EFFECTIVENESS OF MULTISTAGE FILTRATION IN REMOVING IRON, MANGANESE AND ARSENIC FROM GROUNDWATER OF BANGLADESH

MD. MATIAR RAHMAN MONDOL

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BY

MD.MATIAR RAHMAN MONDOL
Roll No. 040404144 F

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The thesis titled “**EFFECTIVENESS OF MULTISTAGE FILTRATION IN REMOVING IRON, MANGANESE AND ARSENIC FROM GROUNDWATER OF BANGLADESH**” submitted by Md. Matiar Rahman Mondol, Roll No.040404144F, Session: April, 2004 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of **MASTER OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING** on October 31,2009.

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Dr. Md. Delwar Hossain Professor Department of Civil Engineering BUET,Dhaka-1000,Bangladesh	Member
Mr. Shamsul Gafur Mahmud National Professional Officer World Health Organization (WHO) Dkaka,Bangladesh	Member (External)

DECLARATION

I hereby declared that the research work reported in this thesis has been performed by me and neither this thesis nor any part thereof has been submitted or is being concurrently submitted anywhere for the award of any degree or diploma (except for publication).

31st October,2009

Md.Matiar Rahman Mondol

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ABSTRACT

The presence of iron, manganese and arsenic in ground water beyond the permissible limit is now considered to be a major problem throughout the world and produce numerous adverse effects. These problems are severe in the context of Bangladesh as groundwater is a vital source for the safe drinking water supply. In the present study seven numbers of multistage filtration units (MSFU) have been constructed in Sirajgonj,Comilla and Jessore (three different hydro-geological conditions) to investigate the effectiveness of multistage filtration in removing iron, manganese and arsenic from groundwater of Bangladesh adopting the technique of adsorption and co-precipitation of arsenic and manganese onto the flocs of ferric hydroxide, making use of the naturally occurring iron of groundwater. The MSFU, which is attached to a tube well, has three chambers, 1st chamber (Aerator plus Down-flow Flocculator), 2nd chamber (Sedimentation plus Up-flow Roughing Filter) and 3rd chamber (Down-flow Roughing Filter) .The flocculation and roughing filtration processes in the MSFU were accomplished through the use of brick chips.

The MSFU is connected to the spout of tube well with a short piece of 75 mm PVC / flexible pipe. Water entering the first chamber is distributed uniformly over the whole bed of course media through a porous thin ferro-cement plate placed on the top, resulting strip out of CO_2 and increase of pH value for the oxidation of soluble iron. In the Down-flow Flocculator oxidation and subsequent precipitation of iron oxy-hydroxides occurs respectively on the top and within the interstices of coarse media which adsorbs arsenic oxy-anions as well as manganese ions. Sinusoidal flow across the coarse media enhance collisions for the flocculation of precipitated particles. Comparatively larger flocculated precipitates settle at the bottom of the sedimentation chamber. Significant removal of precipitated particles occurs by sorption on to iron oxy hydroxides and mechanical straining during up-flow through the comparatively finer coarse media bed in the 2nd chamber. Final removal of precipitated particles occurs through sorption on to iron oxy hydroxides and mechanical straining during down-flow through the comparatively finer coarse media bed in the 3rd chamber.

Water samples collected weekly from different location of the Multi-Stage Filtration Units (MSFU) were tested in the laboratory for determining the concentration of iron, arsenic and manganese. Around 97 % of iron reduction was achieved through the MSFU. Arsenic removal efficiency upto 91 % was achieved through the MSFU without using any chemicals. Two different equations have been developed to express the effect of tube well water iron concentration on iron and arsenic removal performance respectively. Using these equations it will be easy to determine the residual iron concentration in the final effluent achieved through properly designed MSFU treating tube well water of different initial iron concentration.

Manganese removal was observed as a function of raw water manganese concentration. Higher the manganese concentration, greater was the removal performance. Up to 85 % manganese removal performance was achieved through the MSFU. Contribution of DRF alone in removing manganese was observed very significant (around 37%). For tube well water having manganese concentration around 1.5 mg/l and iron concentration around 15 mg/l, a residual Mn concentration below maximum permissible limit (WHO health risk guide line value for Mn) of 0.4 mg/L could be maintained through the MSFU.

Performances of Iron Chips Column (filled with iron chips and iron coated sand.) attachment with the MSFU were also monitored and necessary modifications in the design have been recommended.

Operation and maintenance procedure (cleaning) were determined .The initial effluent flow from the URF were around 85 % of tube well water flow. Length of filter run between cleaning should be maximum 3 - 4 weeks. MSFU will be cleaned when flow from the outlet of URF chamber will reduce by 45-50% of the tube well flow i.e. flow from the URF chamber = 9-10 L/min. Numbers of users and water consumption was increased by about 10 folds after the installation of the MSFU.

Abbreviations and Acronyms

AIT	Asian Institutes of Technology
AIRU	Arsenic Iron Removal Unit
APSU	Arsenic Policy Support Unit.
As	Arsenic
BAMWSP	Bangladesh Arsenic Mitigation Water Supply Project
BGS	British Geological Survey
BUET	Bangladesh University of Engineering and Technology.
DFID	Department for International Development
DPHE	Department of Public Health Engineering
DRF	Down-flow roughinf Filter
DyRF	Dynamic Roughing Filter
EPA	Environmental Protection Agency
E.Coli	Escherichia Coli.
EQS	Environmental Quality Standard.
FC	Fecal Coliform
ICC	Iron Chips Column
HCl	Hydrochloric acid
ITN	International Training Network.
MSF	Multistage Filter
MSFU	Multi Stage Filtration Unit
Mn	Manganese
NAMIC	National Arsenic Mitigation Information Centre
NTU	Nephelometric Turbidity Unit.
ppb	parts per billion
SSF	Slow Sand Filter
TC	Total Coliform
TW	Tube well
URF	Up-flow Roughing Filter
TTC	Thermotolerant Coliform
WHO	World Health Organisation
AWWA	American Water Works Association.

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CHAPTER ONE

INTRODUCTION

1.1 GENERAL

Water is a universal solvent, during percolation through the various strata of soil it dissolves various mineral (chemical impurities) compounds. When the mineral concentration is greater than the acceptable limit then the water becomes unsafe for drinking and not suitable for domestic use. Groundwater in general, has relatively better water quality and usually requires limited treatment with relatively low capital and operational cost. Many countries in the world consequently rely on groundwater to a large extent as a source of drinking water. Groundwater has qualitative problems that could be of natural and / or anthropogenic origin. Many arsenic containing ground water also contain significant level of iron and manganese due to natural geochemistry (Ohio EPA, 2008).The presence of iron, manganese and arsenic in ground water beyond the permissible limit is now considered to be a major problem throughout the world and produce numerous adverse effects. These problems are severe in the context of Bangladesh as groundwater is a vital source for the safe drinking water supply .In some places of Bangladesh the concentration of iron, arsenic and manganese in ground water are at much higher level than the limit acceptable to the rural people. People of those areas generally refuse to use tube well water and inclined to use pond and river waters.

Iron in concentrations greater than 0.3mg/l stains plumbing fixtures and laundered clothes (Steel,1960). Although discoloration from precipitates is the most serious problem associated with water supplies having excessive iron, foul tastes and odors can be produced by the growth of iron bacteria in water distribution mains. These filamentous bacteria, using reduce iron as an energy source, precipitate it, causing pipe encrustations. Decay of the accumulated bacterial slimes creates offensive tastes and odors. Dissolved irons are often found in ground water from wells located in shale, sandstone and alluvial deposits. Impounded surface water supplies may also have troubles with iron.

Manganese is seldom found alone in a water supply. It is frequently found in iron-bearing waters but is more rare than iron. Chemically it can be considered a close relative of iron since it occurs in much the same forms as iron. When manganese is present in water, it is every bit as annoying as iron, perhaps even more so. In low concentrations it produces extremely objectionable stains on everything with which it comes in contact. Deposits collect in pipelines, and tap water may contain black sediment and turbidity due to precipitated manganese. When fabrics are washed in manganese-bearing water, dark brown or black stains are formed due to the oxidation of the manganese(Seelig,B.,1992).

At present arsenic contamination of groundwater is a major public health problem in Bangladesh. The presence of arsenic above the Bangladesh limits of safe drinking water of 50 µg/L was first detected in groundwater of the Bengal Delta Plain (BDP) aquifers in Bangladesh in 1993. This has resulted in a severe environmental disaster affecting several million people in the region, as groundwater is the main source of potable water for nearly 98% of the population in Bangladesh. It is unfortunate that the presence of arsenic in addition to iron in drinking water has emerged as a serious threat to public health challenge (Ahmed,2005).

Arsenic toxicity has no known effective treatment, but drinking of arsenic contamination free water can help the arsenic affected people to get rid of the symptoms of arsenic toxicity(Ahmed,2005). Hence, provision of arsenic contamination free water is urgently needed for mitigation of arsenic toxicity and protection of health and well being of people living in acute arsenic problem areas. Figure 1-1 shows distribution of arsenic concentrations in groundwater of Bangladesh (NAMIC and BAMWSP, 2004)

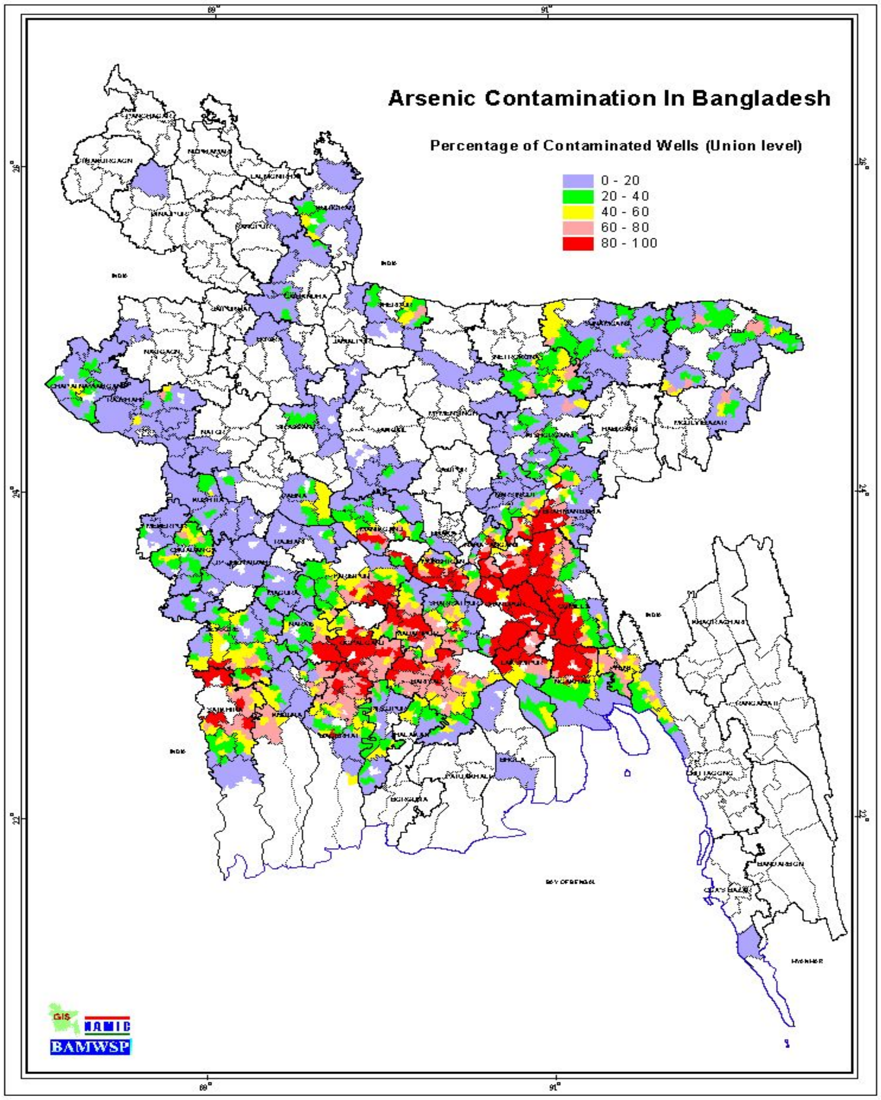


Figure 1-1. Distribution of arsenic in groundwater of Bangladesh (Source: NAMIC and BAMWSP, 2004)

National water quality surveys (BGS and DPHE, 2001) have shown that in Bangladesh, large numbers of wells exceed permissible limits for iron (Fe) and manganese (Mn). This is true of shallow tubewells, and also to some extent for deep tubewells and ring-wells, which are common water supply options in arsenic-affected areas. The National Hydrogeochemical Survey conducted by the British Geological Survey in 1999-2000 found that half of the wells surveyed exceeded the Bangladesh drinking water standard for iron (1 mg/l), and three quarters exceeded the permissible limit for Mn (0.1 mg/l). Both of these limits are based on aesthetic concerns; above these levels, people may be unwilling to drink the water, and turn instead to a better-tasting, but micro biologically less safe, water sources (BRTC,2006). Figures 1-2 and 1-3 show distribution of iron and manganese concentrations respectively in groundwater of Bangladesh (from BGS and DPHE, 2001).

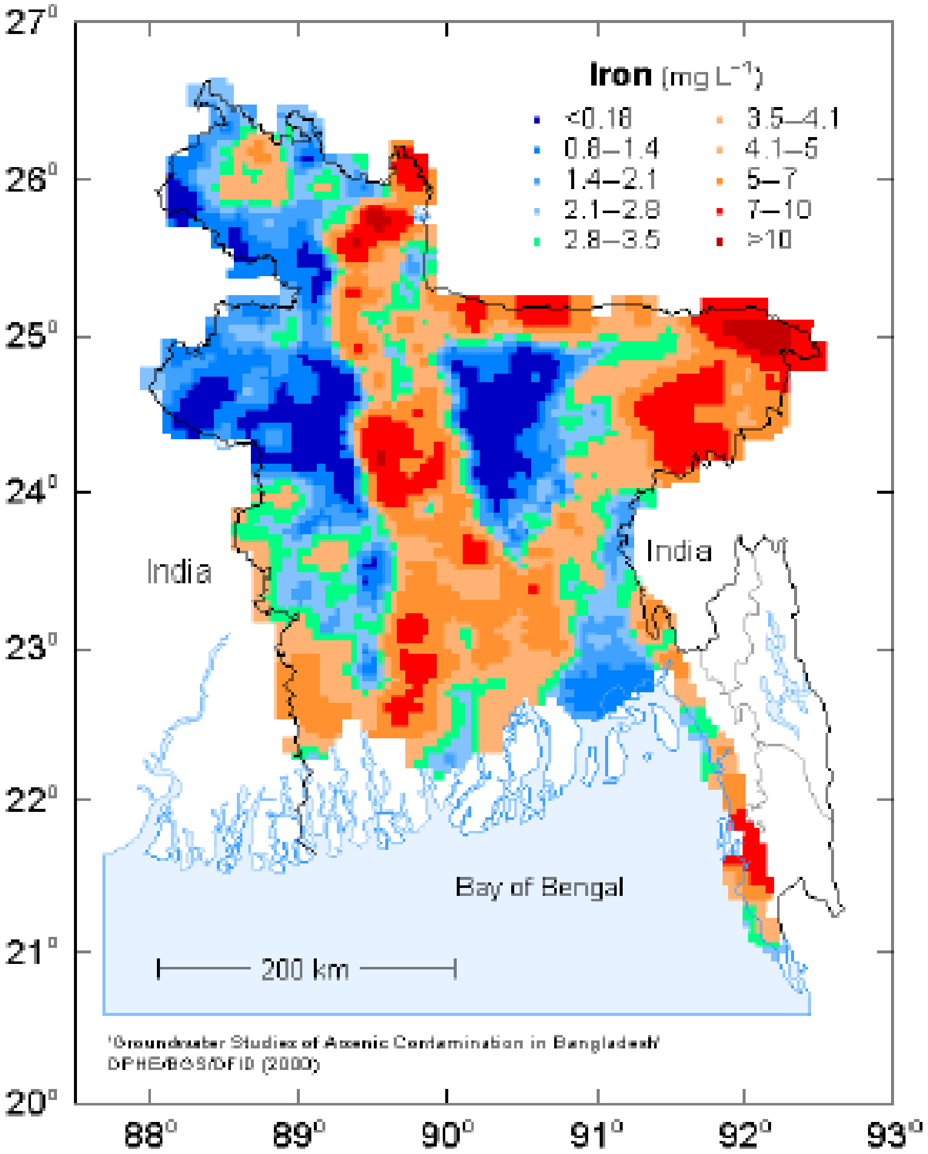


Figure 1-2. Distribution of iron in groundwater of Bangladesh (Source: BGS and DPHE, 2001)

High concentrations of manganese are found in most areas of Bangladesh but relatively high concentrations are seen in the current Brahmaputra and Ganges floodplains. The distribution generally does not correspond to that of arsenic (BGS and WaterAid, 2001). This means that groundwater with acceptable concentration of arsenic may not have acceptable concentration of manganese. Some of the reported iron and manganese concentrations (BGS and DPHE, 2001) are very high, over ten times the permissible limit. Iron and manganese concentration as high as 25 mg/l and 10 mg/l, respectively have been reported. Average iron concentration has been reported to be 3 mg/l (median 1 mg/l) and average manganese concentration 0.5 mg/l (median 0.3 mg/l) [BGS and WaterAid, 2001].

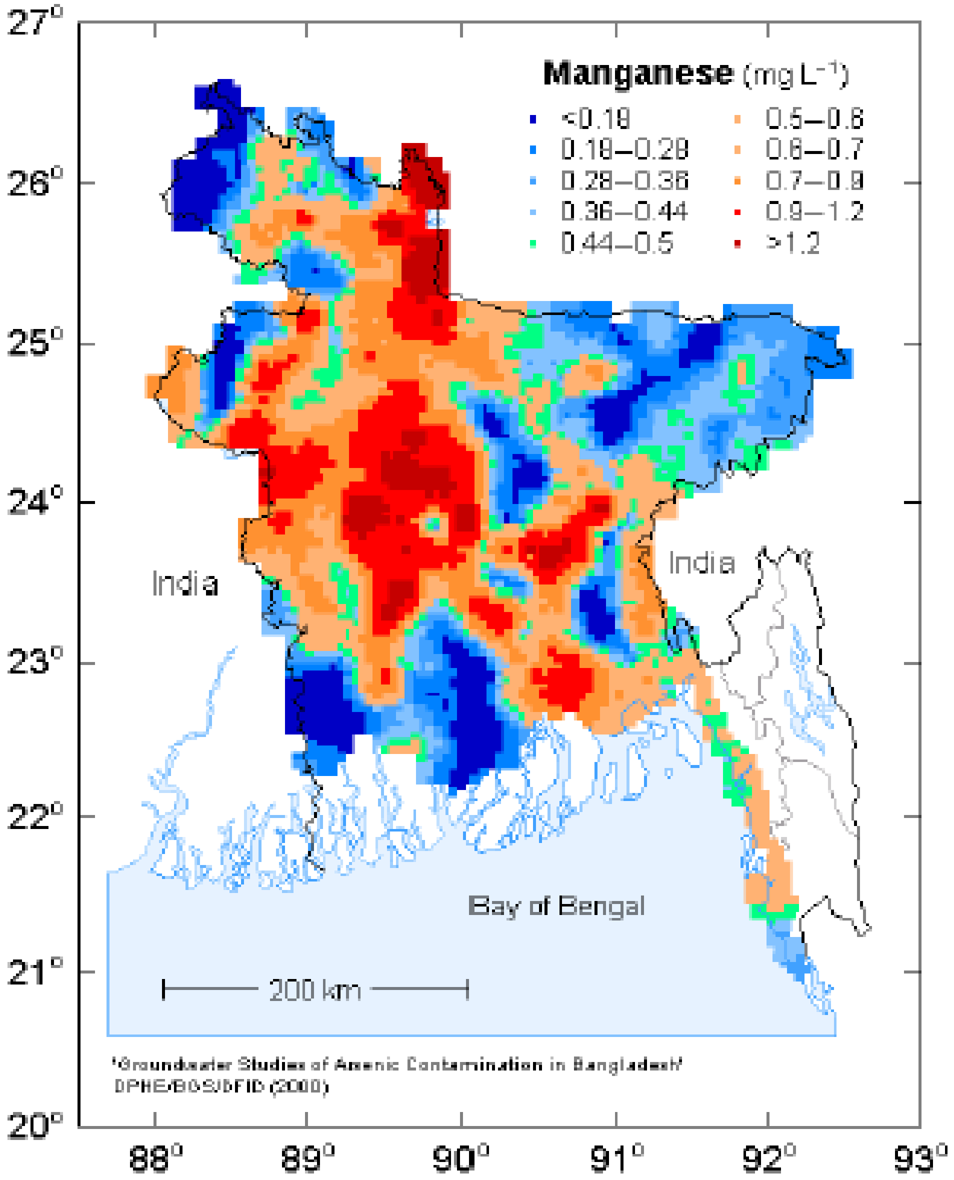


Figure 1-3. Distribution of manganese in groundwater of Bangladesh (Source: BGS and DPHE, 2001)

Manganese also has adverse health impacts, and WHO recommends a guideline value of 0.4 mg/L (BRTC ,2006) to protect against neurological damage. About 40% of wells sampled by the BGS exceeded this limit for manganese as well. The manganese issue has attracted relatively less attention, partly because groundwaters high in Mn are often found to be high in Fe as well, and both result in a similar metallic taste.

