sand-gravel filter. A filtration assisting device made of ½ inch PVC pipe and joints and GI fittings as shown in Fig 3.

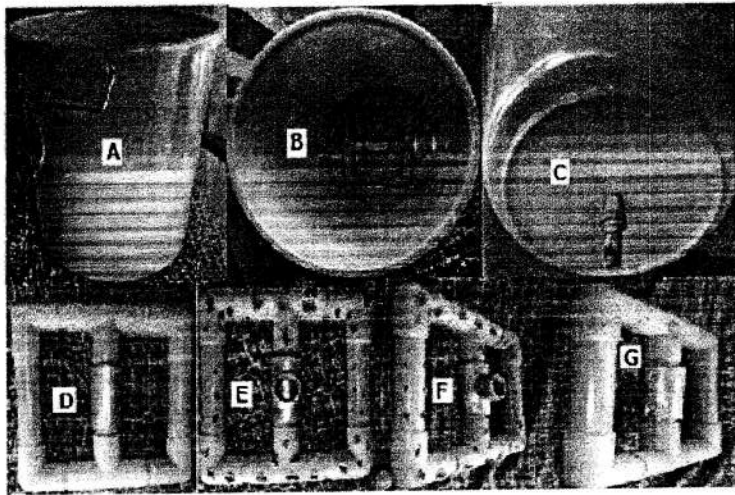


Fig.3: The filtration assisting device

Small Community (like school) Arsiron Nilogon System (Model: SAN): A system installed at a High School with about 500 students and 30 teachers and supporting staff has been shown in Fig. 4. It consists of two treatment tanks of 30 L drums at the top fitted with a tap each, a sand-gravel filter of a 40 L drum in the middle fitted with a rapid filtration device as shown in Fig.3 at its bottom and a storage tank of a 60 L drum at the bottom fitted with a tap. The water can be treated in the two treatment tanks alternately in order to save time. This system can give 300 L water free from arsenic and iron to cater drinking water including the water needed for mid-day meal for the students, teachers and supporting staff of the school.

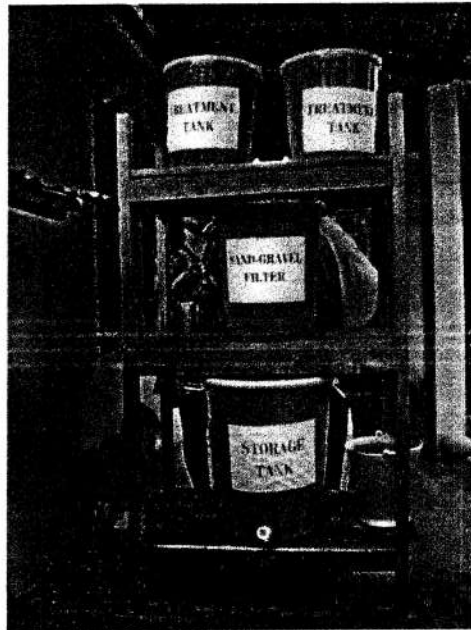


Fig.4: The small community Arsiron Nilogon system (SAN).

The Medium Range Arsiron Nilogon System (Models: MAN-A & MAN-B): For medium community application (like big schools, colleges) or large household application two systems as shown in Fig. 5 and 6 can be used. Their capacities can be up to 1000L.