1.2 RATIONALE OF THE STUDY

The iron problem has long been recognized in Bangladesh, and many technologies have been developed for iron removal at municipal, community and household levels. Municipal Iron Removal Plants (IRPs) were first installed in Bangladesh during the early 1980s. After the detection of arsenic in ground water, many municipal IRPs are now being designed and used for removal of both iron and arsenic. In the backdrop of the discovery of arsenic in many areas of the country, community treatment units designed for removal of both arsenic and iron are becoming popular. Many NGOs are now installing different types of such community-based iron/ arsenic removal plants. However, most of the plants have been constructed without following any technical design parameters (BRTC, 2006). It would be interesting to see whether Mn is removed significantly in the currently operational iron and/or Fe-As removal plants, which have been designed primarily for removal of iron and/or arsenic. Removal of iron is less difficult than removal of manganese. Removal of manganese is almost impossible without either using an oxidizing agent or increasing the pH (Hartmann,2001). It is reported that when high amount of dissolved iron is present in water, Mn removal by chemical oxidation is relatively poor (Afsana, 2004).

From Laboratory based extensive model studies it has been found that up-flow gravel bed flocculator cum roughing filter is very efficient for the removal of both arsenic and iron (over 85%) without using granular sand filter (Ahmed, 1998). Moreover, it has been observed that cleaning and maintenance of the bed can be done simply through periodically flushing/draining without much trouble.

Few years back, ITN-Bangladesh under a research program has developed a combined Arsenic Iron Removal Unit (AIRU) and made some recommendations for future study such as (i) to conduct extensive field tests of the AIRU to study both iron and arsenic removal performances and to determine maximum removal capacity under different water quality conditions,(ii) to study the comparative performances of variable adsorbents (activated alumina, iron coated sand, Read-F etc.) column attachment with the AIRU in acute arsenic problem areas and to find out the most suitable combination and (iii) to study the performance of using brick chips aggregate in stead of gravel for both flocculation and roughing filtration purpose(Ahmed,2005). The present study “Effectiveness of Multistage Filtration in removing Iron, Manganese and Arsenic from groundwater of Bangladesh” has been performed on the basis of the above recommendations with additional attention on manganese issue.

1.3 OBJECTIVES OF THE PRESENT RESEARCH

Following were the major objectives of the study:

(a) To investigate the effectiveness of Multistage Filtration Units (MSFU) for combined removal of iron, manganese and arsenic from groundwater under different hydro-geological conditions of Bangladesh.

(b) To investigate the maximum Iron, Manganese and Arsenic removal capacity of Multistage Filtration Units and to determine the length of run (break through period) between cleaning and the effect of other environmental factors on the removal performance.

(c) To develop fundamental design parameters of MSFU separately for Arsenic-Iron and Iron-Manganese removal .

(d) To determine the operation and maintenance procedure (cleaning) for Multistage Filtration Units.

(e) To investigate the users acceptability of MSF units in Iron. Manganese and Arsenic affected areas.

1.4 SCOPE OF THE STUDY

This study evaluates the removal efficiency of iron, manganese and arsenic from groundwater through the Multistage Filtration Units (MSFU) at the field level following the techniques of adsorption and co-precipitation of arsenic and manganese with natural iron content in 3(three) different water quality conditions of the country. Community participation was the major concern for specially operation and maintenance aspects. The operation and maintenance problems of the MSFU at the field level were assessed through long term monitoring and also by field questionnaire survey regarding the user opinion. It was tried to find out probable solutions of the problems encountered through design modifications and community participation.

1.5 ORGANIZATION OF THE THESIS

Apart from this chapter, the remainder of the thesis has been divided into four chapters:
Chapter 2 presents literature review concerning occurrence of iron, manganese and arsenic, the chemistry of iron, manganese and arsenic, the technologies and unit processes of iron, manganese and arsenic removal , Multi-Stage Filtration Units, Design Parameters of Multi-Stage Filtration Units, Optimising Multi-Stage Filtration Units for use in Bangladesh, Design of BUET-ITN AIRU, its design ,findings and recommendations are also discussed in this chapter.

Chapter 3 briefly reviews the methodologies of this research work concerning the selection of project areas and zoning, water quality characteristics of project area and plant location, selection of the treatment unit processes ,construction of Multistage Filtration Units, sampling, monitoring and analytical methods of testing. Design consideration of the MSFU field construction and subsequent modifications are also discussed in this chapter.

Chapter 4 represents the performance analysis of the MSFU at the field level in respect of different treatment unit process wise iron ,arsenic and manganese removal efficiency as well as overall removal efficiency, development of equations to express the effect of tube well water iron concentration on iron and arsenic removal performance respectively , flow variation, flow recovery, effect of MSFU on water use, users opinion regarding the MSFU. Operation and maintenance procedures, filter run between cleaning interval, performance of Iron Chips Column (ICC) attachment with the existing MSFU, bacteriological analysis, a comparison of overall performance between MSFU and ITN-AIRU are also focused in this chapter.

Finally, in Chapter 5 major conclusions of the study have been cited. It was attempted to set important design parameters for different water quality conditions. Recommendations for future study are also provided here.

CHAPTER TWO

LITERATURE REVIEW

2 INTRODUCTION

Groundwater in general, has relatively better water quality and usually requires limited treatment with relatively low capital and operational cost. Many countries in the world consequently rely on groundwater to a large extent as a source of drinking water. Groundwater have qualitative problems that could be of natural and / or anthropogenic origin. The presence of Fe and Mn in groundwater could confer colour, poor bitter taste, staining of laundry and plumbing fixtures. Arsenic, on the other hand, if present does not pose any aesthetic problem, but is potential health hazard if its concentration is in excess of guideline value. Many arsenic containing ground waters also contain significant levels of iron and manganese due to natural geochemistry. In the following sections attempts have been made to provide an overview of the most common and accepted processes available for the removal of iron manganese and arsenic, their various advantages and disadvantages.

2.1 TREATMENT OF IRON AND MANGANESE CONTAMINATED WATER

Removal of iron is less difficult than removal of manganese. Removal of manganese is almost impossible without either using an oxidizing agent or increasing the pH (Hartmann,2001). When both iron and manganese present together, removal is usually carried out in two steps, first iron is removed either by a physical-chemical or biological process and then manganese is removed by a physical-chemical process. However, it is advisable to explore whether it is possible to remove both iron and manganese simultaneously.

2.1.2 Iron and Manganese Chemistry

2.1.2.1 Iron and manganese occurrence and chemical forms:

Iron and manganese, which comprise 5% and 0.1% respectively of the earth's crust, are found widely distributed in both surface and ground waters in nearly all geographic areas. Dissolution of these elements occurs by various processes and results in a variety of conditions regarding the concentration and chemical forms in which they are found in water.

Iron exists in soil and minerals mainly as insoluble ferric oxide and iron sulphide (pyrite). It occurs in some areas as ferrous carbonate which is very slightly soluble. Some ground waters usually contain significant amount of CO_2, appreciable amounts of ferrous carbonate may be dissolved by the reaction shown in the equation: $FeCO_3 + CO_2 + H_2O \rightarrow Fe^{2+} + 2HC0_3^-$

2.1.2.2 Solubility of iron and manganese:

Iron (II) (Fe^{2+}) and Manganese (II) (Mn^{2+}) are chemically reduced, soluble, invisible in ferrous form and may exist in tubewell waters or anaerobic reservoir bottom water under the following conditions:

In absence of DO, at high CO_2 concentration (>100 mg/L), at lower pH (<6.5), lower

alkalinity (<130 mg/L as $CaCO_3$) and complex with organic materials.
Iron (III) (Fe^{3+}) and Manganese (IV) (Mn^{4+}) are oxidized, insoluble, visible under the following conditions:
In presence of DO, at higher pH value (>7.5) due to release of CO_2 concentration
(<10 - 15 mg/L), higher alkalinity and in absence of organic materials.
Manganese is oxidized and precipitate in the form of MnOOH rather than manganese dioxide, MnO_2, The chemistry of manganese oxidation is more complex than that of iron.(O'Conner,1971)

2.1.2.3 Factors affecting iron & manganese oxidation and precipitation

The single most important factor in the control of iron and manganese oxidation is that sufficient oxidation be conducted with sufficient detention time to allow for complete and efficient removal.

Iron Concentration

Rate of ferrous iron oxidation is of the first order with respect to ferrous iron concentration and the partial pressure of oxygen (Ghosh et al., (1966). Rate of oxidation remains unaffected by DO concentration, if the iron concentration exceed 5mg/L. At low iron concentration chemical oxidants (oxidizing agent) is required

pH Value

Reaction rate are strongly pH dependent and there is a second order relationship, quite slow at pH 6.00 (Stumm et al., 1961) and very rapid at pH >7.5. Solubility of ferric hydroxide decreases with increasing pH only upto about 10.0.

Manganese is much more slowly oxidized than iron- infact, the rate is negligible at pH levels below 9.0.

Alkalinity Value

It is normally assumed that hydroxide ppt is formed following oxidation. However, depending on the amount of carbonate alkalinity (>250 mg/L as $CaCO_3$) ferric carbonate is formed rather than hydroxide.

Oxidation reaction is incomplete and very slow for low alkaline water (<130 mg/L as $CaCO_3$). Within a pH range of 7.49 - 7.78 an increase of alkalinity from 395 to 610 mg/L as $CaCO_3$, causes a 10 fold decrease in half time.

Temperature

Rate increases about 10 fold for a 15°C increase in temperature(Stumm et al., 1961).

Presence of other Ions

Chloride and sulphate ions have a significant retarding influence on the rate constant in the pH range from 6.5-7.2 (Sung and Morgan,1980).

Presence of Organic Matter

Organic materials interferes with removal of iron and manganese by the formation of organic complexes which is resistant to oxidation, even in the presence of DO (Theis and Singer,1974). Prior to oxidation these complexes must be broken down by the application of strong oxidizing agents. Permanganate in this application will function adequately at neutral pH, however, other oxidants require pH levels above 8.5 for manganese oxidation.

Catalyst

For a given pH and DO concentration, the addition of as little as 0.02 mg/1 of Cu^+ reduces the oxygenation time by a factor of 5.

If water contains organic materials such as humic or fulvic acid, aeration is sufficiently rapid if it is catalyzed by pyrolusite or by accumulation of oxidation products (Fe_2O_3 and MnO_2) on a porous bed such as coke or gravel. Simple aeration will not provide oxidation and precipitation within a reasonable time, although elevation of the pH will increase the rate substantially.

2.1.3 Unit Processes of Iron Removal

2.1.3.1 Aeration

This is the process of bringing water into intimate contact with air with the objectives of (a) addition of O_2 (b) removal of CO_2 (c) removal of various organic compounds responsible for taste and odour. This is a physical phenomenon in which gas molecules are exchanged between a liquid and a gas at a gas-liquid interface(Ali,1990).

In water treatment plant for iron removal, aeration is done with the aims of removal of CO_2 from water which in turn will result in an increase in pH value and in the mean time addition of O_2 to water to oxidize dissolved ferrous iron to insoluble ferric iron.

The solubility or addition of a gas depends on:

(1)Its partial pressure in the atmosphere in contact with water
(2)The water temperature
(3) The concentration of impurities.

In order that the reaction will go to completion and precipitate the ferric hydroxide, it is necessary that the pH be approximately 7 or higher. If possible the pH should be raised to 7.5 to 8.0 but even then the reaction may take 15 minutes retention before it is complete and in cases as much as 1 hour retention has been necessary (Walker, 1978). The length of retention time depends on the degree of aeration and the dissolved oxygen content of the aerated water. Aeration can be optimized by increasing contact time and interfacial area.

2.1.3.2 Coagulation

In many water treatment facilities, a chemical coagulation process is used to enhance the removal of colloidal and dissolved substances from water.When ferrous iron solution is oxygenated the precipitate is roughly concentrated in the sub micron size range. Agglomeration of particles into groups increases the effective size and therefore the settling velocities. Hydrolysis of metal ions and aqueous chemistry of these ions are essential to an understanding of their role in coagulation.

Iron undergoes a series of hydrolytic reactions prior to precipitation of $Fe(OH)_{3(s)}$. Iron salts dissociate to yield trivalent Fe^{3+} ions, which hydrate to form the aquometal ion, $Fe(H_2O)_6^{3+}$. The aquometal ion can then react and form several hydrolysis species including mononuclear species and polynuclear species.

Hasan(2003) mentioned that Stumm and O'Melia (1968) and others have given the stepwise conversion of the tripositive iron ion to negative iron ion as pH increases as follows:

$$\begin{tikzcd} {[Fe(H_2O)_6]^{3+}} \arrow[r] & {[Fe(H_2O)_5OH]^{2+}} \arrow[r] \arrow[d] & {[Fe(OH)_2]^{4+}} \arrow[r] & {[Fe\ (H_2O)_3(OH)]_{(s)}} \arrow[r] & {[Fe(H_2O)_2[(OH)_4]^-} \\ & {[Fe(H_2O)_4(OH)_2]^+} \arrow[ur] & & & \end{tikzcd}$$

The charge on hydrolysis products and the precipitation of metal hydroxides are both mainly controlled by pH. Sullivan and Singley (1968) have estimated the quantity of mononuclear iron species (monomers) at different pH. The dominant species upto pH 4.0 is Fe^{3+}, from 4.0 to 6.0 it is $Fe(OH)_3$ and above pH 6.0 it is $Fe(OH)_6^{2-}$ (Hasan, 2003).

2.1.3.3 Gravel bed flocculator

Usually the source of power for flocculation devices are gravitational, pneumatic or mechnical. But neither mechanical mixing nor baffle mixing are feasible and practicable in many small community water supply systems. A simple solution to the flocculation process is the one involving course media bed in which water is allowed to flow through a packed bed of course media. The sinuous flow of water through the interstices of course media will provide repeated contacts among the small suspended particles to form compact settleable flocs. A portion of the agglomerated flocs will settle on the surface and within the interstices of course media. Which will further help in adsorbing finer particles as they come into contact with the settled floes. Moreover, in an up flow system as the flow of water emerges from the course media, due to sudden drop of velocity, agglomerated flocs will settle on the top of coarse media bed forming a layer of sludge which is also effective in the removal of finer particles. This type of flocculator occupies small area and no external source of power is required. Moreover the whole bed of coarse media is effective for flocculation purposes. This type of flocculator is now in use of many small community water supply systems in Thailand, India, Bangladesh and Latin American countries(Hasan, 2003).

2.1.3.4 Sedimentation

Sedimentation is the removal of particulate matter, chemical floc and precipitate from suspension through gravity settling (Hammer, 1977). The sedimentation process in water treatment provides for the settling and removal of heavier and larger suspended particles from water. Most commonly, it is used for removal of flocculated particles prior to filtration. The removal efficiency in the sedimentation basin determines the subsequent loading on the filters

and accordingly, has a marked influence on their capacity, the length of filter runs and the quality of the filtered water.
The factors that affect the sedimentation process are density, size and velocity of settling particles, drag co-efficient, acceleration due to gravity, detention period and effective depth of the settling basin etc. Sedimentation can be accelerated by increasing particle size or decreasing the distance a particle must fall prior to removal. The first is achieved by coagulation and flocculation prior to sedimentation. The second can be achieved by making the basin shallower or by providing tube settlers.

2.1.3.5 Filtration

Filtration is a unit process widely used in water treatment for the removal of particulate materials. In this process, water passes through a filter medium and particulate materials either accumulate on the surface of the medium or are collected through its depth. Filters have been found effective for removing particulate of all size ranges provided that proper design parameters are used. Figure 2-1 shows the application of filters in conventional water treatment.

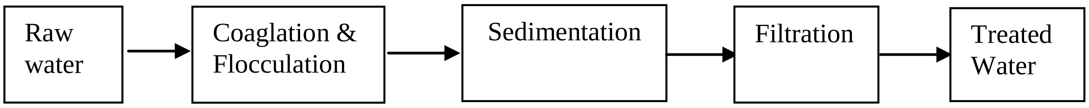


Figure 2-1. Application of filters in conventional water treatment

The principal mechanisms that are believed to contribute to the removal of materials in filter are (a) impaction (b) interception (c) sedimentation (d) adhesion (e) biological growth etc.The efficiency of filtration is dependent on various design variables. A decrease in porosity ofthe granular media will increase the particulate removal efficiency. In addition, increasing the filter depth or decreasing the filter media size will improve particle capture. Two general types of filters are commonly used in water treatment: the slow sand filter and the rapid sand filter.

2.1.3.5.1 Slow sand filtration

It consists of a layer of ungraded fine sand through which water is filtered, at a low rate. The traditional rate of filtration used for normal operation is 0.1 m/hr, although it is possible to produce safe water at rates as high as 0.4 m/hr. The sand bed thickness varies between 1.0 and 104m. Filter sand should have an effective size between 0.15 and 0.35mm and uniformity co-efficient between 1.5 and 3.0. Slow sand filters are more practical in the treatment of water with turbidity below 50 NTU, although higher turbidities can be tolerated for a few days. The best purification occurs when the turbidity is below 10 NTU. The filter is cleaned by periodically scraping a thin layer of dirty sand from the surface when it becomes too clogged with impurities at intervals of several weeks to months. The low rate of filtration allows the formation of an active layer of microorganisms, called the schmutzdecke on the top of the sand bed which provide biological treatment. This layer is particularly effective in the removal of microorganisms from water (Schulz and Okun, 1984).

2.1.3.5.2 Rapid sand filter

It consists of a layer of graded sand or in some instances a layer of coarser filter media (e.g., anthracite) placed on top of a layer of sand, through which water is filtered. The rate of filtration used for normal operation is much higher than slow sand filter. Normal filtration rate is 4 m/hr., although it can be as high as 21 m/hr. Effective size of filter sand is 0.55 mm and higher and uniformity coefficient 1.5 and lower. The filter is cleaned by back washing ·with water. Because of the higher filtration rates, the space requirement for a rapid sand filtration plant is 20% of that required for slow sand filters (Schulz and Okun, 1984).

2.1.3.5.3 Roughing filtration

It allows deep penetration of suspended materials into a filter bed and they have a large silt storage capacity. Roughing filtration uses much larger media than either slow or rapid sand filtration and the media size is greater than 2.0 mm. The rate of filtration, can be as low as se used for slow sand filters or higher than those used for rapid sand filters, depending upon the type of filter, the nature of turbidity and the desired degree of turbidity removal. Roughing filters are limited, however, to average raw water turbidities of 20 to 150 NTU. The solid materials retained by the filters are removed by flushing or if necessary, by excavating the filter media, washing it and replacing it. There are basically two types of roughing filters, which are differentiated by their direction of flow and these are:

(a)Vertical flow roughing filters
(b)Horizontal flow roughing filters

International Reference Center for Community Water Supply and Sanitation (1983) has described the advantages of course grained roughing filter which has large pores that are not liable to clog rapidly. The large pores also allow cleaning at low backwash rate, since no expansion of the filter bed is needed. In up flow type roughing filters grain sizes of 15 mm to 7 mm arranged in different layers and a flow rate of 0.5 to 1.0 m/hr have been recommended. Equina (1979) has made a study on the pretreatment of water containing iron and manganese using a horizontal-flow filter with crushed stone as the filter media. The regression analysis was made to determine the factor(s) affecting the filter performance. The length of the filter run was found to be the most important factor for the removal of iron from groundwater. At the filtration rate of 0.4 cu.m.lsq.m1hr and average iron concentration of 1.24 mg/L could be removed around 47%.

2.1.4 Iron and Manganese Removal Techniques

To remove soluble iron it is generally accepted that an oxidation process followed by a suspended solids removal process is most effective. Usually oxidation of soluble iron is accomplished by simple aeration or chlorination/potassium permanganate application. Coagulation - flocculation with sedimentation and filtration are employed as solid removal processes.

Ahmed (1987) developed a low-cost iron removal plant based on four major units, e.g. aeration channel, sedimentation and two brick chips adsorption chambers. Several plants were constructed and it was found to be effective in removing iron from No.6 tube well with yielding capacity of 9 to 13 L/min. The plants have been found to be very effective In removing soluble iron from tube well water in excess of 90 percent.

Ahmed (1987) conducted some studies on horizontal flow roughing filter for the removal of iron from water. It was observed that in a roughing filter of 0.4 m long with 4 to 10 mm filter grain size and a filtration rate of 0.4 m/hr, an average of over 92% iron removal could be achieved during a total run of 100 hours. It was also observed that the most important factor that affects the performance of a roughing filter is the increasing depth of penetration of iron sludge with time.

In 1986-87 UNICEF developed an improved iron removal plant consists of three units e.g. perforated ferrocement channel, sedimentation chamber and brick chip filter. The plant was found to be effective in iron removal and the filter run was also satisfactory. A study by WHO,UNICEF and DPHE (1990) on these iron removal plants showed that iron removal was satisfactory. The iron concentration was reduced to around 1.5 ppm from 15 ppm with average cleaning period of 12 days (with minimum of 5 days). With the same interval of . cleaning it has been observed that the higher the concentration in raw water the higher the concentration in treated water but it was not exceeded 2.5 ppm.

For the elimination of iron from hand pump tubewell water, Aowal (1981) proposed to introduce a spray aeration, a settling tank and a plain sand filter, all housed in a single chamber. Although an effective removal was achieved the length of run between cleaning was very short, less than 24 hours. The top layer of fine sand was needed to be removed, washed and dried for the next use, which is not easy.

Kibret (1986) has shown that dry filter is one of the alternatives that can be applied for iron removal and the process uses the self-purification capacities of iron bacteria. Investigation made on the pilot plants showed that iron removal process by dry filtration depends on the hydraulic load, filter depth, size of filter material, the development of the microorganisms and iron concentration in the raw water. Dry filter does not only remove iron but it also removes manganese, ammonia, and carbon dioxide and provides sufficient oxygen supply to the treated water. The results obtained from the test plants were not bellowing the standard limits except from the full-scale production plant. However, complete removal of iron by dry filter is feasible provided the best possible favorable combinations of the factors on which iron removal depends are found.

In 1985-86 over hundred iron removal units, which were originally designed by BUET under a research programme, were built at sirajgonj and comilla. These units are reported to fail due to following reasons (Hasan,2003):

(a) Lack of community participation in all activities of the project.
(b) Faulty construction of the unit.
(c) Lack of continued support and technical advice from DPHE/UNICEF.
(d) Difficulty in cleaning the filter due to short filter runs.
(d) Complicated design of the unit .

In1988, DPHE with the help of UNICEF, Dhaka Bangladesh, designed and constructed iron removal plant for hand pump tube wells in different parts of Bangladesh. Those plants were also failed due to faulty design of sedimentation chamber, where flocs were gradually settled and mixed with treated water.

Wong (1984) has shown that processes in which oxidation is followed by removal of suspended solids can effectively remove soluble iron and manganese from water. He has developed three common processes for removing iron and manganese, e.g. (i) aeration-f-iltration (ii) chlorination-filtration and (iii) potassium permanganate-manganese greensand filtration.

Other processes such as ion exchange, chlorine dioxide filtration, stabilization with polyphosphates etc. have also been applied but with less frequency, owing to cost and operational considerations. Removal processes are selected on the basis of iron concentration and other conditions.

There are four general methods used for the removal of iron:

A. The primary method involves oxidation, precipitation followed by solid transfer (sedimentation and filtration).
B. The second method involves ion exchange.
C. The third method involves stabilisation of iron in suspension using dispersing agents to prevent the deposition of iron.

D. Sub-surface aeration.

2.1.4.1 Oxidation, precipitation followed by flocculation, sedimentation and filtration

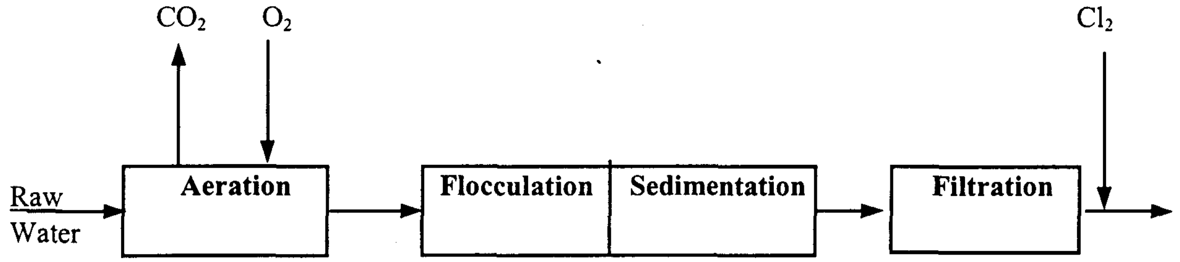
The most popular method of iron removal involves oxidation of more soluble iron (II) to relatively insoluble iron (III) and subsequent removal of the precipitates thus formed by sedimentation and filtration.

2.1.4.1.1 Oxidation through simple aeration

The simplest form of iron oxidation is plain aeration. Stoichiometrically 1.0 mg/L of O_2 is required to oxidize 7.0 mg/L of Fe. However, aeration alone is not effective for manganese oxidation at normal pH level.

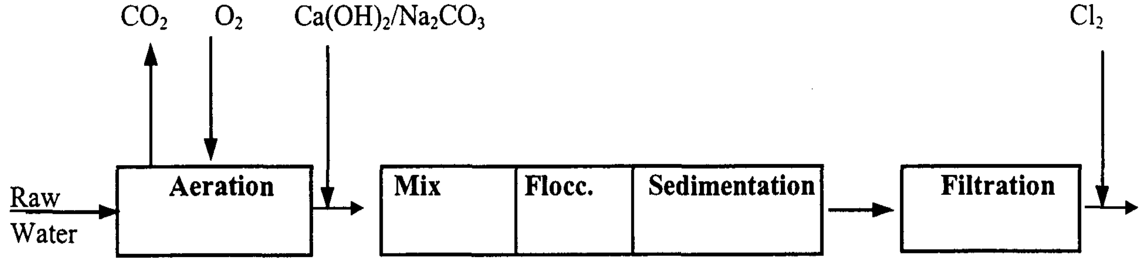
$$4Fe(HCO_3)_2 + 0_2 + 2H_20 \rightarrow 4\ Fe(OH)_{3(s)} + 8CO_2$$

Iron, Fe(II) alone in ground waters which contains little or no organic matter with reasonable alkalinity when aerated CO_2 and H_2S are released raising the pH and oxidized to insoluble ferric iron, Fe(III).



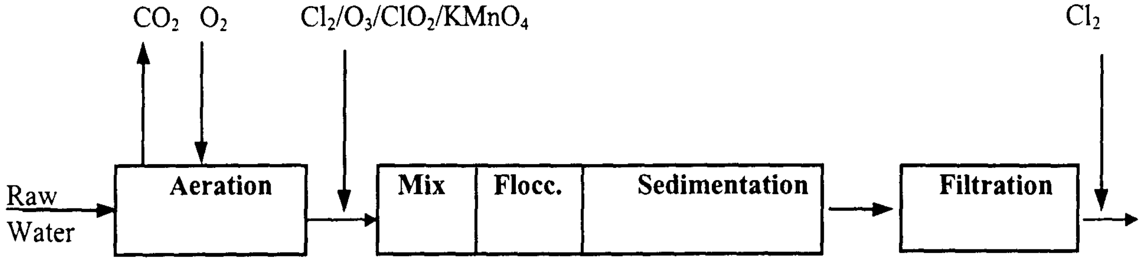
2.1.4.1.2 Aeration oxidation under increased alkalinity

Low alkalinity water (<130 mg/L as $CaCO_3$) needs some chemical additive to raise both pH and alkalinity like lime [$Ca(OH)_2$], soda ash [Na_2CO_3] etc. Manganese also can be oxidized at increased pH value greater than 9.0. If the water is softened by addition of lime, additional benefits include removal of iron. Aeration prior to lime addition reduces the cost of chemicals through CO_2 reduction.



2.1.4.1.3 Chemical oxidation in presence of organic matter.

Organic material interferes with removal by forming soluble complexes. Preliminary aeration strips out dissolved gases and adds oxygen. In low alkaline or organic content water, the application of strong oxidizing agents such as chlorine, ozone, chlorine dioxide, or potassium permanganate can serve to modify or to destroy the organic material and to oxidize iron more rapidly. 1.0 mg/L of potassium permanganate will oxidize 1.06 mg/L of iron and 0.52 mg/L of manganese respectively and 1.0 mg/L of chlorine is required for 1.56 mg/L of iron oxidation.

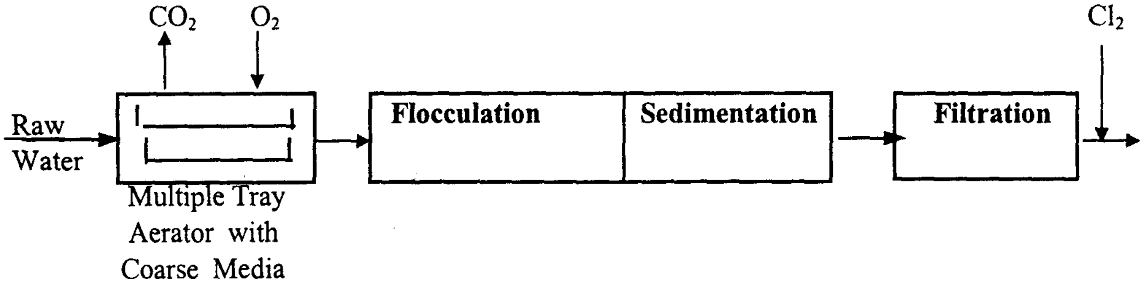


2.1.4.1.4 Catalytic contact oxidation in presence of organic matter & low alkalinity

If the water contains organic matter such as humic or fulvic acid and if the alkalinity is low, aeration is sufficiently rapid only if it is catalyzed by accumulation of oxidation products (Fe_2O_3) on a porous bed (aeration tower containing trays with coarse media). Previously precipitated iron and manganese act as a catalyst for precipitates the compounds in the media.

Hydrous oxides of metal i.e Fe(III) and Mn(IV) have high sorption capacities for unoxide metal ions. Both hydrous $Fe(OH)_3$ & MnO_4, for instance, tend to sorb Fe^{++} & Mn^{++} ions.

Removal of iron is generally hastened and made more efficient by letting water trickle downward or rise upward through gravel or other relatively coarse heavy materials(Fair, 1966). As the contact interfaces become coated with hydrous oxides of metal, the removal by sorption becomes swifter and more complete. When the sorption capacity of surfaces of this kind has been exhausted, they can, in a sense, be regenerated with oxidants like Bleaching powder or Potassium Permanganate. Iron is removed from solution by adsorption on the bed.



2.1.4.1.5 Biological oxidation

Gallionella ferruginea , Leptothrix and other iron bacteria are capable to oxidise iron.

Solid Transfer:

Oxidized and precipitated iron particles should be removed through effective flocculation, sedimentation and filtration, since a significant amount of the flocculated metal oxides are not heavy enough to settle by gravity. Direct filtration is not always recommended to avoid frequent clogging of filter bed, particularly when the concentration of iron is high.

2.1.4.2 Manganese zeolite process /ion exchange

Manganese zeolite (Pyrolusite) is natural green sand (Glauconite) coated with manganese dioxide that removes soluble iron and manganese from solution. Unlike other zeolite processes, it does not involve an ion-exchange reaction. After the zeolite becomes saturated with metal ions, it is regenerated using $KMnO_4$. Cation-exchange resins will remove iron, but care must be taken to ensure that it remains in the reduced state, otherwise, it will form coating on the resin reducing the exchange capacity(Azim,1991).

2.1.4.3 Stabilization

According to Clark et. al. (1977) Sodium hexa-metaphosphates at dosages of 5 mg per mg of Fe and Mn are used for this purpose. This process is limited for Fe + Mn concentration upto 1.0 mg/L. Moreover, when the water is heated, the polyphosphate will revert to orthophosphate and loose its dispersing properties. The application of polyphosphate must take place prior to aeration or chlorination because the polyphosphate do not effectively stabilize precipitated ferric hydroxide. Polyphosphate dosages are limited to less than 10 mg/L because the availability of phosphorus may stimulate bacterial growths in distribution systems.

2.1.5 Summary of Iron and Manganese Removal Kinetics

A. Kinetics of iron oxidation, precipitation and removal

a)The rate of ferrous iron oxidation is of the first order with respect to ferrous iron concentration present and the partial pressure of oxygen.
b)Reaction rate are strongly pH dependent and there is a second order relationship (100-fold rises with a unit increase in pH), quite slow at pH < 6.5 and very rapid at pH > 7.5.
c)Oxidation reaction is incomplete and very slow for low alkaline water (< 130 mg/l as $CaCO_3$). Within a pH range of 7.49 - 7.78 an increase of alkalinity from 395 to 610 mg/l as $CaCO_3$, causes a 10-fold decrease in half time.
d)Aeration is sufficiently rapid only if it is catalyzed by accumulation of oxidation products (Fe_2O_3 and MnO_2) on a porous bed. Previously precipitated iron (Fe_2O_3) serves to catalyze the oxidation of iron.
e)Moreover, hydrous oxides of metal, e.g. ferric oxide, Fe(III) and manganic oxide, Mn(IV) have high sorption capacities for un-oxide metal ions including Fe++ ion.

B. Kinetics of manganese oxidation, precipitation & removal

a)Manganese is much more slowly oxidised through aeration than iron. In fact, the rate is negligible at pH levels below 9.0.
b)Chemical oxidation of Mn requires a pH level above 8.5 and 1.0 mg of chlorine can oxidise 1.3 mg of Mn.
c)Mn oxidation through chlorine <u>requires 2-4 hours to react</u> completely.
d)Both hydrous $Fe(OH)_3$ & MnO_2, tend to sorb Fe++ & Mn++ ions.
e) $Mn(II) + MnO_2\,(s) \longrightarrow Mn(II).MnO_2\,(s)$ [This reaction is fast].
f)Removal of iron and manganese is generally hastened and made more efficient (swifter) by letting water trickle downward or rise upward through gravel or other relatively coarse heavy materials coated with hydrous oxides of Fe(III) and Mn(IV) precipitates by sorption.
g)If Fe(II) > Mn(II) rather than Mn(II) alone, removal than becomes predominantly a matter of sorption of Mn++ on incipient ppt. of iron

2.2 Treatment of Arsenic Contaminated Water

2.2.1 Sources of Arsenic

In nature, arsenic is generally found only in the trivalent and pentavalent states. H_3AsO_3, an un-dissociated weak acid, is predominant in the pH range of 2-9. Therefore, any As(III) present in a typical water supply would occur as H_3AsO_3., On the other hand, As(V) in water occur as a strong acid and dissociates into ions according to the pH value.

2.2.2 Oxidation States of Arsenic and Solubility

Arsenate[As(V)] and Arsenite[As(III)] are common oxidation states of arsenic in water. Arsenate is dominant in oxygenated water while arsenite is dominant in non-oxygenated water. In ground water, both the arsenate and arsinite usually exist in soluble form and unlike iron they can not be oxidised into insoluble precipitates through aeration process, as result their removal from ground water through simple aeration, precipitation and Solid Transfer Unit Operations (e.g. flocculation, sedimentation followed by sand filtration processes) is not feasible.

2.2.3 Chemical Precipitation of Arsenic

Arsenic can be chemically precipitated as arsenic (III) sulfide, calcium arsenate, or ferric arsenate. The sulfide As_2S_3 has its lowest solubility at pH value 4.0. A number of calcium arsenates [e.g., $Ca_3(AsO_4)_2$] can be precipitated from As(V) solutions by lime addition to high pH. Arsenic (V) can also be precipitated from process solutions at about pH value 2.0 with Fe(III) to form ferric arsenate, $FeAsO_4.2H_2O$. Therefore, at neutral pH range removal through chemical precipitation is not feasible.

2.2.4 Oxidation / Dissociation of Arsenic Compounds in to Arsenic Ions

Effective removal of arsenic from water requires the complete ionization/dissociation of arsenic species.

2.2.4.1 Dissociation through pH increase

Arsenite [As(III)] dissociates in to arsenite ions at pH value greater than 9.0. While arsenate [As(V)] dissociates in to different species of arsenate ion at wide range of pH from less than 7 to greater than 11.5, as shown in the following table.

Table 2-1. Occurrence of arsenic species under different environmental conditions

Type of Arsenic	Arsenite, As(III)	Arsenate, As(V)
Occurance	Predominates in reducing Condition Lower redox potentials Occur as un-dissociated week acid, Arsenious acid, H_3AsO_3 (pH 2–9)	Predominates in oxic Conditions. High redox potentials Occur as strong acid & dissociates in to different species of Arsenate ion depending on pH
Species	pH >8.0 dissociate into $H_2AsO_3^-$ arsenite ion. pH > 11.0 dissociate into $HAsO_3^{2-}$ arsenite ion.	pH < 7.0 dissociate into $H_2AsO_4^-$ arsenate ion. pH 7.0 – 11.5 dissociate into $HAsO_4^{2-}$ arsenate ion. pH > 11.5 dissociate into AsO_4^{3-} arsenate ion.

2.2.4.2 Dissociation through chemical oxidation

The oxidation of As(III) in to As(V) spices is the primary step in the removal process of arsenic. In the oxidation processes with dosing of chemicals, effective oxidants are free chlorine, hypochlorite, ozone, permanganate, and Fenton's reagent (H_2O_2/Fe^{2+}), but not the chloramines. These oxidants can convert As(III) into As(V) in the absence of oxygen.

Chlorine is widely used for oxidation purpose, but may lead to chlorinated by-products, namely Trihalomethenes (THMs), from reactions with natural organic matter.

Ozone, widely used in surface water treatment for oxidation and disinfection, is quite effective but is not feasible for a specific application with As(III) oxidation.

The most feasible oxidants are potassium permanganate and Fenton's reagent. Chlorine and permanganate are able to oxidize arsenic (III) to (V) within a very short time, e.g., half an hour or even few minutes.

2.2.5 Adsorption-Desorption Theory

Adsorption-desorption reactions are very important in determining the mobility of arsenic in nature as well as its removal in many treatment systems. Both arsenate and arsenite adsorb to surfaces of a wide range of solids including iron, aluminum and manganese oxides (e.g., iron oxyhydroxides), and clay minerals.

Arsenic is a metalloid, exhibiting metallic as well as non-metallic characteristics and corresponding chemical processes. Unlike many heavy metals (e.g., lead, zinc, cadmium) which exist in water primarily as cations, arsenic exists primarily as oxyanions (e.g., $HAsO_4^{2}$, $H_2AsO_4^{-}$) and adsorb on hydrous oxide surfaces as anions.

Adsorption-desorption of arsenic onto iron oxide surfaces are important controlling reactions in the subsurface because iron oxides are widespread in the hydro-geologic environment as coatings on other solids, and because arsenate adsorbs strongly to iron oxide surfaces in acidic and near-neutral pH conditions. Desorption of arsenate is favored at higher (i.e., alkaline) pH values.

2.2.6 Factors Affecting Arsenic Adsorption Processes

2.2.6.1 Effect of oxidation states

Arsenic(V) has been found to be more efficiently removed than Arsenic (III). Because the Arsenic(III) usually occurs in non-ionized form which is not easily removed by adsorption on metal hydro-oxide flocs. Oxidation of Arsenic(III) to Arsenic(V) is therefore required as pretreatment.

2.2.6.2 Effect of presence of other anion

Besides arsenic, a number of other ions present in natural water (e.g., phosphate, silicate, sulfate) also have strong affinity for solid surfaces and presence of high concentrations of these ions can reduce removal efficiency of arsenic in adsorption-based treatment systems.

Phosphate has the higher affinity for metal oxides and its presence reduces the arsenic removal significantly. The theoretical affinity at neutral pH for anions sorption on metal oxides are as follows:

$$PO_4 > SeO_3 > AsO_4 > AsO_3 > SiO_4 > SO_4$$

2.2.6.3 Effect of pH value

The pH dependence of arsenate adsorption-desorption appears to be related to the change in net charge on iron-oxide surface with pH. The net charge on iron oxide surface changes from positive to negative as pH increases above the “zero-point-of-charge” (pH at which net surface charge is zero). The zero-point-of-charge” is about 7.7 for goethite (crystalline iron oxide) and about 8.0-8.5 for ferrihydrite (amorphous iron oxide). Thus as pH increases above about 8.0-8.5, the net negative surface charge on iron oxides can repel the negatively charged ions such as arsenate.

Some investigators reported that the removal capacities for As(V) on Activated Alumina can be maximised at pH values around 6.0.

Anion are best adsorbed below pH value 8.2, a typical “zero point charge”, below which surface has a net positive charge. At relatively high pH (8.6), the adsorption of As(V) on alumina is severely reduced by competition from hydroxide ions. This leads to poor As(V) uptake compared to adsorption at optimum pH of 6.0. The As(III) uptake at higher pH (8.0) is however, slightly improved compared to that at pH 6.0 because of the increase in the fraction of charged H_3AsO_3. Arsenic removal through membrane filter is independent of pH value.

2.2.6.4 Effect of adsorption media size

Alumina is commercially available in four typical size ranges, 8x10, 14x28, 28x48, and 48x100 mesh from largest to smallest. The kinetics of removal are such that the smallest particle sizes provide the most surface area for adsorption/exchange of arsenic. However, smaller particle will have a greater tendency to be washed out of the bed during backwash and frequent clogging of bed if suspended particles exist, resulting increased loss of head.

2.2.6.5 Effect of presence of iron

Presence of iron may significantly affect the performance of an adsorption media. The reason is the possible fouling of the porous adsorption media by precipitated iron particles on the surface. It will clog the filter medium thereby reducing the filtration rate. Accumulation of iron particles on the adsorption surface will decrease the readily available sorption sites for arsenic. Presence of iron and manganese in water lead to scaling and membrane fouling. The membrane once fouled by impurities can not be backwashed. Pre treatment of ground water is must before membrane filtration in our country.

2.2.6.6 Effect of empty bed contact time

Since pentavalent arsenic easily adsorbed onto adsorption bed, contact time does not play any important role on bed volume, however, for high iron content water with low influent arsenic content the effect has found to be positive.

It has been noticed that the removal efficiency of trivalent arsenic increased significantly with increasing contact time. This is simply because when the contact time was long arsenic species in the influent had more chance to be adsorbed on the adsorption surface.