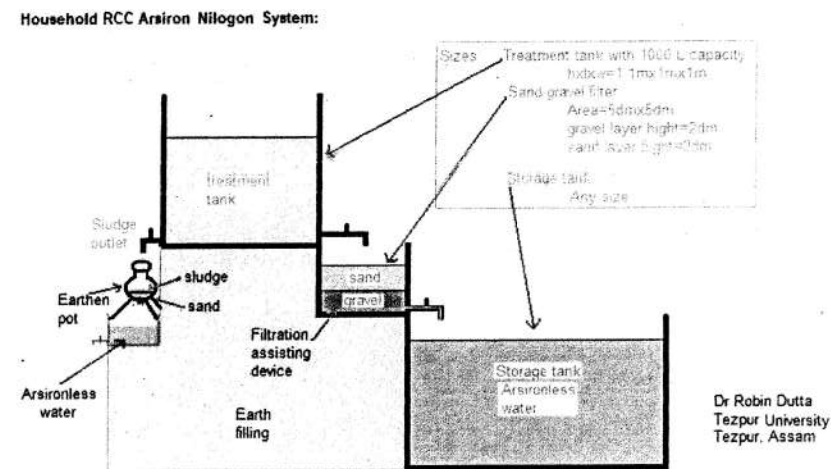
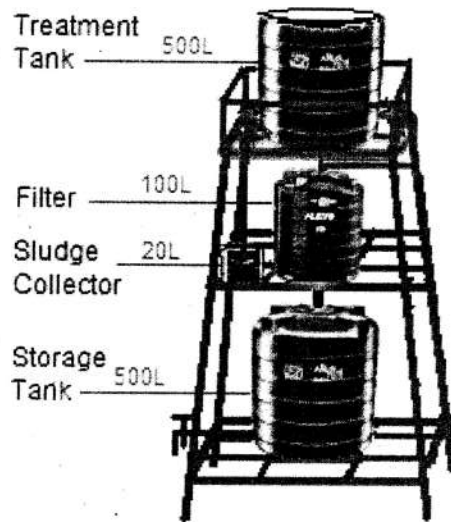


Fig. 5: A medium range Arsiron Nilogon System (MAN-A)



Arsiiron Removal System
Capacity = 500L

Fig. 6: A medium range Arsiiron Nilogon System (MAN-B)

Large Community Scale Arsiiron Nilogon System (Model LAN): For large community scale application, e.g., in PHED piped water supply schemes, the system as shown in Fig. 7 can be used. It needs an additional treatment chamber in the existing schemes.

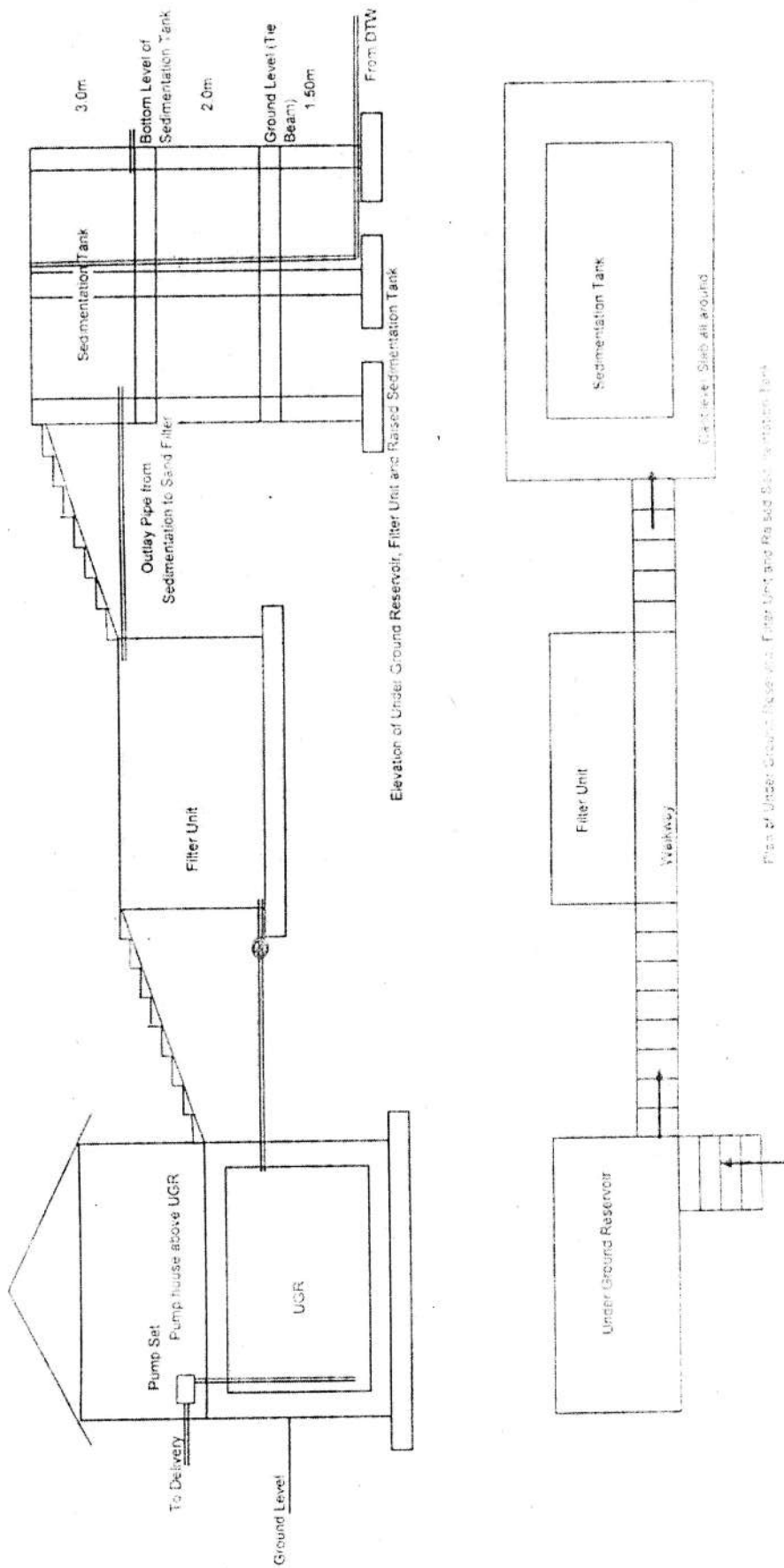


Fig. 7: Large community scale Arsiron Nilogon system (Model: LAN)

(7) To check the usefulness of the units by chemical and bacteriological testing of the water before and after treatment and through user trial:

The pH of the treated water by the present method is about 7.3 which is well within the acceptable range for drinking water. The present Arsiron removal method adds sodium, potassium and chloride to the water in very small quantities. The increments in the concentrations of these ions in the treated water are insignificant in view of their natural concentration in the groundwater as can be seen in Table 2.

Table 2. The added Na⁺, K⁺ and Cl⁻, their natural concentrations and BIS guideline values.

Ion	Average in the water in mg/L	Guideline value in mg/L	Added in dose in mg/L
Na ⁺	100	None	27
K ⁺	7	None	0.25
Cl ⁻	20	250	8

We have seen from bacteriological test carried out at Indian Institute of Toxicological Research (IITR), Lucknow that the present arsenic and iron removal method, viz., Arsiron Nilogon does not increase the bacteria in the water which can be seen from Table 3. Since, potassium permanganate is a mild disinfectant, the Arsiron Nilogon method is expected to remove bacteria during Arsiron Nilogon, if present in the water. Thus the present Arsiron Nilogon technique based on oxidation coagulation at optimized pH is a safe method. The present method also removed other heavy metals present in the water along with As as shown in Table 4.

Table 3. Results of bacteriological test of water before and after Arsiron Nilogon

Sample	Total coliform bacteria*	<i>Escherichia coli</i> or thermotolerant coliform bacteria*	Bacteriological Quality
	MPN/ 100ml	MNP/ 100 ml	
Before	<1.8	<1.8	Acceptable
After	<1.8	<1.8	Acceptable

*Maximum Acceptable Limit is <1.8 (not detectably) total coliform and *Escherichia coli* or thermotolerant coliform bacteria/100ml as per Indian Standard for Drinking Water Specification of Bureau of Indian Standards (BIS), 2005; IS 10500:2004.

User Trial: A field cum user trial of our arsenic removal method using our arsenic removal kit was carried out at two villages, viz., Tatigaon and Kharikatia in Titabor, at Jorhat district of Assam, India. Some of the water sources of Tatigaon contain arsenic of about 200 ppb and no iron. The treated water samples, collected by the users of three arsenic removal systems for one month, showed arsenic between 10-1 ppb. The Kharikatia sources have arsenic about 225 ppb and iron about 5 ppm. With the same dose of potassium permanganate the arsenic level came

down to only 25 ppb. But use of additional quantity of potassium permanganate removed arsenic to less than 10 ppb.