2.2.6.7 Effect of alkalinity

If the alkalinity of tube-well water is very low (less than 130 mg/L as $CaCO_3$) and iron concentration is less than 1 mg/L then, oxidation and precipitation of iron flocs will very negligible which will affect the co-precipitation and passive sedimentation processes.

2.2.6.8 Effect of presence of oxidising agent

Presence of oxidising agent affect the membrane quality

2.2.7 Arsenic Removal Techniques

2.2.7.1 Ion transfer

Since oxidation-precipitation and chemical-precipitations are difficult in case of arsenic spices, their removal from water is mainly based on ion transfer techniques.

Coagulation, adsorption, co-precipitation and filtration

The most commonly used technology includes, coagulation and adsorption onto coagulated flocs and subsequently removed through co-precipitation.

In Alum coagulation process the dissolved aluminium sulphate reacts with natural alkalinity of water and $Al(OH)_3$ macro-flocs are produced. During the stirring (flocculation) process all kinds of micro-particles and negatively charged arsenic ions are removed by electrostatic attachment to the flocs. More than 90 % arsenic removal can be achieved, provided pre-oxidation of As(III) to As(V) and pH adjustment (6.0 – 7.0) are done.

In coagulation with Iron salts freshly precipitated amorphous $Fe(OH)_3$ is formed upon addition of the coagulant. Arsenic is primarily removed by adsorption on the surface of $Fe(OH)_3$ flocs and subsequently co-precipitated. Iron coagulation seems to perform better than aluminium coagulants primarily because iron hydroxide is insoluble over a wide pH range (6.0 – 8.5) and is less soluble than aluminium hydroxide. Moreover, iron coagulants form stronger and heavier flocs.

In Lime softening process precipitated $Ca(OH)_2$ acts as sorbing flocculant for arsenic. The highest removals are achieved at pH value 10.6 – 11.4.

Available treatment units:

Two Bucket Treatment Unit, Stevens Institute Technology, DPHE-DANIDA Fill and Draw Units, Arsenic Removal Unit attached to TW(India), and etc.

Two bucket treatment unit:

The Bucket Treatment Unit (BTU), developed by DPHE-Danida Project is based on the principles of coagulation, co-precipitation and adsorption processes. It consists of two buckets, each 20 liter capacity, placed one above the other. Chemicals are mixed manually with arsenic contaminated water in the upper bucket by vigorous stirring with a wooden stick for 30 to 60 seconds and then flocculated by gentle stirring for about 90 seconds. The mixed water is then allowed to settle for 1-2 hours. The water from the top bucket is then allowed to flow into the lower bucket via plastic pipe and a sand filter installed in the lower bucket. The flow is initiated by opening a valve fitted slightly above the bottom of the upper bucket to avoid inflow of settled sludge in the lower bucket. The lower bucket is practically a treated water container.

The DPHE-Danida Project in Bangladesh distributed several thousands BTU units in rural areas. These units are based on chemical dosages of 200 mglL aluminum sulfate and 2 mglL of potassium permanganate supplied in crushed powder form. The units were reported to have very good performance in arsenic removal in both field and laboratory conditions (Sarkar et aI., 2000). Extensive study of DPHE-Danida BTU under BAMWSP, DFID, Water Aid (200 I) rapid assessment program showed mixed results. In many cases, the units under rural operating conditions fails to remove arsenic to the desired level of 0.05 mgIL in Bangladesh (Ahmed, 2001). Poor mixing and variable water quality particularly pH, phosphate, nitrate, sulfate and chloride of groundwater in different locations of Bangladesh appeared to be the cause of poor performance in rapid assessment.

Bangladesh University of Engineering and Technology (BUET) modified the BTU and obtained better results by using 100 mg/L of ferric chloride and 1.4 mg/L of potassium permanganate in modified BTU units. The arsenic contents of treated water were mostly below 20 ppb and never exceeded 37 ppb while arsenic concentrations of tubewell water varied between 375 to 640 ppb (Ahmed, 2001). The BTU is a promising technology for arsenic removal at household level at low cost. It can be built by locally available materials and is effective in removing arsenic if operated properly.

Stevens Institute Technology:

This technology also uses two buckets, one to mix chemicals (reported to be iron sulfate and calcium hypochloride) supplied in packets and the other to separate floc by the processes of sedimentation and filtration. The second bucket has a second inner bucket with slits on the sides to help sedimentation and keeping the filter sand bed in place. The chemicals form visible large floes on mixing by stirring with stick. Rapid assessment showed that the technology was effective in reducing arsenic levels to less than 0.05 mg/L in case of 80 to 95% of the samples tested (BAMWSP, DFID, Water Aid, 2001). The sand bed used for filtration is quickly clogged by floes and requires washing at least twice a week.

DPHE-DANIDA fill and draw units:

It is a community type treatment unit designed and installed under DPHE-Danida Arsenic Mitigation Pilot Project. It is 600 L capacity (effective) tank with slightly tapered bottom for collection and withdraw of settled sludge. The tank is fitted with a manually operated mixer with flat-blade impellers. The tank is filled with arsenic contaminated water and required quantity of oxidant and coagulants are added to the water. The water is then mixed for 30 seconds by rotating the mixing device at the rate of 60 rpm and left overnight for sedimentation. The water takes some times to become completely still which helps flocculation. The floc formation is caused by the hydraulic gradient of the rotating water in the tank. The settled water is then drawn through a pipe fitted at a level, few inches above the bottom of the tank and passed through a sand bed and finally collected through a tap for drinking purpose. The mixing and flocculation processes in this unit are better controlled to effectively higher removal of arsenic (Ahmed, 2001). The experimental units installed by DPHE-Danida Project are serving the clusters of families and educational institutions.

Arsenic removal unit attached to tubewell:

The principles of arsenic removal by alum coagulation, sedimentation and filtration have been employed in a compact unit for water treatment in the village level in West Bengal, India. The arsenic removal plant attached to hand tubewell has been found effective in removing 90% arsenic from tubewell water having initial arsenic concentration of 300 μg/L (Ahmed, 2001). The treatment process involves addition of sodium hypochloride and aluminum alum in diluted form, mixing, flocculation, sedimentation and up flow filtration in a compact unit. This process was found effective in removing arsenic but associated with high operation costs of chemicals as well as frequent maintenance due to clogging of filter bed.

Table 2-2. Effectiveness of different types of coagulants and their limitations in the arsenic removal process

Type of Arsenic	Arsenite, As(III)		Arsenate, As(V)	
Coagulants (Advantages & Limitations)	Optimu pH value	Percent Removal Capacity	Optimum pH value	Percent Removal Capacity
Alum Coagulation (Pre-oxidation of As(III) to As(V) required	6.0-7.0	<20%	6.0-7.0	>90%
Iron Coagulation (More efficient than Alum on weigh basis)	6.0-8.5	about 50%	6.0-8.5	>90%
Lime Softening (pH adjustment is required & most common chemical)	11.0	about 80%	>10%	>95%

2.2.7.2 Adsorption on metal oxides surface

Hydrous oxides of metal have high sorption capacities for unoxide metal ions. The strong adsorption of arsenic onto hydrous iron, aluminum and other solids has also been utilized in removing arsenic using a wide range of solid sorption media. These include Hybrid Aluminous and composite metal oxides particles, Activated alumina, Activated Alumina catalyzed with metal oxides, Iron coated sand, granular ferric hydroxide, and a wide range of other materials including clay minerals.

Available treatment units:
BUET Activated Alumina Arsenic Removal unit, Alcan Enhanced Activated Alumina Unit, Apyron Arsenic Treatment Unit, SIDKO Granular Ferric Hydroxide based Arsenic Removal Unit, Read-F Arsenic Removal Unit, Iron Coated Sand Filter, Shapla Arsenic Filter, Sono-3 Kalsi Filter, Safi Filter, Chiyada Arsenic Removal Unit and etc.

The BUET and Alcan activated alumina have been extensively tested in field condition in different areas of Bangladesh under rapid assessment and found very effective in arsenic removal (BAMWSP, DFID, Water Aid, 2001). The arsenic removal units (ARU) of Project Earth Industries Inc., USA used hybrid aluminas and composite metal oxides as adsorption media and were able to treat 200-500 Bed Volume (BV) of water containing 550µg/L of arsenic and 14 mg/L of iron (Ahmed et aI., 2000). The Apyron Technologies Inc. (A TI) also uses inorganic granular metal oxide based media that can selectively remove As(III) and As(V) from water. The Aqua-Bind ™ arsenic media used by ATI consists of non-hazardous aluminium oxide and manganese oxide for cost-effective removal of arsenic. The proponents claimed that the units installed in India and Bangladesh consistently reduced arsenic to less than 10µg/L (Ahmed, 2001).

Granular Ferric Hydroxide:

MIS Pal Trockner (P) Ltd., India and Sidko Ltd., Bangladesh installed several Granular Ferric Hydroxide based arsenic removal units in India and Bangladesh. The Granular Ferric Hydroxide (Adsorb As$^{(R)}$) is arsenic selective adsorbent developed by Technical University, Berlin, Germany. The unit requires iron removal as pretreatment to avoid clogging to filter bed. The proponents of the unit claim to have very high arsenic removal capacity and produces non-toxic spent granular ferric hydroxide (Ahmed, 2001).

Read-F Arsenic Removal Unit

Read-F is an adsorbent produced and promoted by Shin Nihon Salt Co. Ltd., Japan for arsenic removal in Bangladesh. Read-F displays high selectivity for arsenic ions under a broad range of conditions and effectively adsorbs both arsenite and arsenate without the need for pretreatment. The Read-F is Ethylene-vinyl alcohol copolymer (EVOH)-borne hydrous cerium oxide in which hydrous cerium oxide (Ce02.nH20), is the adsorbent. The material contains no organic solvent or other volatile substance and is not classified as. hazardous material. Laboratory test at BUET and field testing of the materials at 4 sites under the supervision of BAMWSP showed that the adsorbent is highly efficient in removing arsenic from groundwater (Hasan,2003).

Iron Coated Sand:

BUET has constructed and tested iron coated sand based small-scale unit for the removal of arsenic from ground water. Iron coated sand has been prepared following a procedure similar to that adopted by Joshi and Choudhury (1996). The iron content of the iron coated sand was found to be 25 mg/g of sand. For raw water having both As(III) and As(V) of concentration 300µg/L when filtered through iron coated sand, it was found that 350 bed volume (BV) could be treated satisfying the Bangladesh drinking water standard of 50 ppb (Ali, 2001). The saturated medium is regenerated by passing 0.2N sodium hydroxide followed by washing with distilled water. No significant change in bed volume (BV) in arsenic removal was found after 5 regeneration cycles. It was interesting to note that iron coated sand is equally effective in removing both As(III) and As(V). Iron coated brick dust has also been developed in Bangladesh for arsenic removal from drinking water.

Indigenous Filters:

There are several filters available in Bangladesh that use indigenous material as arsenic adsorbent. Red soil rich in oxidized iron, clay minerals, iron ore, iron scrap or fillings and processed cellulose materials are known to have capacity for arsenic adsorption. Some of the filters manufactured using these materials include:

i) Shafi Filter
ii) Adarsha Filter
iii) Bijoypur Clay/Processed Cellulose Filter
iv) Sono 3-Kolshi Filter
v) Gamet Home-made Filter
vi) Chari Filter

The Shafi and Adarsha filters use clay material as filter media in the form of candle. The Shafi filter was reported to have good arsenic removal capacity but suffered from clogging of filter media (Ahmed, 2001). The Adarsha filter participated in the rapid assessment program but failed to meet the technical criterion of reducing arsenic to acceptable level (BAMWSP, DFID and Water Aid, 2000). Bijoypur clay and treated cellulose were found to absorb arsenic from water (Khair, 2000).

The Sono 3-Kolshi Filter uses zero valent iron fillings and coarse sand in the top Kolshi, wood coke and fine sand in the middle Kolshi while the bottom Kolshi is the collector of the filtered water (Khan et aI., 2000). This unit has been found to be very effective in removing arsenic but the media was found contaminated with the growth of microorganism (BAMWSP, DFID and Water Aid, 2000). The one-time use unit becomes quickly clogged, if groundwater contains excessive iron.

The Garnet homemade filter contains relatively inert materials like brick chips and sand as filtering media. No chemical is added to the system. Air oxidation and adsorption on ironrich brick chips and flocs of naturally present iron in groundwater could be the reason for arsenic removal from groundwater. The unit produced inadequate quantity of water and did not show reliable results in different areas of Bangladesh and under different operating conditions (Ahmed, 2001). The Chari filter also uses brick chips and inert aggregates in different Charis as filter media. The effectiveness of this media in arsenic removal is not known (Ahmed, 2001).

MRT-1000 and Reid System Ltd.:

Jago Corporation Limited promoted a household reverse osmosis water dispenser MRT1000 manufactured by B & T Science Co. Limited, Taiwan. This system was tested at BUET and showed a As(III) removal efficiency more than 80% (Ahmed, 2001). A wider spectrum reverse osmosis system named Reid System Limited was also promoted in Bangladesh. Experimental results showed that the system could effectively reduce arsenic content along with other impurities in water (Ahmed, 2001). The capital and operational costs of the reverse osmosis system would be relatively high.

Low-pressure Nanfiltration and Reverse Osmosis:

Oh et at. (2000) applied reverse osmosis and nanofiltration membrane processes for the treatment of arsenic contaminated water applying low pressure by bicycle pump. A nanofiltration membrane process coupled with a bicycle pump could be operated under condition of low recovery and low-pressure range from 0.2 to 0.7 Mpa. Arsenite was found to have lower rejection than arsenate in ionized forms and water containing higher arsenite requires pre-oxidation for reduction of total arsenic acceptable level. In tubewell water in Bangladesh the average ratio of arsenite to total arsenic was found to be 0.25 (Ahmed, 2001). However, the reverse osmosis process coupled with a bicycle pump system operating at 4 Mpa can be used for arsenic removal because of its high arsenite rejection. The study concluded that low-pressure nanofiltration with pre-oxidation or reverse osmosis with a bicycle pump device could be used for the treatment of arsenic contaminated groundwater in rural areas (Oh et aI., 2000).

2.2.7.3 Ion exchange resin

The process is similar to that of the adsorption process, just the media is a synthetic resin of better defined ion exchange capacity where exchange of anion take place between the strong base anion resin and arsenic contaminated water. When arsenic contaminated water passes through a column containing ion exchange resins, chloride ions on the exchange sites of the resins are exchanged for the arsenic ions that are present in the water. The column gradually becomes saturated with the arsenic ions as more water passes through it. The exhausted column can be regenerated by passing concentrated sodium chloride solutions through the column. If the column is operated beyond exhaustion, peaking may occur. The effectiveness of ion change process depends on the relative affinity of the resin for arsenic. Sulphate ions in the influent decrease the effectiveness substantially by competing for the adsorption sites.

Available treatment units: Tetrahydron arsenic removal unit

2.2.7.4 Passive sedimentation

If the natural groundwater collected from the field is highly alkaline and concentration of iron is very high natural oxidation and precipitation of soluble ferrous iron into insoluble ferric iron occurs within a few hours. Plain settling around 6 hours resulted in a significant decrease in both iron and arsenic concentration. Arsenic is removed through co-precipitation with iron.
Available Treatment Units: Water Aid Arsenic Removal Unit

2.2.7.5 Coarse media (roughing) filtration bed

Up-flow coarse media (gravel/brick khoa) bed has been found to be effective in the removal of both arsenic and iron from ground water through flocculation, sedimentation and adsorption processes while the water containing both arsenic and iron flows through the interstices of coarse media.

Available Treatment Units: BUET-ITN AIRU

2.2.7.6 Comparative merits and demerits of arsenic removal technologies

The following Table summarizes the relative advantages and disadvantages of different arsenic removal technologies.

Table 2-3. A Comparison of the Main Arsenic Removal Technologies (Ahmed, 2001)

Technologies	Advantages	Disadvantages
Oxidation-precipitation		
• Air Oxidation	• Simple and Low cost	• Less Removal Efficiency
• Chemical Oxidation	• Simple and Rapid process	• Toxic Residual
Coagulation-Coprecipitation		
• Alum Coagulation	• Easily Available Chemical	• Produces Toxic Sludge
• Iron Coagulation	• Effective Over Wider pH Range	• Relatively Costly Chemicals
Sorptive Techniques		
• Activated Alumina	• Commercially Available	• Produces Toxic Waste
• Iron Coated Sand	• Plenty of Possibilities	• HighTechnical O & M
• Ion Exchange Resin	• High Removal Efficiency	• Relatively High Cost
Membrane Techniques		
• Reverse Osmosis	• No Toxic Waste Produces	• High Technical O & M
• Electrodialysis	• Capable of Removing Other Contaminants	• Toxic Waste Water Produces
• Microbial Processes	• Should be Less Costly	• NotYet Fully Established

2.2.8 Multistage Filtration Units

There are basically three types of roughing filter, which are differentiated by their direction of flow. Structural constraints and available head limit the use of vertical upflow filters, but high filtration rate and back washing of the filter media are possible. On the other hand, horizontal-flow filters enjoy practically unlimited filter length, but normally are subjected to lower filtration rate and generally required manual cleaning of the filter media. Dynamic Roughing Filter (DyRF) includes a shallow layer of medium size filter media in their upper part and coarse media that covers the under drains (Ahmed, 2006).

With moderate levels of suspended solids in the source water, DyRF gradually clogs. If quick changes in water quality occur, the clogging may be much faster. Eventually the gravel bed will be blocked and the total water volume will just flow over the clogged surface area to waste, protecting the subsequent treatment steps that are more difficult to maintain. A combination of down-flow at the beginning and an up-flow at the end may be advantageous.

2.2.8.1 Design parameters of multistage filtration units

The following are the fundamental design parameters of roughing pre-filtration system and SSF(Ahmed,2006).:
Type, size and gradation of filter media; filtration rate or face velocity; and depth and length of filter bed. The rate of filtration and size of coarse materials depend on the desired degree of turbidity removal.

(a) Size and Grading of Filter Media.
(b) Recent designs used gravel filter materials that decreases in size with flow direction and size range is between 5 mm to 50 mm. Schulz and Okun have recommended coarse media size range between 4 mm to 15 mm for up-flow roughing filter. AIT study recommended an effective size(D_{10}) of coarse media varying from 2.8 mm to 9.1 mm.

The International Research Center (IRC) manual recommends filter sand with effective size(D_{10}) of 0.15 mm to 0.30 mm with a uniformity coefficient between 3 and 51. Schulz and Okun have recommended an effective size(D_{10}) of sand in between 0.15 mm to 0.35 mm. McGhee has indicated that effective sizes of 0.10 mm to 0.3 mm and uniformity coefficient of 2 to 3 are commonly employed for slow sand filtration.

(c) Filtration Rates

Good turbidity reductions were obtained at filtration rates less than 2 m/h through coarse media. In AIT a horizontal flow roughing filter operated at a filtration rate of 0.6m/h produced a filtrate of 10 -15 NTU from raw water turbidity range of 20 –120 NTU2. The acceptable range of filter filtration rate for up-flow roughing filter has been found in the range of 0.5 m/h to 4 m/h.

AWWA has recommended typical roughing filtration rate in the range of 0.3 m/h to 1.5 m/h and slow sand filtration in the range of 0.09 m/h to 0.24m/h. McGhee has proposed that the filtration rate of SSF should be normally less than 0.4 m/h. SSF operated at 0.3 m/h always produced a filtrate of lowest turbidity while those operated at 0.2 m/h and 0.3 m/h gave filtered waters of higher turbidity but less than1 NTU. Although the normal flow rate for SSF is between 0.1 m/h and 0.4 m/h, a conservative filtration rate of 0.29 m/h was chosen in North Haven.

(d) Depth of Filter Media and Under-drainage System

McGhee has also indicated that sand bed depth around 1000 mm should bed be used for slow sand filtration. The American Water Works Association (AWWA) has suggested that the sand bed depth should generally be between 460 mm and 800 mm, however, the minimum depth

before re-sanding should be 460 mm. The sand layer of SSF is supported by a layer of coarse media of about 300 mm
thick which is graded from effective size of about 5 mm at the top to 50 mm at the bottom. Underdrains, normally constructed of perforated pipes. Regarding the under-drainage system plastic piping system has been proposed in some study.

2.2.8.2 Optimising multi-stage filtration units for use in Bangladesh:

In order to develop an appropriate design criteria for multi-stage filtration (MSF) units for use in Bangladesh a research was undertaken by ITN Center, BUET for the Arsenic Policy Support Unit (APSU). The MSF system considered under the research comprised of three units; Dynamic Roughing Filter(DyRF) unit, Up-flow Roughing Filter(URF) unit and Slow Sand Filter (SSF) unit. Following were the major findings and recommendations of the research.

Dynamic Roughing Filter was capable to handle raw water with high level of turbidity and on an average 58% turbidity removal was achieved during the last three experimental runs. Subsequent removal of turbidity through Up-flow Roughing Filter process was also around 64%, resulting in an average combined 85% turbidity removal in two-stage pre-filtration processes. These removal performances were found almost same for all ranges of raw water turbidity level up to 470 NTU, indicating that removal efficiency of turbidity through DyRF and URF were independent of raw water turbidity level (Ahmed,2006)..

Because of substantial turbidity removal through coarse media pre-filtration processes, removal of turbidity through slow sand filtration process was not very significant. Overall removal of turbidity through the three MSF units were around 99% and average SSF effluent turbidity values in all the experimental runs reduced from 85 NTU to 0.75 NTU which is much lower than the Bangladesh Environmental Quality Standard (EQS,1997) of 10 NTU.It was observed that two-stage coarse media pre-filtration units reduced the densities of all four microbial indicators, thermotolerant coliforms (TTC), E. coli, C. perfringens and coliphages over 50% and in case of TTC and *C.* perfringens this removal efficiency was 83% and 71% respectively. Under uninterrupted flow condition maximum overall removal of TTC and E. coli through the three MSF units were around 99.97% and 100% respectively at a filtration rate of 0.1 m/h.

Coarse media size range and depth of bed in DyRF and URF are more important design parameters for MSFs rather than SSF media size range for the reduction of turbidity. A coarse media size range from 4.75mm to 25 mm for DyRF and 6.3 mm to 25 mm for URF placed in three layers have been found suitable.

Slow sand filter bed materials size range and grading particularly on the top layer of filter bed are very important design parameters for efficient microbial removal performance. Filter sand having following characteristics have been found appropriate:
FM = 1.8-2.0, D_{10}=0.21-0.22 mm, D_{60} = 0.45-0.47 mm, U = 2.14 -2.16 and Filter Media Size Range = 0.15 mm to 1.1 mm.

A moderate influent turbidity limit of around 20 NTU may be proposed for SSF. In case of raw water turbidity level greater than 150 NTU, either pre-settling process in a plain sedimentation tank would be necessary, or water should be passed through an infiltration gallery for the removal of settleable suspended solids before putting into the two-stage pre-filtration processes (DyRF and URF) in multistage filtration system. If the raw water level remains within 60 NTU, the DyRF step may be omitted.

For a maximum filtration rate of • 0.1m/h, an acceptable level of microbial quality of water may be obtained and at a filtration rate up to 0.15 m/h, TTC and E. coli may appear occasionally. Beyond a 0.20-0.25 m/h filtration rate, microbial quality deteriorates significantly.

For a slow sand filtration rate of around 0.20 m/h, a maximum of 40 cm head loss may be expected for an influent turbidity level less than 20 NTU and cleaning of bed within 6-8 weeks operation period would be required.

For an Up-flow coarse media filtration rate of 0.43 m/h, a maximum of 10 cm head loss may be observed before cleaning of bed within 8 weeks operation period. For a Down-flow coarse media filtration rate of 1.6 m/h, a maximum of 2 cm head loss may be experienced before cleaning of bed within 8 weeks operation period. At the beginning of each filter run, the removal efficiencies of microbial contaminants were low in comparison to the subsequent periods and approximately 7 to 10 days were required to improve the removal performances under the laboratory test conditions. At least 7 to 10 days interval should be allowed for the ripening of the “Schmutzdecke” on filter sand (SSF) before the filter bed is brought in to full operation for domestic use. Twin bed filter chambers may be used in place of single bed and cleaning may be performed alternatively to achieve the above objective.

Exposure of filters increased the algal activity on filter bed and affected the physical water quality improvement performance slightly. However, occasional sloughing of algal mats from the surface of sand bed not only seriously affected the microbial quality improvement performance, but also become very unpredictable. On the other hand, shading of filters helped reduce the algal activity on the filters but did not affect the filter performance. Filter beds should therefore, be kept covered to avoid the unnecessary growth of algae particularly on slow sand filter bed.

Reduction of the dissolved oxygen level was inversely related to the flow rate of water, and on an average 40% reduction was observed during nominal flow rates maintained in the experimental runs. Around 50% of average reduction of organic matters was achieved and this removal is approximately independent of rate of flow. Complete removal of ammonia was achieved through multi stage filtration processes. Like organic pollutant reduction, this reduction happened due to biological activity in filter media, i.e. biological oxidation of ammonia by nitrifying bacteria. During the filtration process there was a slight decrease of pH value due to mainly formation of CO2 as an end product of biological activity.

2.2.9 BUET-ITN AIRU

ITN-Bangladesh under a research program has developed a combined arsenic- iron removal unit (AIRU) adopting the technique of adsorption and co-precipitation of arsenic onto the flocs of ferric hydroxide, making use of the naturally occurring iron of groundwater. The AIRU, which is attached to a tubewell, has mainly two chambers, down-flow flocculator and up-flow roughing filter. The flocculation and roughing filtration processes in the AIRU were accomplished through the use of coarse media gravel beds.

2.2.9.1 Selection of unit processes for the ITN-AIRU

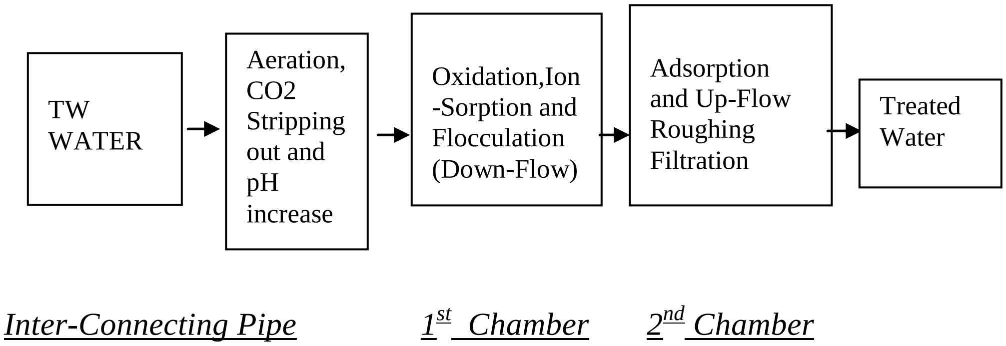


Figure 2-2. Flow diagram of the unit process of ITN-AIRU

2.2.9.2 Design of the ITN-AIRU

Aeration:

PVC 3 in diameter pipe was used for aeration purpose and for stripping out the CO_2.

Flocculator:

From Hazen's equation, the following experimental relationships were obtained (Ahmed, 1995).

Mean Velocity Gradient, G = 8.38 x *(Q/a)* x *(S/d)* ------------------(I)

Camp Number, G.td = 3.354 x (S/d) x L ----------------------------(II)

Where, Q = Flow of Water; a = X-Sectional Area of the Flocculator Bed; S = Shape Factor =(*6/•*),

• = 0.89 ~ 0.92 for Gravel; d = Avg. dia of Gravel.

Some experimentally best fit data for using the above two equations were obtained (Ahmed, 1995). Where, G = 10-20 Sec$\cdot^{I}$; Face Velocity *(Q/a)* = 0.1~.3 cm/sec.; S = 6.5; d = Avg. dia of Gravel (cm); G.td = 2000.

Value of Q for hand pump tube well was obtained = 15 lit/min. = 0.9 m^3/hr (Ahmed, 1985).

From equation (I): 10 = 8.38 x 0.2 x *(6.5/d)* =>d = 1.0 cm = 10 mm.
From equation (II): 2000 = 3.354 x *(6.5/1.0)* x L => L = 91.74 cm = 3 ft.
Now, Face Velocity = 0.2 cm/sec. = 7.2 m/hr.
a = *(Q/Face* Velocity) = (0.9 $m^3/hr.)/(7.2$ m/hr.) = 0.125m^2 = 1.345 sq.ft.
Thus, a = (I '-4" x l')

Sedimentation chamber:

Considering Detention Time, t = 25 min. = 0.4 hr.
Volume of Sed. Chamber= Flow x Detention Time. Thus, V = 0.9 $m^3/hr.$ x 0.4 hr. = 0.36 m^3.
Now, A = 12.3 sq.ft. = 1.14 m^2. Now, Depth h = V/A = 0.36 m^3/1.14 m^2 = 0.3 m =>h = 1 ft.

Roughing filter:

The optimum face velocity for removal of iron and arsenic is 0.016 cm/sec = 0.576 m/hr; The most efficient gravel size is 0.75 cm dia and the depth of bed = 38.5 cm = 15.2 in • 16 inch (Ahmed, 1998).
Now, a = (Q/Face Velocity) = (0.9 m^3/hr.)/(0.79 m/hr) = 1.139 m^2 = 12.25sq.ft.
=>a = 3' -6" x 3' -6"
Note: Face Velocity 0.79 m/hr. in stead of 0.576 m/hr was used considering 70% operating time efficiency.

2.2.9.3 Major results obtained from the BUET-ITN AIRU

a) Over 75% arsenic removal can be achieved without using any chemicals through adsorption on to natural iron oxides surfaces provided that the raw water arsenic concentration is within 200ppb and the iron-arsenic concentration ratio is around 30 .
b) For higher arsenic concentration above 200ppb and iron-arsenic concentration ratio less than 30; intermittent dosing of oxidizing agent is necessary to convert the As(III) into As(V) to ensure more adsorption of arsenic and hence maintaining the treated water within the acceptable limit.
c) Use of an additional filter-attachment with the AIRU containing sorptive media (Activated Alumina, Read-F, Iron Coated Sand etc.) can eliminate the use of oxidizing agent. The active life of the sorptive media would be extended long due to major removal of As and Fe from raw tube well water passing through the AIRU.

2.2.9.4 Major recommendations for future study from the BUET-ITN AIRU

a) To conduct extensive field tests of the AIRU to study both iron and arsenic removal performances and to determine maximum removal capacity under different water quality conditions.
b) To study the comparative performances of variable adsorbents (activated alumina, iron coated sand, Read-F etc.) column attachment with the AIRU in acute arsenic problem areas and to find out the most suitable combination.
c) To study the performance of using brick chips aggregate in stead of gravel for both flocculation and roughing filtration purpose and to find out the effective and economic solution (Ahmed,2005).

2.2.10: Summary of arsenic dissociation, adsorption and removal theory

a) Both arsenate and arsenite (less efficient) adsorb strongly on hydrous oxide surfaces of a wide range of solids including iron (e.g., iron oxy- hydroxides), aluminum and manganese oxides-hydroxides and clay minerals.
b) Therefore, oxidation & ionization of non-ionized As(III) to ionized As(V) through adding oxidizing agents or direct ionization of As(III) through increasing of $pH > 9$, is the first step of As removal.
c) Arsenic ions are also absorbed on solid chemical flocs surfaces, which are subsequently removed through co-precipitation.
d) Through aeration of iron content water or Alum coagulation process macro-flocs of $Fe(OH)3$ / $Al(OH)3$ are produced which can be used for the co-precipitation of ionized arsenic contaminants.

CHAPTER THREE

METHODOLOGY

3.1 INTRODUCTION

Few years back, ITN-Bangladesh under a research program has developed a combined Iron-Arsenic Removal unit (AIRU) and made some recommendations for future study such as (i) to conduct extensive field tests of the AIRU to study both iron and arsenic removal performances and to determine maximum removal capacity under different water quality conditions,(ii) to study the comparative performances of variable adsorbents (activated alumina, iron coated sand, Read-F etc.) column attachment with the AIRU in acute arsenic problem areas and to find out the most suitable combination and (iii) to study the performance of using brick chips aggregate in stead of gravel for both flocculation and roughing filtration purpose. The present study "Effectiveness of Multistage Filtration in removing Iron, Manganese and Arsenic from groundwater of Bangladesh.." has been performed on the basis of the above recommendations with additional attention on manganese issue. With the help of ITN-BUET assistance (2nd Phase research) seven numbers of Multistage Filtration Units (MSFU) have been constructed in three different places of Bangladesh (different hydro-geological conditions) and effectiveness of those units for combined removal of Arsenic-Iron/ Iron-Manganese have been investigated and necessary modifications in the design have been recommended.A brief description of the methodology that was followed in conducting the study is given below:

3.1.2 Selection of Project Areas and Zoning

Three zones had been selected in three different hydro-geological condition areas as shown in figure 3.1. These areas are:

Zone-1 (Iron- Manganese affected area): Sirajgonj (Rajshahi Division)
Zone-2 (Iron - Arsenic affected area): Comilla (Chittagong Division).
Zone-3 (Iron-Arsenic affected area): Jessore (Khulna Division).

Actual location of project area have been selected on the basis of Iron, Manganese and Arsenic concentration in groundwater. Department of Public Health Engineering (DPHE) which is the main organization responsible for community and rural water supply of the country, were contacted and requested to extend their co-operation for this research work. The field sites were first identified by direct co-operation of the DPHE staffs. Final selection of the field sites were made by long discussion and motivation of the local people. The consequences of iron ,manganese and arsenic problems in drinking water were addressed and the intervention measures were discussed among them for their participation in all aspects of the project. Active participation of the local people was ensured in all aspects (layout, construction, operation and maintenance) of the project works. The targets of selecting sites for MSFU(s) were to remove manganese and arsenic with iron by co-precipitation and adsorption.

Study Area ●

Figure 3-1. Map of Bangladesh showing the locations of study area

3.1.3 Construction of Multistage Filtration Units

It was stated in the previous chapter that there are basically three types of roughing filter, which are differentiated by their direction of flow. Structural constraints and available head limit the use of vertical upflow filters, but high filtration rate and back washing of the filter media are possible. On the other hand, horizontal- flow filters enjoy practically unlimited filter length, but normally are subjected to lower filtration rate and generally required manual cleaning of the filter media. Dynamic Roughing Filter(DyRF) includes a shallow layer of medium size filter media in their upper part and coarse media that covers the underdrains. In the Construction of Multistage Filtration Units, considering the water quality characteristics of project area, a combination of down-flow at the beginning, an up-flow at the middle and a down-flow at the end have been incorporated. Total seven numbers of MSFUs have been constructed in the three zones. The water quality characteristics of the project area and plant location have been shown in table 3-1.

Table 3-1. Water quality characteristics of project area and plant location

Location of MSFU		pH	Alkalinity (mg/L as $CaCO_3$)	Iron (mg/L)	Arsenic (µg/L)	Manga-nese (mg/L)	Remarks
Kodda,Sirajgonj,Sadar, Sirajgonj (MSFU-1)	Zone-1	>6.5	174	16	70	1.625	(Iron-Manga-nese affected area)
Chala,Kamarkhond, Sirajgonj(MSFU-2)		>6.5	134	15	120	0.752	
Digholkandi,Sirajgonj, Sadar, Sirajgonj (MSFU-3)		>6.5	132	16	30	1.825	
Homna,Comilla (MSFU-4)	Zone-2	>6.5	286	16	336	-	Iron-Arsenic affected sites
Polua,Chowgacha, Jessore(MSFU-5)	Zone-3	>6.5	407	8	410	0.234	
Sadipur,Jhikorgacha, Jessore(MSFU-6)		>6.5	220	8	216	0.1	
Sonakur,Jhikorgacha Jessore(MSFU-7)		>6.5	292	4.6	337	-	

3.1.4 Selection of the Unit Process for the MSFU with Schematic Diagram

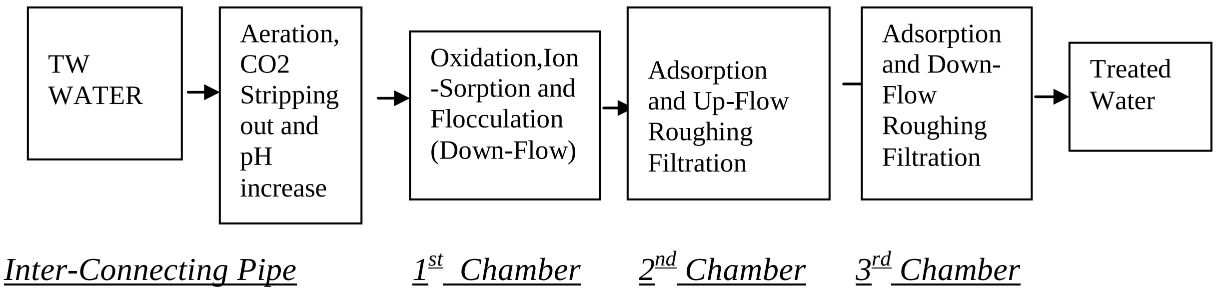


Figure 3-2. Flow Diagram of the unit Process of the MSFU

Inter-Connecting pipe:

The MSFU is connected to the spout of tube well with a short piece of 75 mm PVC / flexible pipe. Water entering the first chamber is distributed uniformly over the whole bed of course media through a porous thin ferro-cement plate placed on the top, resulting strip out of CO_2 and increase of pH value for the oxidation of soluble iron.

1st Chamber (Down-flow coarse media brick aggregate flocculator):

Oxidation and subsequent precipitation of iron oxyhydroxides occurs respectively on the top and within the interstices of coarse media which adsorbs arsenic oxyanions. Sinusoidal flow across the coarse media enhance collisions for the flocculation of precipitated particles.

2nd chamber (sedimentation chamber plus up-flow roughing filter):

Sedimentation:

Comparatively larger flocculated precipitates settle at the bottom of the 2nd chamber.

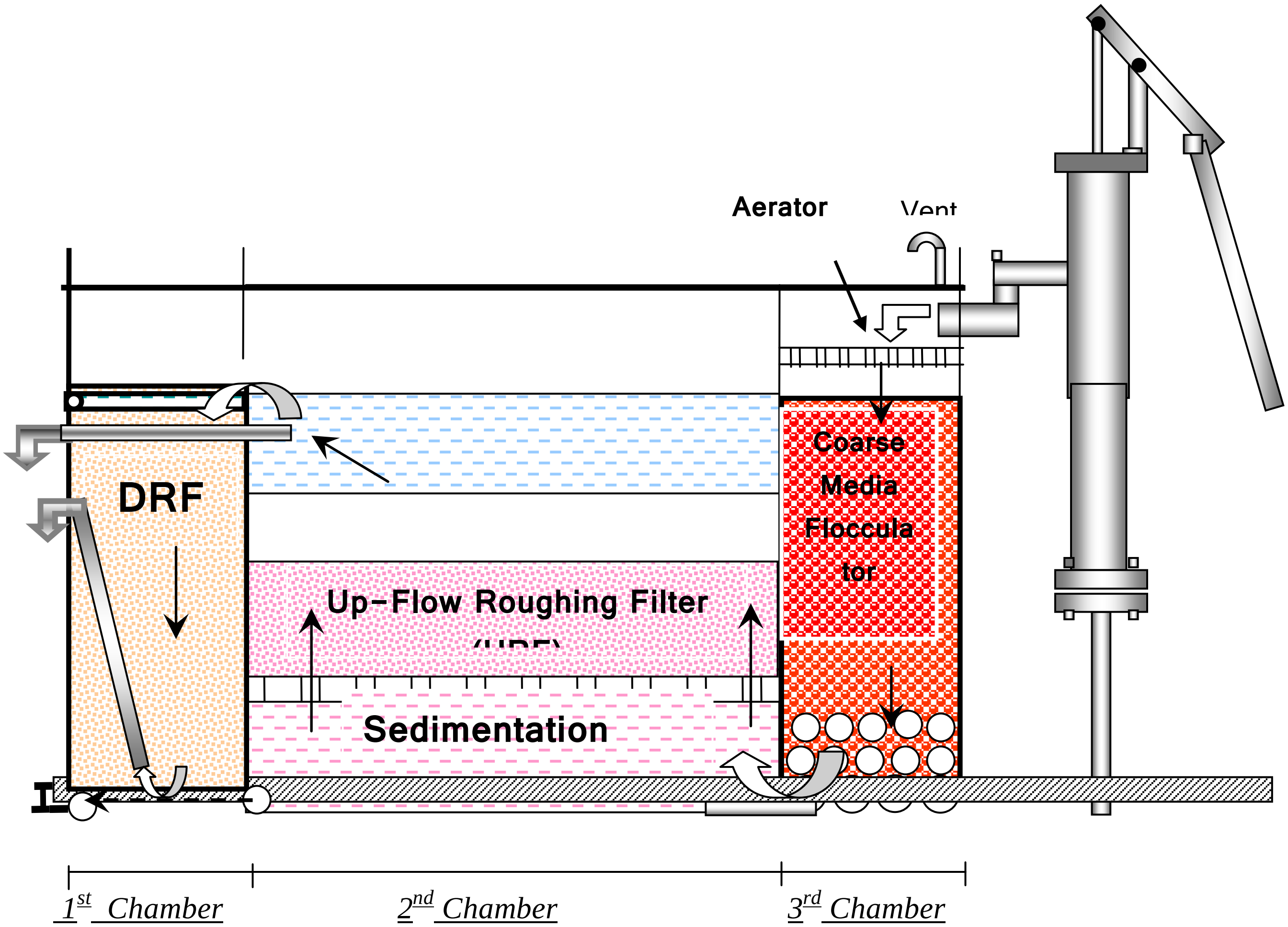


Figure 3-3 . Schematic diagram of the MSFU for field construction.

Up-flow roughing filtration (URF):
Maximum removal of precipitated particles occurs by sorption on to iron oxy hydroxides and mechanical straining during up-flow through the comparatively finer coarse media bed in the 2nd chamber.

3rd Chamber (down-flow coarse media brick aggregate roughing filtration):
Final removal of precipitated particles occurs through sorption on to iron oxy hydroxides and mechanical straining during down-flow through the comparatively finer coarse media bed in the 3rd chamber.