Table 4: Removal of other heavy metal ions along with As by the Arsiron removal method. The figures shown in the table are before and after the treatment.

Source of samples*		Presence of heavy metals (mg/L)								
		As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb
1	Before	0.250	0.001	0.001	ND	0.008	3.154	0.079	ND	ND
	After	0.005	ND	ND	ND	0.004	0.056	ND	ND	ND
2	Before	0.250	0.001	0.001	ND	0.009	2.610	0.081	ND	ND
	After	0.005	0.001	ND	ND	0.001	0.085	ND	ND	ND
3	Before	0.200	0.001	ND	ND	ND	ND	0.097	ND	ND
	After	ND	ND	ND	ND	ND	ND	ND	ND	ND
BIS [#]		0.010	0.010	-	0.050	0.050	0.300	0.100	0.020	0.500

*Sources of samples: Tube well of: 1. Kharikotia L. P. School, Jorhat, Assam, 2. Kharikotia High school, Jorhat, Assam, 3. Tatigaon Namghor, Titabor Jorhat, Assam. [#]BIS guideline values. ND- Not detectable.

Thus, the user trial of the Arsiron Nilogon technique was quite successful. Dr G.J. Samathanam, Adviser and Head, TDT, DST visited our user trial at school and village in Kharikatiya and Titabor and interacted with the users. Dr Samathanam, after seeing the functioning of the systems and the high level of satisfaction of the users has assures us of all possible support for popularizing the Arsiron Nilogon Technique in the arsenic affected areas all over Assam. Our effort to popularise the Arsiron Nilogon technique is on and has been receiving support and cooperation and encouragement of the DST, various Colleges and other organizations of Assam.

(8) Testing of an As detection kit to be provided by the DST vis-a-vis analytical and test strip method:

This was an additional work assigned by the DST for carrying out along with the project work. The As detection kit which was supposed to be provided was not provided despite several requests made by me to the person. The matter was reported to the PAC in a meeting.

8. (a) Milestones fixed as per the agreement:

The milestones fixed were as shown below:

1. All preparatory works, e.g., study of literature, collection of water samples, banana ash, etc., will be done within 1st half of the 1st year.
2. The analysis of representative water samples of the As affected areas including speciation of As in the samples will be completed within the 1st year.
3. Study of the kinetics of catalysis of oxidation of As(III) to As(V) by MnO₂ added externally and formed in situ from Mn of groundwater and dissolved oxygen. This will also be completed in the 1st year.
4. Laboratory study of removal of As by the Fe removal process using ash will be studied in the 2nd half of the 1st year and the 1st half of the 2nd year.
5. Fabrication of the model As removal systems, study of their efficiency in removing As and Fe by the proposed method including optimization of various parameters will be started in the last quarter of the 1st year and completed by the 1st half of the 3rd year.
6. Study of adsorption of As as a function of amount of ash and ferrihydrite; and chemical and structural characterization of the sludge will be done with an aim to explore suitable disposal of the sludge by the middle of the 3rd year.
7. Field trial of the As removal systems, preparation of reports and filing of patent will be completed by the end of the 3rd year.
8. Testing of the As detection kit provided by the DST vis-a vis analytical and test strip method will be done throughout the project work but the results will be reported every year.

The bar diagram was as follows:

Work	1 st year	2 nd year	3 rd year
Study of literature			
Collection of water samples, ash and chemicals			
Analysis of water samples and speciation of As			
Study of oxidation of As(III) to As(V)			
Laboratory study of removal of As along with Fe by the proposed method			
Testing of As detection kit vis-a-vis other methods			
Devising of As-Fe removal systems and study of their efficiency in As removal			
Chemical and bacteriological analysis of purified water and optimization of the parameters			
Study of adsorption of As, sludge and its disposal.			
User Trial			
Preparation of report and Filing of patent			

8. (b) Milestones achieved:

The milestones of the core project, except for those which were considered trivial or only of academic interest, were met in time as described below:

1. All preparatory works, e.g., study of literature, collection of water samples, banana ash, etc., were done within 1st half of the 1st year.
2. The analysis of representative water samples of the As affected areas including speciation of As in the samples were completed within the 1st year.
3. Study of the kinetics of catalysis of oxidation of As(III) to As(V) by KMnO_4 and dissolved oxygen was completed in the 1st year.
4. Laboratory study of removal of As by the Fe removal process using ash was studied in the 2nd half of the 1st year and the 1st half of the 2nd year. We have carried out some further studies on arsenic removal by carbonates and bicarbonates of sodium and potassium as they were found to be more effective than the ash. We have finally developed a very efficient, simple and low-cost arsenic and iron removal method.
5. Fabrication of the model As removal systems, study of their efficiency in removing As and Fe by the proposed method including optimization of various parameters were started in the last quarter of the 1st year and completed by the 1st half of the 3rd year.
6. Study of adsorption of As as a function of amount of ash and ferrihydrite; and chemical and structural characterization of the sludge was completed by the middle of the 3rd year.
7. Field trial of the As removal systems, preparation of reports and filing of patent were completed by the middle of the 3rd year, i.e., six months before time.
8. Testing of the As detection kit provided by the DST vis-a vis analytical and test strip method could not be done as mentioned earlier (Sec 7b(8)).

9. Deviations made from the original objectives if any, while implementing the project and the reasons thereof:

We initially had planned to develop integrated arsenic and iron removal method using banana ash modifying our earlier method of removal of iron using banana ash. Though finally we have been successful in developing a very efficient, simple and low-cost integrated arsenic and iron removal technology, we have done it using some other substances instead of ash. However, the clue to choosing the number one chemical used in the method, i.e., sodium bicarbonate, was in the banana ash (potassium carbonate is the active component in banana ash) through potassium carbonate and potassium bicarbonate. As potassium bicarbonate has been found to be more effective than potassium carbonate in removing iron and arsenic and the former gives a moderate pH to the treated water while the latter produces higher pH, we had initially chosen the former for the purpose of As and Fe removal instead of the ash. Later, of course we have finally chosen sodium bicarbonate in the place of potassium bicarbonate as the common people are familiar with the former as baking soda.

Thus, this deviation in the work was made during implementation in order to get better results.

A major difficulty faced: We could have published more papers if we had an Atomic Absorption Spectrophotometer. Strip analyses of arsenic are acceptable only in the field work. We have to give samples to others for ASS analysis and keep waiting and sometimes end up with some erratic analytical data.

10. Conclusions summarizing the achievements and indications of scope for future work:

The Achievements: A highly efficient integrated arsenic and iron removal technique, named Arsiron Nilogon, based on oxidation-coagulation at optimized pH (OCOP) has been developed and successfully field tested. Some salient points of the technique are as follows.

- The chemicals used in the technique are common, viz., baking soda (NaHCO_3) as the pH regulator, potassium permanganate (KMnO_4) as oxidant and ferric chloride (FeCl_3) as coagulants in very small quantities.
- The technique brings down arsenic and iron in groundwater (say from 500 ppb and 5 ppm) to less than 5 ppb and 0.1 ppm, respectively, with a recurring cost of just Re 1 per 100 L of water.
- The technique is safe with respect to treated water quality and sludge management.
- The removal involves treatment and settling in a treatment tank followed by filtration, preferably by sand filtration. The method has no limitation regarding quantity of water to be purified and the systems can be custom designed. Some models suitable for household, school and small communities have been successfully tried in the field.
- The technique has been demonstrated in schools and villages at various places of Assam. It has also been demonstrated to PHED engineers, NGOs, school teachers and others at a DST-sponsored workshop organized for that purpose at Tezpur University.
- The method is being used at some schools and villages and more people are interested in acquiring a system.
- That the technique is gaining popularity is reflected in coverage of the technique in periodical and newspapers and choosing of the technique as a subject of science exhibition by school children.