3.1.5 Sampling, Monitoring and Analytical Methods of Testing

Performance of seven MSFUs was individually assessed in this study in terms of their effectiveness in removing dissolved iron, arsenic and manganese from raw water. In addition, bacteriological quality of the treated water was also assessed. User satisfaction with the treatment units was also evaluated. The pH, Iron and arsenic contents of the water samples were determined in the field. In this process Arsenic and iron concentration were determined using HACH field kit and pH were determined by field pH meter.

At each treatment plant location, raw and treated water samples were collected for subsequent analysis of iron, manganese, arsenic and other selected water quality parameters in the laboratory. At each location, raw and treated water samples were collected in pre-washed 500 ml plastic bottles. Water samples in pre-washed bottles were acidified with 1 ml concentration Nitric acid, which were later used for analysis of dissolved arsenic, manganese and iron in the laboratory. In the laboratory, arsenic and iron concentrations of water samples were determined using Flame-AAS (Atomic Absorption Spectrophotometer) and manganese concentrations were determined using HACH spectrophotometer.

Samples, for analysis of bacteriological water quality, were collected in especial sample bags and immediately put in ice box for transportation to the laboratory. Bacteriological analysis was commenced within 8 hours (maximum) of sample collection.

Flows of water, variation of head loss with time, length of run between cleaning have also been observed. Rate of flow from the unit was measured through a known volume of bucket and counting time over the period. Moreover, pre and post-construction water consumption survey was carried out and peoples' opinion regarding the quality of treated water and difficulties in operation and maintenance of the MSFU(s) were collected through questionnaire survey.

3.1.6 Stepwise Modifications of MSFU over ITN-AIRU

Multi-Stage Filtration Units (MSFUs) are the stepwise modification of ITN-AIRU.
Followings alternative arrangements were conducted to improve the performance:

a) Introduced separate water collection point for drinking and cooking purposes,

b) Tried with local arsenic adsorption media (single column filled with iron chips and iron coated sand) ICC after URF bed in Jessore to investigate its effectiveness in removing arsenic because residual arsenic concentration in the effluent of URF was not within the permissible limit.

c) Used arsenic adsorption media (U-shaped double column filled with Iron chips and iron coated sand) ICC after URF bed in Jessore (Polua & Sadipur) to investigate the effectiveness in removing arsenic because residual arsenic concentration in the effluent of single column ICC was not within the permissible limit.

d) Tried with U-shaped double column ICC after URF bed in Sirajgonj (Kodda & Chala) to investigate its effectiveness in removing manganese because residual manganese concentration in the effluent of URF was not within the permissible limit.

e) Incorporated 3rd adsorption chamber of Down-flow Roughing Filtration (DRF) bed in place of ICC in Polua to investigate its effectiveness in removing arsenic as because residual arsenic concentration in the effluent of double column ICC was not within the permissible limit.

f) Incorporated 3rd adsorption chamber of Down-flow Roughing Filtration (DRF) bed in place of ICC in Kodda and Chala to investigate its effectiveness in removing manganese because residual manganese concentration in the effluent of double column ICC was not within the permissible limit. DRF process was found more effective than ICC, particularly for manganese removal. This was because that detention time of DRF process is much higher than ICC and detention time of ICC does not meet the requirement of complete Mn oxidation. For arsenic removal the difference between effectiveness of DRF and ICC was found negligible.

g) Attachment of additional U-shaped double column ICC after DRF bed in Jessore (Polua & Sonakur) as because residual arsenic concentration in the effluent of DRF was not within the permissible limit. Observed results indicate that arsenic concentration in the effluent of additional ICC satisfies the drinking water standard for arsenic in Bangladesh (50 ppb).

After modification followings are the brief description of existing MSFUs with DRF &ICC.

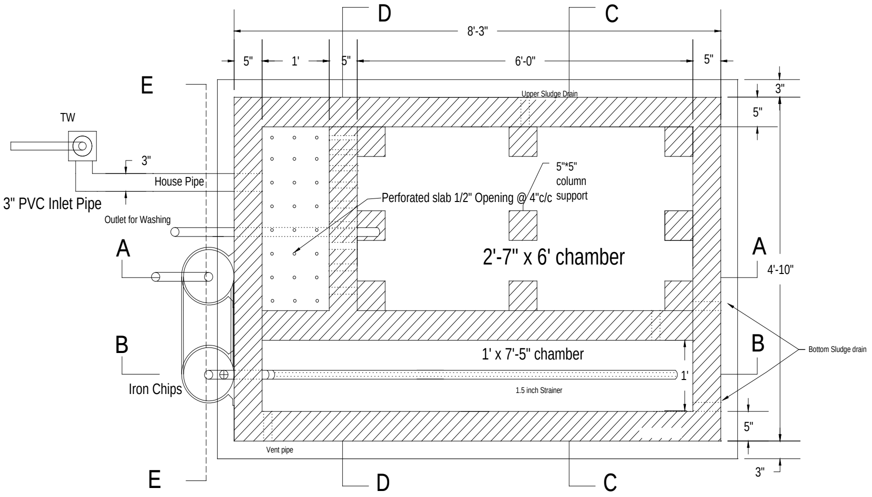
a)DRF bed have been incorporated with the MSFUs located at Kodda, Chala,Digholkandi,Homna,Polua and Sonakur.

b)Double column ICC attachment after URF bed is now being used with the MSFU located at Sadipur (as because residual arsenic concentration in the effluent of double column ICC was found within the permissible limit).

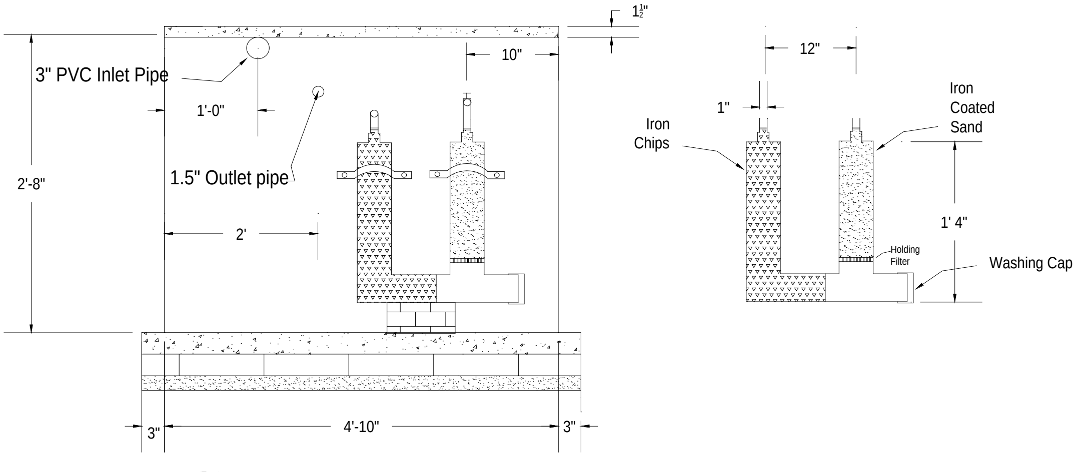
c)Additional double column ICC after DRF bed have been attached in Polua & Sonakur to maintain the residual arsenic concentration in the final effluent within the permissible limit.

3.1.7 Detailing of Iron Chips Column(ICC)

ICC is a 3 inch diameter plastic pipe fittings(filled with iron chips and iron coated sand). On



(a) Typical section of MSFU



(b) Section E-E

Figure 3-4. Detailing of Iron Chips Column(ICC)

a trial basis single column ICC was incorporated after URF bed in Jessore as an arsenic adsorption media. Single column ICC was replaced by double column ICC.In double column

ICC down-flow portion are filled with iron chips and up flow portion of ICC are filled with iron coated sand. Detailing of ICC have been shown in figure 3.4. Iron coated sand has been prepared following a procedure similar to that used by Joshi and Chowdhuri (1996). The procedure basically consists of pre- washing sand by immersing in an acid (20% commercial grade hydrochloric acid) solution for 24 hours. After drying, the sand is mixed with 2M ferric nitrate and 10 N sodium hyroxide solution (80 mL of ferric nitrate solution and 4 mL of sodium hyroxide solution is required for each 200 cm^3 of sand). The mixture is then heated in an oven at 110 ºC for 14 hours. It is then washed with distilled water a number of times and then dried. In this study, locally available sand passing # 30 sieve and retaining on # 40 sieve (as suggested by Joshi and Chowdhuri,1996) was used.

CHAPTER FOUR

FIELD PERFORMANCE ANALYSIS

4.1 INTRODUCTION

Water samples collected weekly from different location of the Multi-Stage Filtration Units (MSFU) were tested in the laboratory for the determination of iron, arsenic and manganese concentrations to investigate the performance of MSFU in removing of these impurities. The variation of yield with time was also observed regularly. Finally the users' opinion in using tube well water attached with MSFU were taken and their acceptance after the construction were observed. The data collected in the field and laboratory test results have been analyzed and presented in the following articles.

4.2 IRON REMOVAL PERFORMANCE

4.2.1 Variation of Iron Concentration with Operation Period i Different Treatment Unit Processes

Variation of average iron concentration with operation period in the effluent of different treatment unit processes of MSFU installed at different zone have been explained below.

MSFU-1(Kodda,Sirajgonj)

Figure 4-1 shows variation of average iron concentration in the effluent of different treatment unit processes of the MSFU-1. The initial concentration of iron in the effluent of URF and DRF were found to be 1.4 mg/L and 0.8 mg/L indicating average iron removal efficiency of 91 % and 95 % respectively . With the passage of time the iron concentration in the effluent of URF and DRF decreased upto 0.4 mg/L and 0.2 mg/L indicating iron removal

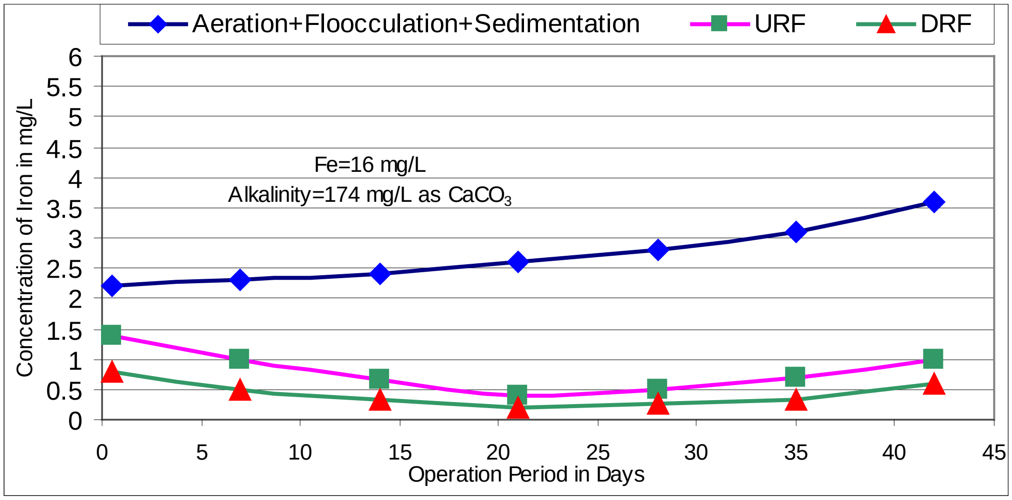


Figure 4-1. Variation of average iron concentration in different treatment unit processes (Kodda, Sirajgonj)

performance of 97 % and 98 % respectively. This was due to gradually adsorption of precipitated iron flocs on the coarse media surfaces and gradually deposition of the same in the interstices. This results indicate that removal of iron through Up-Flow Roughing Filter (URF) were very significant and removal through Down-Flow Roughing Filter (DRF) were negligible. However, after 4 weeks of run the iron concentrations in the effluent of URF and DRF again started to increase. This was because when the coarse media pores were clogged the increased pore velocities caused shearing / sloughing of precipitated iron particles which ultimately appeared with the effluent water.

It was observed that iron concentration in the effluent of sedimentation chamber increased with the passage of time. Because there was gradual accumulation of the iron flocs at the bottom of sedimentation chamber and continuous flow of tube well water due to repeated use by the users caused scouring of deposited iron particles which ultimately appeared with the effluent water.

MSFU-2 (Chala, Sirajgonj)

Figure 4-2 represents the variation of average iron concentration in the effluent of different treatment unit processes of the MSFU-2. The above figure shows that average initial iron concentration in the effluent of URF and DRF have been found equal to 1.6 mg/L and 0.8 mg/L indicating average iron removal efficiency of 89 % and 94 % respectively .

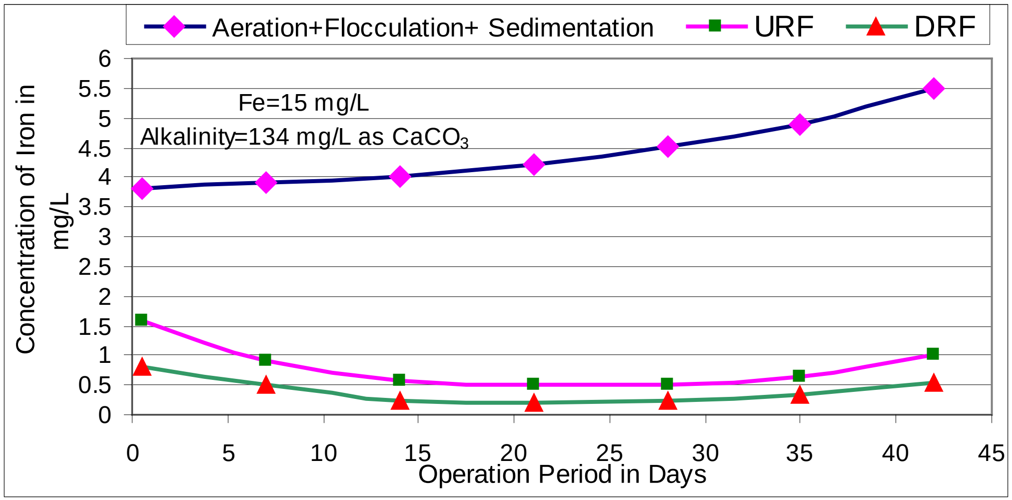


Figure 4-2. Variation of average iron concentration in different treatment unit processes (Chala, Sirajgonj)

With the passage of time the iron concentration in the effluent of URF and DRF decreased upto 0.5 mg/Land 0.25 mg/L indicating iron removal performance of 96 % and 98 % respectively. This figure indicates that the trend of the variation of iron concentration in the effluent of URF and DRF were similar to those of MSFU-1.This figure also shows that the role of URF in removing iron was better than that of MSFU-1 and role of aeration cum flocculation cum sedimentation in removing iron was less effective than MSFU-1.Because the number of users using MSFU-2 were more than that of MSFU-1 . As a result gradually accumulated iron flocs at the bottom of the sedimentation chamber were remained in suspension most of the time which ultimately carried over with the effluent of sedimentation chamber. However, the following treatment units removed the suspended particles.

MSFU-3(Digholkandi , Sirajgonj)

Variation of average iron concentration in the effluent of different treatment unit processes of the MSFU-3 have been shown in figure 4-3. The figure reveals that though the tube well water iron concentration and alkalinity of this unit is similar to those of previous two units but the average concentration of iron in the effluent of URF and DRF were much higher than both the previous units. This was because the size of URF chamber of MSFU-3 was around 33% smaller than MSFU-1 and MSFU-2 which resulted increased face velocity.

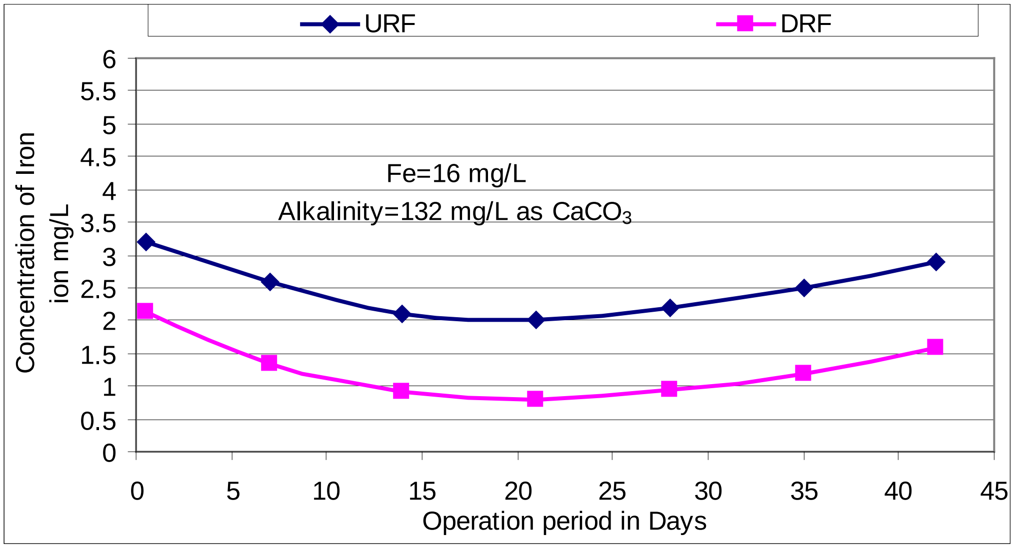


Figure 4-3. Variation of average iron concentration in different treatment unit processes (Digholkandi, Sirajgonj)

MSFU-4(Homna, Comilla)

Variation trend of average iron concentration in the effluent of different treatment unit processes of the MSFU-4 have been shown in figure 4-4. The figure reveals that initial concentration of iron in the effluent of URF and DRF were 1.7 mg/L and 0.8 mg/L indicating average iron removal efficiency of 89 % and 95 % respectively .With the passage of time the iron concentration in the effluent of URF and DRF decreased upto 0.5 mg/Land 0.22 mg/L indicating iron removal performance of 97 % and 98 % respectively.

The overall iron removal performance of this unit was found to be similar to those of MSFU-1 and MSFU-2 . This was because that the tube well water iron concentration of Homna and Sirajgonj were almost same.

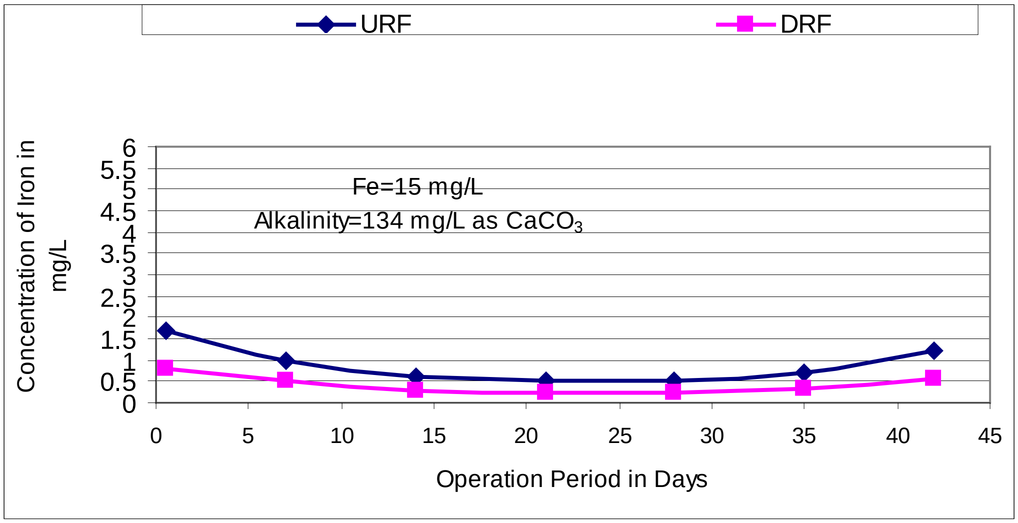


Figure 4-4. Variation of average iron concentration in different treatment unit processes (Homna,Comilla)

<u>MSFU-5 (Polua, Jessore)</u>

The in figure 4-5 represents the variation of average iron concentration in the effluent of different treatment unit processes of the MSFU -5. The initial iron removal efficiency around 78% and 89% have been observed through URF (1.9 mg/L iron concentration in the effluent) and DRF (1.0 mg/L iron concentration in the effluent) respectively . With the passage of time the iron removal performance through URF(0.85 mg/L iron concentration in the effluent) and DRF(0.5 mg/L iron concentration in the effluent) increased

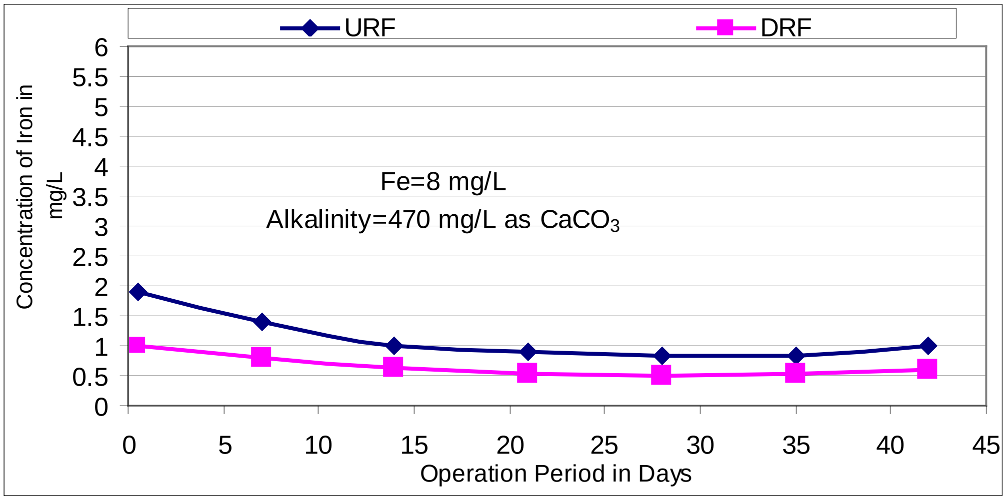


Figure 4-5. Variation of average iron concentration in different treatment unit process (Polua,Jessore)

.respectively. As the tube well water iron concentration of this unit was less than that of Sirajgonj & Homna, so the iron removal performance of this unit was less than Sirajgonj & Homna. Because the rate of ferrous iron oxidation is of the first order with respect to ferrous iron concentration present in water.

MSFU-6 (Sadipur, Jessore)

Figure. 4-6 shows the variation of average iron concentration in the effluent of different treatment unit processes of the MSFU-6. The trend of variation of iron concentration in the treated water of this unit were found similar to those of unit-5.This was because that the tube well water iron concentration of both the units were similar.

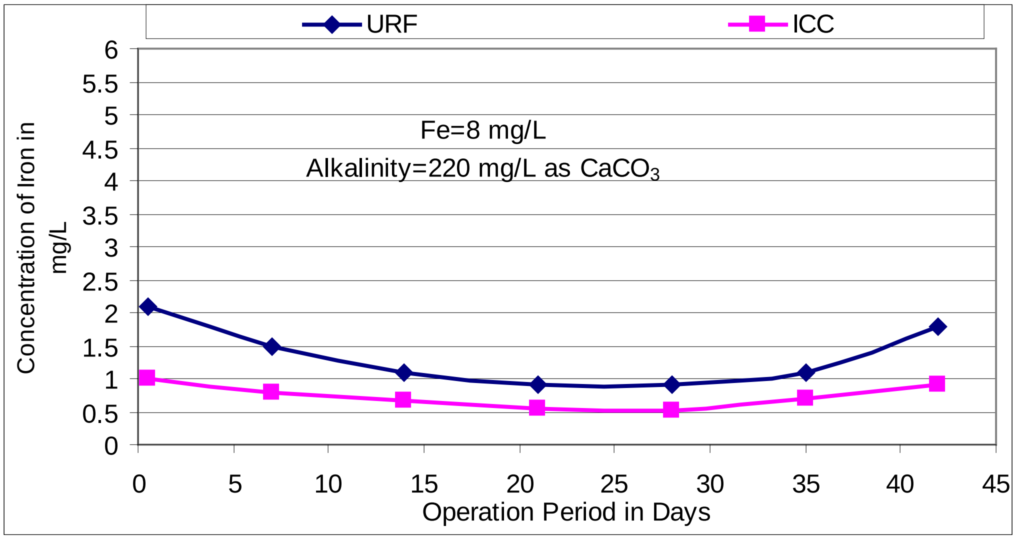


Figure 4-6. Variation of average iron concentration in different treatment unit process (Sadipur,Jessore)

MSFU-7 (Sonakur, Jessore)

Figure 4-7 shows variation of average iron concentration in the effluent of different treatment unit processes of the MSFU-7. The initial concentration of iron in the effluent of URF and DRF were found to be 1.5 mg/L and 0.97 mg/L indicating average iron removal efficiency of 68 % and 79% respectively . With the passage of time the iron concentration in the effluent

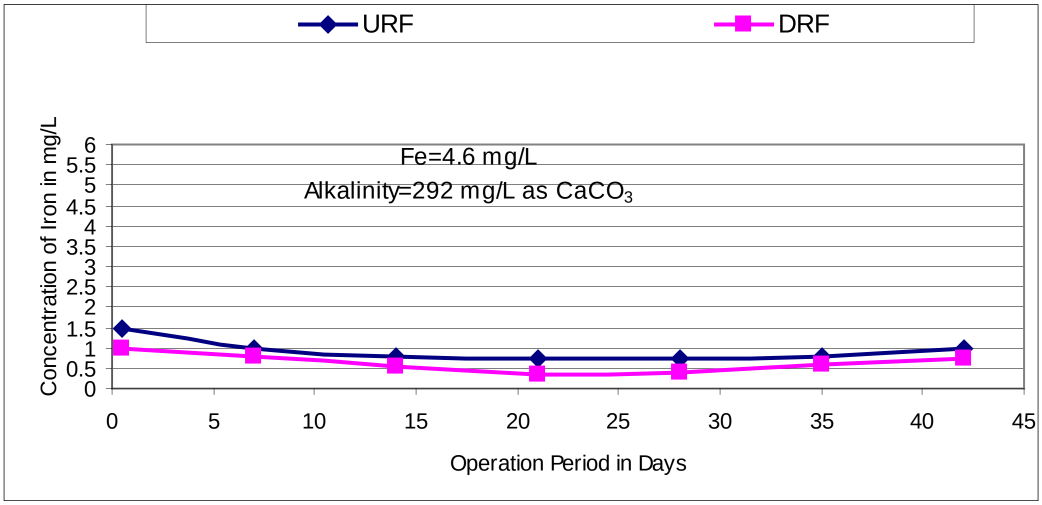


Figure 4-7. Variation of average iron concentration in different treatment unit process (Sonakur,Jessore)

of URF and DRF decreased upto 0.73 mg/L and 0.35 mg/L indicating iron removal performance of 84 % and 92 % respectively. As the tube well water iron concentration of Sonakur was less than those of Sirajgonj,Homna,Polua and Sadipur, so the iron removal performance of this unit was less than Sirajgonj,Homna,Polua and Sadipur. Because the rate of ferrous iron oxidation is of the first order with respect to ferrous iron concentration present in water.

4.2.2 Comparison among Different MSFU in Respect of Overall Iron Removal Performance

Comparison among different MSFU (installed at different zones) in respect of overall iron (Fe) removal performance have been presented in figure 4-8 .Similar type of iron removal performance have been observed in the MSFUs (1 and 2) installed at Sirajgonj. This is due to environmental conditions (pH, alkalinity, initial iron content of tube well water) of both the locations are almost same. The overall iron removal performance of MSFU-4 was found to be similar to those of MSFU-1 and MSFU-2. This was because that the tube well water iron concentration of Homna and Sirajgonj were almost same.

The iron removal performance of MSFU-5 (Polua,Jessore) was not observed as efficient as Sirajgonj & Homna. Because the tube well water iron concentration of Polua was less than Sirajgonj and Homna and the rate of ferrous iron oxidation is of the first order with respect to ferrous iron concentration present in water. As the tube well water iron concentration of MSFU-5 and MSFU-6 were same,so the iron removal performance of of both the units were observed almost same. Finally, as the tube well water iron concentration of Sonakur (MSFU-7) was less than those of Sirajgonj, Homna, Polua and Sadipur, so the iron removal performance of this unit was less than Sirajgonj,Homna,Polua and Sadipur.

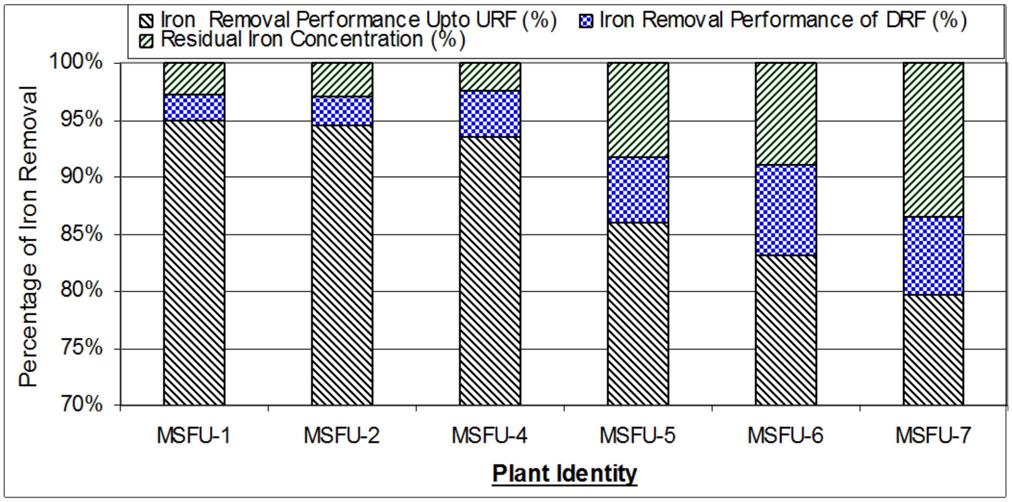


Figure 4-8. Comparison among different MSFU in respect of overall iron (Fe) removal performance.

4.2.3 Effect of Tube Well Water Iron Concentration on Iron Removal Performance

The effect of tube well water iron concentration on iron removal performance has been determined through comparing the iron removal performance data of six individual MSFU treating tube well water having different iron concentrations (iron concentrations range from 4.6 mg/L to 16 mg/L). The results have been presented in figure 4-9. The result reveals that higher the initial tube well water iron concentration , greater is the iron removal performance. Because the rate of ferrous iron oxidation is a function of ferrous iron concentration present in water .

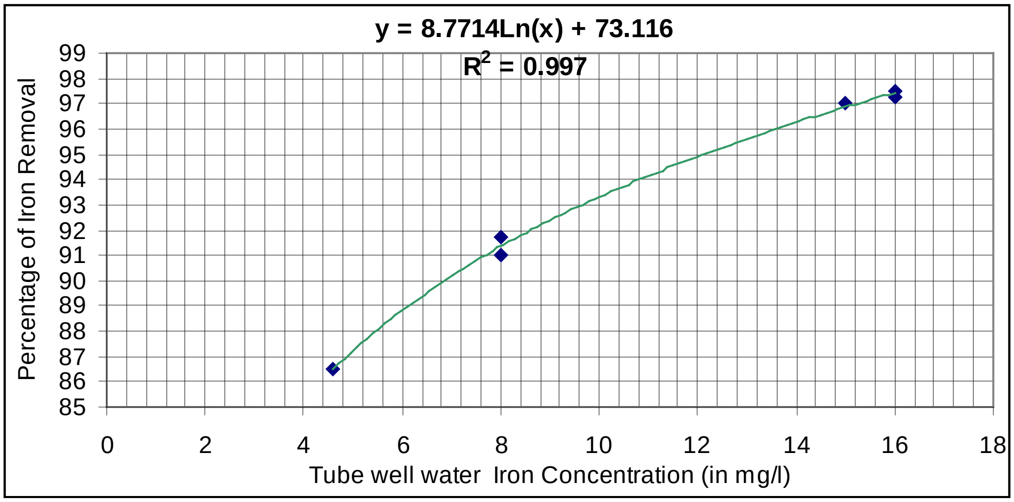


Figure 4-9. Effect of tube well water iron concentration on iron removal performance.

The effect of tube well water iron concentration on iron removal performance can be expressed through the following equation

$$y = 8.7714\mathrm{Log}_e(x) + 73.116$$

Where, y =percentage of iron removal

x = tube well water iron concentration (mg/L)

Using the above equation it will be easy to determine the residual iron concentration in the final effluent achieved through properly designed MSFU treating tube well water of different initial iron concentration range from 4.6 mg/L to 16 mg/L.

4.2.4 Iron Removal Performance of Different Treatment Unit Processes

Average iron removal performance of the different treatment unit processes of the Multi-Stage Filtration Units have been shown in the following figures.Figure. 4-10 shows average iron removal performance of different treatment unit processes of MSFUs(Sirajgonj-1 and 2).This figure indicates that major removal of iron (78%) occurred through Aeration cum Flocculation cum Sedimentation Processes. Effect of Up-flow roughing filtration process (URF) in removing iron was found significant (16%) .Since most part of iron removal have been occurred before the Down-flow roughing filtration(DRF) process, so the effect of DRF in removing iron was negligible (only 3% of the total raw water iron concentration).

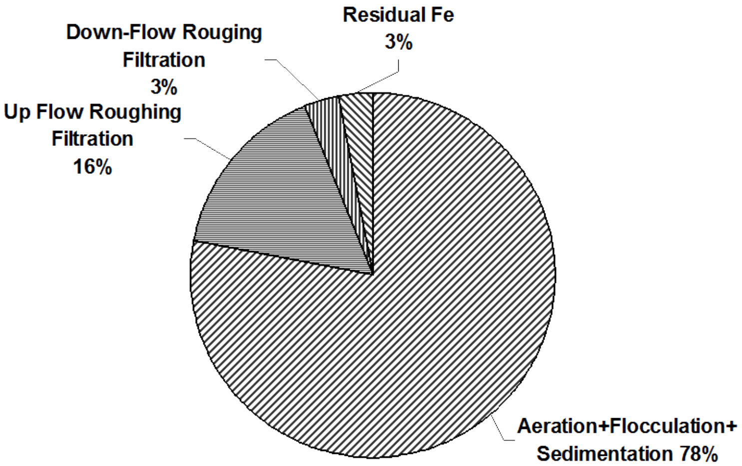


Figure 4 –10. Average iron removal performance of different treatment unit processes (average of Kodda & Chala)

4.3 ARSENIC REMOVAL PERFORMANCE

4.3.1 Variation of Arsenic Concentration with Operation Period in Different Treatment Unit Processes

Variation of average arsenic concentration with operation period in the effluent of different treatment unit processes of MSFUs installed at different zone have been illustrated below.

MSFU-1(Kodda,Sirajgonj)

Figure 4-11 represents variation of average arsenic concentration in the effluent of different treatment unit processes of the MSFU-1. The initial concentration of arsenic in the effluent of URF and DRF were found to be 11 ppb and 9 indicating average iron removal efficiency of 84% and 87% respectively. With the passage of time the arsenic concentration in the effluent of URF and DRF decreased upto 7 ppb and 5 ppb indicating arsenic removal performance of 90% and 92% respectively. This was because there were gradually adsorption of precipitated iron flocs on the coarse media surfaces and gradually deposition of the same in the interstices and these iron particles along with other metal oxy-hydroxides provided increased adsorption Surfaces for the arsenic ions to be adsorbed. However, after 4 weeks of run the arsenic concentrations in the effluent of URF and DRF again started to increase. This was because when the coarse media pores were clogged the increased pore velocities caused shearing / sloughing of precipitated iron particles which resulted less adsorption site available for arsenic ions and ultimately appeared with the effluent water.

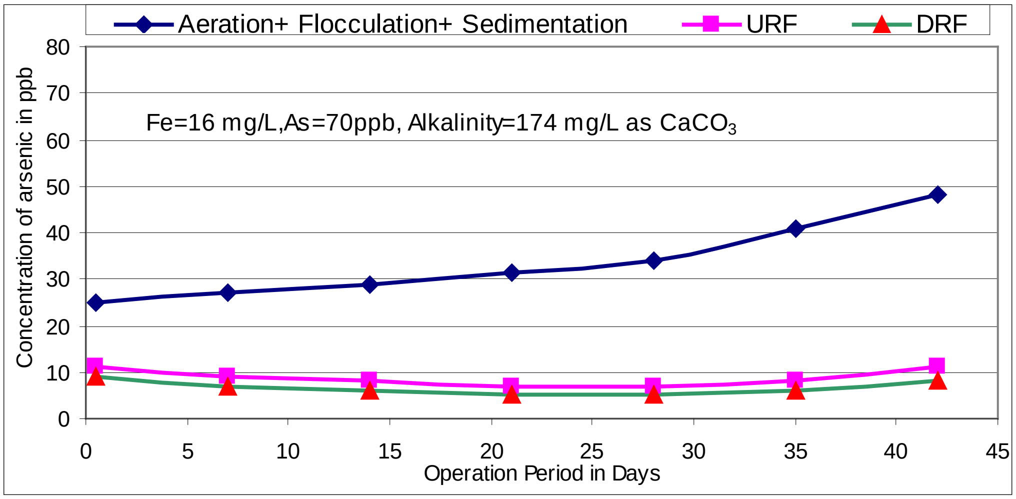


Figure 4-11. Variation of average arsenic concentration in different treatment unit process (Kodda, Sirajgonj)

From the beginning of the filter run a continuous increasing trend of arsenic concentration in the effluent of sedimentation chamber have been observed .Because with the passage of time gradually accumulated iron flocs at the bottom of sedimentation chamber along with adsorbed arsenic ions were carried over and ultimately appeared in the effluent of this chamber.

MSFU-2(Chala,Sirajgonj)

Figure 4-12 represents the variation of average iron concentration in the effluent of different

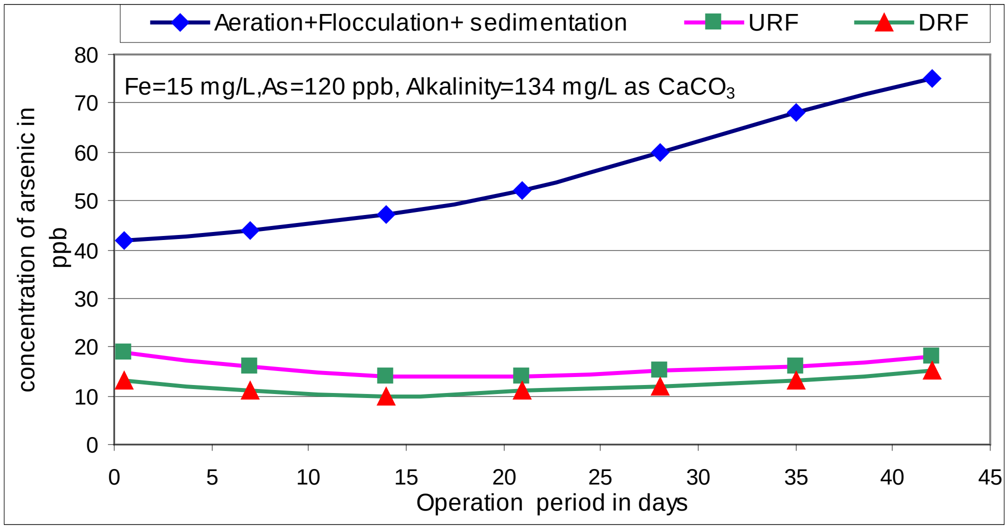


Figure 4-12. Variation of average arsenic concentration in different treatment unit process (Chala, Sirajgonj)

treatment unit processes of the MSFU-2(Chala,Sirajgonj). At the beginning of the filter run the average concentration of arsenic in the effluent of URF and DRF have been found around 19 ppb and 13 ppb indicating average arsenic removal efficiency of 84 % and 89 % respectively With the passage of time the arsenic concentration in the effluent of URF and DRF decreased upto 14 ppb and 10 ppb indicating arsenic removal performance of 88 % and 92% respectively. Overall arsenic removal performance of this unit was found similar to MSFU-1. This is due to environmental conditions (pH, alkalinity, initial iron content of tube well water) of both the locations are almost same.

MSFU-3(Digholkandi,Sirajgonj)

Tube well water arsenic concentration of this unit was 30 ppb and it does not need any treatment. However, the arsenic concentration in the treated water was found nil.

MSFU-4(Homna,Comilla)

The trend of variation of average arsenic concentration with operation period in URF and DRF processes of the MSFU-4 have been presented in figure 4-13. At the initial stage of filter run the average arsenic concentration in the effluent of URF and DRF were observed around 110 pbb and 45 ppb indicating 78% and 86% removal efficiency respectively. Effluent arsenic concentration of URF and DRF decreased with the passage of time upto 72 ppb and 27 ppb indicating removal efficiency of 78 % and 92% respectively. Overall arsenic removal efficiency of this unit was found similar to the both the both units of Sirajgonj. This was because that the tube well water iron concentration of Sirajgonj and Homna were approximately same.

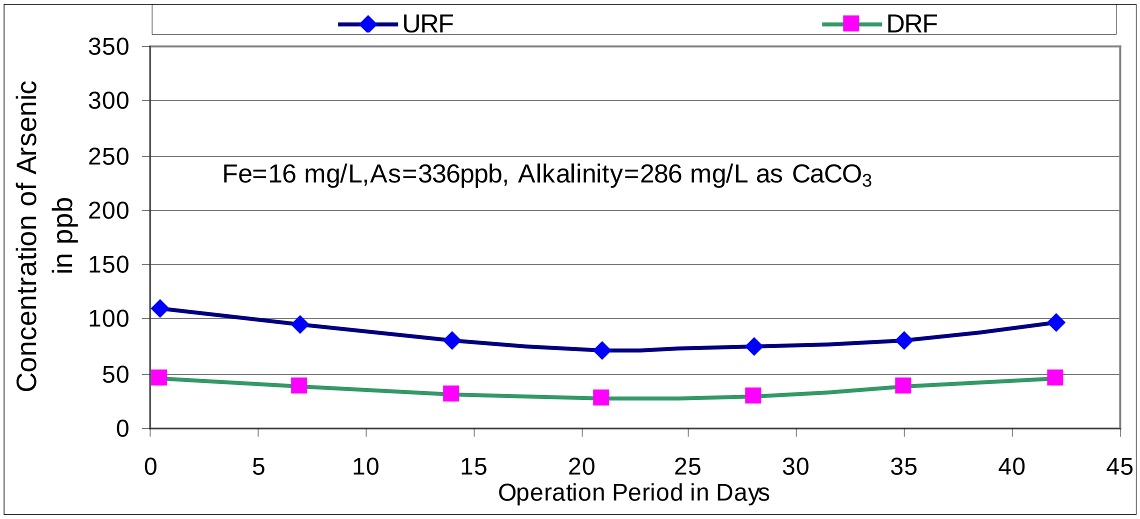


Figure 4-13. Variation of average arsenic concentration with operation period in URF and DRF processes (Homna,Comilla)

MSFU-5(Polua,Jessore)

Figure 4-14 shows variation of average arsenic concentration with operation period in different treatment unit processes of the MSFU-5 (Polua,Jessore). During the filter run overall arsenic concentration in the treated water after URF and DRF were found around 129 ppb and 69 ppb respectively indicating the needs of intermittent dosage of oxidizing agent to maintain the residual arsenic concentration below maximum permissible limit of 50 ppb. As tube well water iron the concentration of Polua is less than Sirajgonj & Homna , so the overall arsenic removal performance of this unit (84%) was found less than Sirajgonj & Homna .