Scope for future work: In order to get the full benefit of the present arsenic and iron removal method the following works can be done at the earliest:

- Field trial at large community scale piped water supply schemes: We have carried out a field trial of the Arsiron Nilogon Technique in domestic and school levels. Though the technique has been found to work nicely at such levels, application of the technique in large community scale will benefit people at large scale. For application at large community scale, a pilot project should be carried out first.
- Development of an automated online arsenic and iron removal system for domestic and institutional application: For more convenient application of the technique at domestic and institutional levels, an automated online arsenic and iron removal system may be developed.
- The Arsiron Nilogon technique may be applied in the arsenic affected areas of the country.
- Further R&D works can be done on management of the arsenic rich solid iron sludge produced in the technique.

11. S & T benefits accrued:

(i) List of research Publications with details:

Journals:

- (1) S. Bordoloi, S.K. Nath and R.K. Dutta, "Iron Ion Removal from Groundwater using Banana Ash, Carbonates and Bicarbonates of Na and K, and their Mixtures", *Desalination*, xxx(2011)001-009, doi:10.1016/j.desal.2011.07.057
- (2) S. Bordoloi and R.K. Dutta, "Arsenate Ion Removal from Water using Banana Ash, Carbonates and Bicarbonates of Na and K, and their Mixtures", *Communicated*.
- (3) S. Bordoloi, S.K. Nath, S. Gogoi and R.K. Dutta, "Integrated Arsenic and Iron Ion Removal by Oxidation-Coagulation at Optimized pH", *manuscript under preparation*.
- (4) S. Bordoloi, S.K. Nath, S. Gogoi and R.K. Dutta, "Field trial of an Integrated Arsenic and Iron Removal Technique based on Oxidation-Coagulation at Optimized pH: Arsiron Nilogon", *manuscript under preparation*.

Articles in Books:

- (1) Dr. Robin Kumar Dutta, Ms. Shreemoyee Bordoloi and Mr. Suresh Nath, "Technology for Removal of Arsenic and Iron from Groundwater", in **Technology Manual on Water Treatment**, prepared by Department of Drinking Water and Sanitation (DDWS), Ministry of Rural Development, New Delhi, Govt. of India. (*in press*)

National Seminar:

- (1) R.K. Dutta, "Arsenic in groundwater of Assam and its mitigation", *Proceedings of National Seminar on Crisis of fresh water, a challenge to humanity and life processes, what is the solution?* 17-18 Aug, 2010, D.R. College, Golaghat, p.47-49.
- (2) R.K. Dutta, Removal of Groundwater Arsenic: A Field Trial of 'Oxidation-Coagulation at pH' Technique, *National Seminar on Urban waste disposal and its impact on environment and public health*, 23-25 Sept, 2010, Sibsagar College, Sibsagar.
- (3) R. K. Dutta, Shreemoyee Bordoloi, Suresh K. Nath, "Arsiron (Arsenic+iron) Removal by Oxidation-Coagulation at Optimum pH: A Green Technique, *National Seminar on Water Pollution and Health Hazards*, Feb1-2, 2011, Brahmananda College, Kanpur.
- (4) S. Bordoloi, S.K. Nath and R.K. Dutta, Removal of iron from contaminated groundwater by carbonate or bicarbonate salts of sodium or potassium or their mixtures with banana ash, *National Seminar on Crisis of Water*, DR College, Golaghat, Assam, 17-18 August, 2010.
- (5) R.K. Dutta, S. Bordoloi, S.K. Nath, L. Boruah, J. Ojah and D. Dutta, "Arsiron Nilogon: A Green Method of Arsenic Removal from Groundwater, *National Seminar on Green Chemistry*, Gargaon College, Simoluguri, Assam, Feb 4-5, 2011.

Workshop:

- (1) A workshop on 'Integrated Arsenic and Iron Removal from Groundwater: Arsiron Nilogon', sponsored by the DST, was held in Tezpur University on 25 June 2011, for popularization of the Arsiron Nilogon method. The method was demonstrated in detail to 270 participants comprising PHED personnel, School teacher, NGO, etc. A souvenir was published which included the Arsiron Nilogon technique in detail.
- (2) R.K. Dutta, "Arsenic Contamination of groundwater of Assam and Arsiron Nilogon", in Workshop on Arsenic Removal, Sonari College, 18 July, 2011.