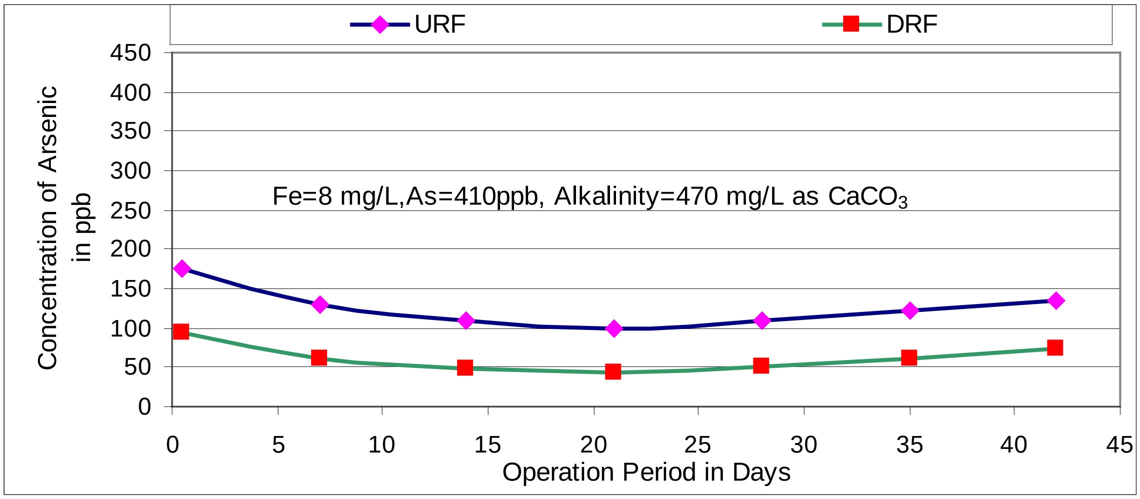


Figure 4-14. Variation of average arsenic concentration with operation period in URF and DRF processes (Polua,Jessore)

Because higher the iron concentration , greater is the iron oxide precipitation & this greater amount of iron precipitations provide more adsorption surface for arsenic ion adsorption and here the condition is vice versa .

MSFU-6 (Sadipur,Jessore)

In figure 4-15, the variation of average arsenic concentration with operation period in different treatment unit processes of the MSFU-6 (Sadipur,Jessore) have been shown. Tube well water iron concentration of Polua and Sadipur are same ,so the overall arsenic

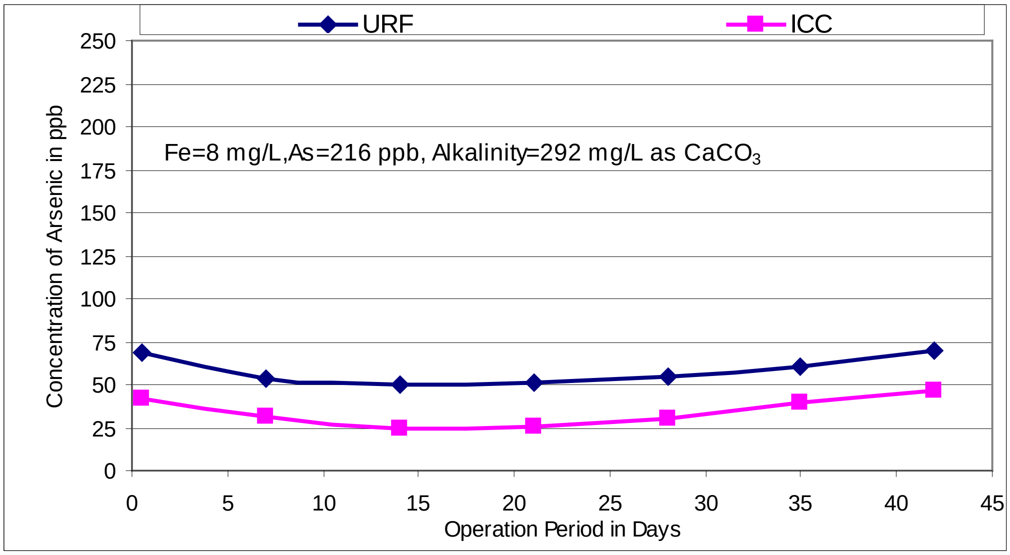


Figure 4-15. Variation of average arsenic concentration with operation period in different treatment unit processes (Sadipur,Jessore)

removal performance of MSFU-5 and 6 were observed approximately same. But as the tube well water arsenic concentration of this unit was much lower than that of previous unit , so most of the time, the residual arsenic concentration in the treated water of this unit satisfies the maximum permissible limit of 50 ppb.

MSFU-7(Sonakur,Jessore)

Following figure 4-16 illustrates the variation of average arsenic concentration with operation period in different treatment unit processes of the MSFU-7. The average concentration of arsenic in the treated water after URF and DRF were found to be 118 ppb and 70 ppb

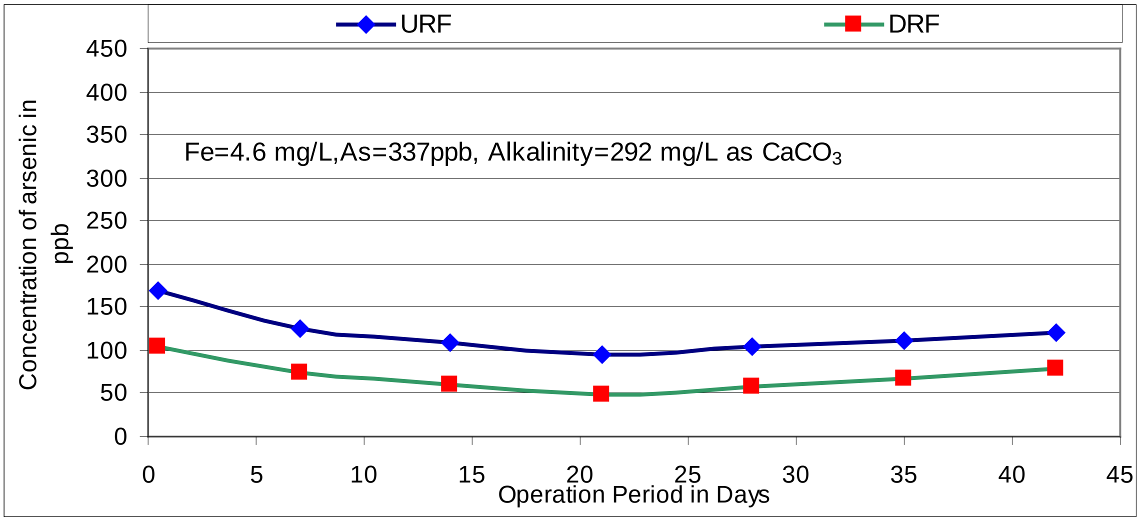


Figure 4-16. Variation of average arsenic concentration with operation period in different treatment unit processes (Sonakur,Jessore)

indicating the needs of intermittent dosage of oxidizing agent to maintain the residual arsenic concentration below maximum permissible limit of 50 ppb. As the tube well water iron concentration of Sonakur (MSFU-7) was less than those of Sirajgonj, Homna, Polua and Sadipur, so the arsenic removal performance of this unit was less than Sirajgonj,Homna,Polua and Sadipur.

4.3.2 Comparison among Different MSFU on the Basis of Overall Arsenic Removal Performance

Overall arsenic removal performance of different MSFU (installed at different zones) have been determined and comparison among these units on the basis of overall arsenic As) removal performance have been presented in figure 4-17. Similar type of arsenic removal performance have been observed in the MSFUs (1 and 2) installed at Sirajgonj. This is due to environmental conditions (pH, alkalinity, initial iron content of tube well water) of both the locations are almost same. The overall arsenic removal performance of MSFU-4 was found to be similar to those of MSFU-1 and MSFU-2. This was because that the tube well water iron concentration of Homna and Sirajgonj were almost same. The arsenic removal performance of MSFU-5 (Polua,Jessore) was not observed as efficient as Sirajgonj & Homna. Because the tube well water iron concentration of Polua was less than Sirajgonj and Homna . As the tube well water iron concentration of MSFU-5 and MSFU-6 were same, so the arsenic removal performance of both the units were observed almost same. Finally, as the tube well water iron concentration of Sonakur (MSFU-7) was less than those of Sirajgonj, Homna, Polua and Sadipur, so the arsenic removal performance of this unit was less than Sirajgonj,Homna,Polua and Sadipur.

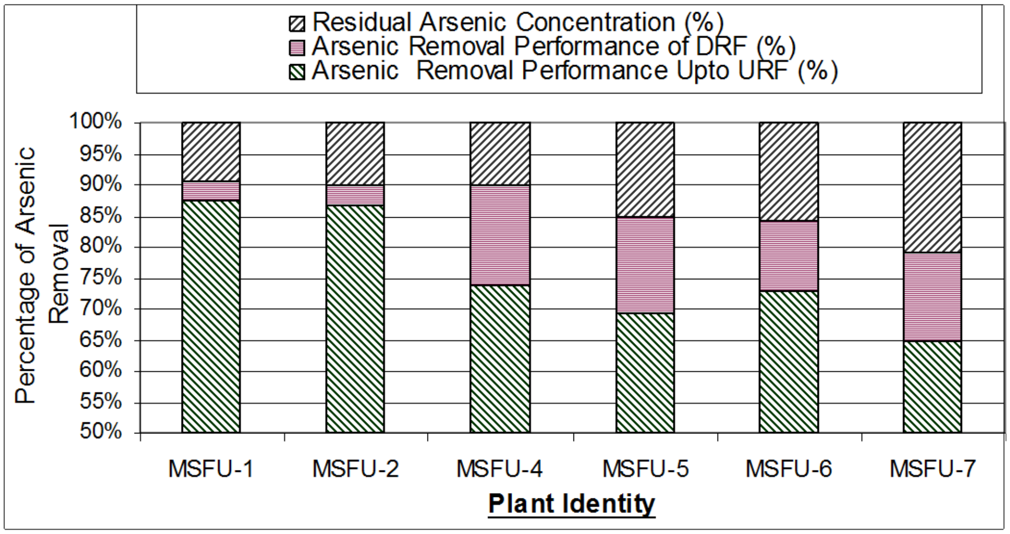


Figure 4-17. Comparison among different MSFU on the basis of overall arsenic removal performance

4.3.3 Effect of Tube Well Water Iron Concentration on Arsenic Removal Performance

The effect of tube well water iron concentration on arsenic removal performance has been determined by comparing the arsenic removal performance data of six individual MSFU treating tube well water having different iron and arsenic concentrations(iron concentrations range from 4.6 to 16 mg/L and arsenic concentration range from 70 to 410 ppb). The results have been presented in figure 4-18. The result reveals that arsenic removal performance significantly increased with iron concentration of tube well water, because higher the iron concentration, greater is the iron oxide precipitation and this greater amount of iron precipitations provide more adsorption surface for arsenic ion adsorption. The trend of the arsenic removal performance with respect to initial iron concentration of tube well water can be expressed by the following equation

$$\mathbf{y = 8.8742\ Log_e(x)+65.86}$$

Where,
y =Percentage of Arsenic Removal
x = Tube well water Iron Concentration (mg/L)

Using the above equation it will be easy to determine the residual arsenic concentration in the final effluent achieved through properly designed MSFU treating tube well water of different initial iron and arsenic concentration (iron concentrations range from 4.6 to 16 mg/L and arsenic concentration range from 70 to 410 ppb).

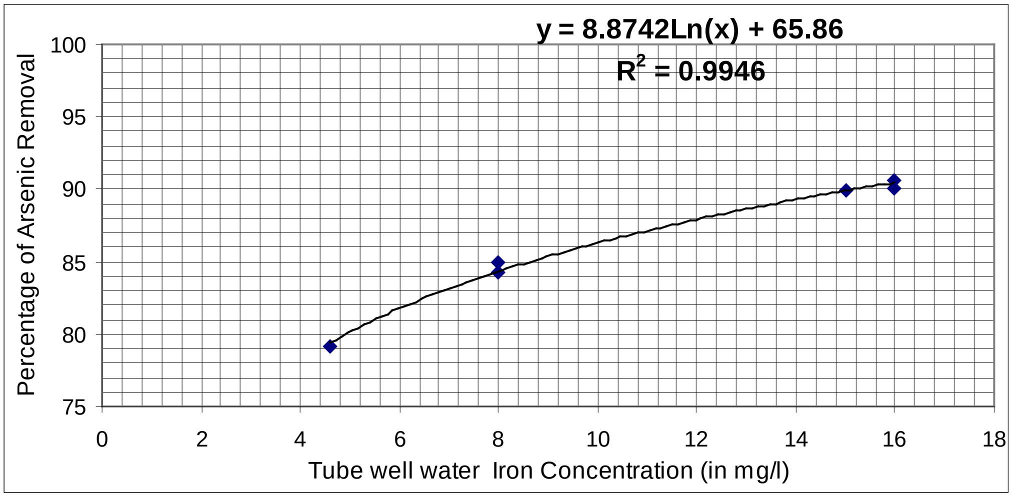


Figure 4-18. Effect of tube well water iron concentration on arsenic removal performance.

4.3.4 Arsenic Removal Performance of Different Treatment Unit Processes

Average arsenic removal performance of the different treatment unit processes of the Multi-stage Filtration Units of Sirajgonj (Kodda & Chala) have been shown in figure. 4-19.This figure indicates that major removal of arsenic (53%) occurred through Aeration cum Flocculation cum Sedimentation Processes. Effect of Up-flow roughing filtration process in removing arsenic was found significant (34%) .Since most part of arsenic removal have been occurred before the Down-flow roughing filtration(DRF) process, so the effect of DRF in removing arsenic was negligible (only 3% of the total raw water iron concentration).

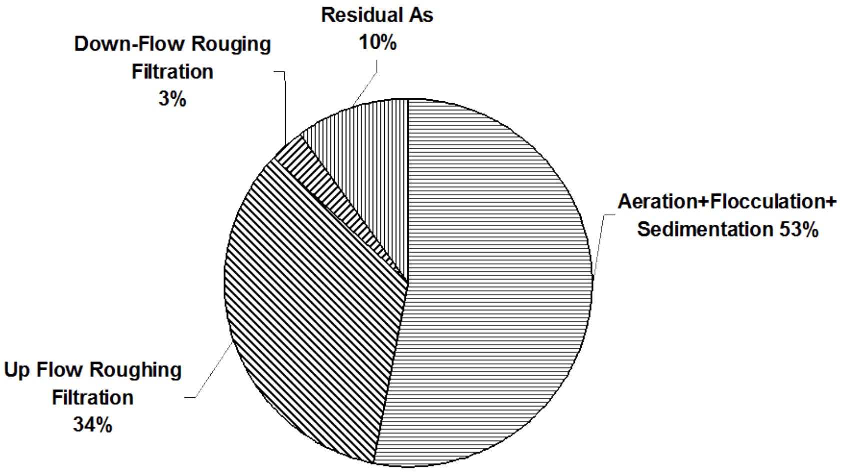


Figure 4-19. Average arsenic removal performance of different treatment unit processes (average of Kodda & Chala)

4.3.5 Effectiveness of Additional Iron Chips Column Attachment after DRF in Removing Arsenic

From the previous discussions, it is clear that arsenic removal performance is directly proportional to the iron concentration present in tube well water. For tube well water having arsenic concentration >350 ppb and <400 ppb ,a residual arsenic concentration below maximum permissible limit of 50 ppb could be achieved through MSFU without using any chemicals provided the minimum iron concentration of tube well water is also 15 mg/L. Problems have been observed in the case of MSFU-5 (TW arsenic concentration = 410 ppb, iron concentration = 8 mg/L) and MSFU-7 (TW arsenic concentration = 337ppb,iron concentration= 4.6 mg/L). So intermittent dosage of bleaching powder was used as an oxidizing agent to maintain the residual arsenic concentration below maximum permissible limit of 50 ppb. But due to obnoxious smell of bleaching powder an attempt was initialized to minimize the problems by launching an additional Iron Chips Column (ICC) with the existing MSFU after the DRF. Effect of iron chips column attachment after DRF in removing arsenic have been presented in the following figures.

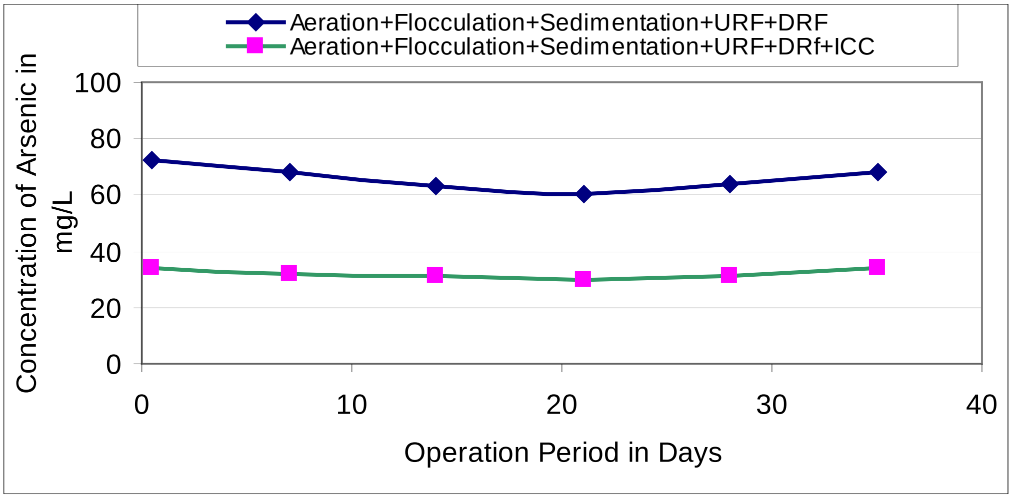


Figure 4-20.Effect of additional iron chips column attachment after DRF on arsenic removal performance (Polua,Jessore)

Figure 4-20 and 4-21 represents the effect of additional ICC attachment on arsenic removal performance as well as the comparison of residual arsenic concentration in the final effluent with and without ICC attachment. Both the figures indicate that residual arsenic concentration in the effluent of additional ICC satisfies the drinking water standard for arsenic in Bangladesh (50 ppb). So for tube well water having arsenic concentration around 350 ppb to 400 ppb and iron concentration < 11 mg/L an additional attachment of ICC after DRF is essential to achieve arsenic concentration in the treated water below maximum permissible limit of 50 ppb.

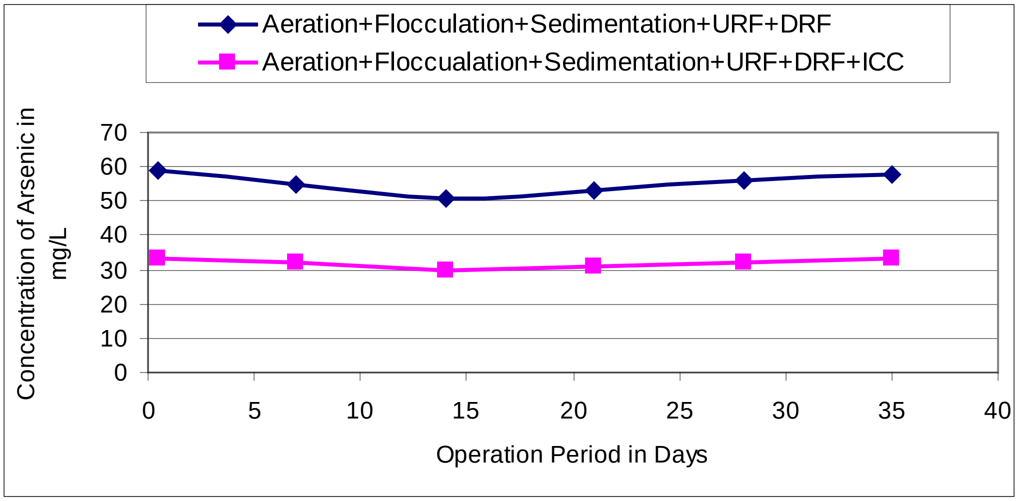


Figure 4-21. Effect of additional iron chips column attachment after DRF on arsenic removal performance (Sonakur,Jessore)

4.4 MANGANESE REMOVAL PERFORMANCE

4.4.1 Variation of Average Manganese Concentration with Operation Period in Different Treatment Unit Processes

Variation of average manganese concentration with operation period in the effluent of different treatment unit processes of MSFUs installed at Sirajgonj have been stated below.

MSFU-1(Kodda,Sirajgonj)

The variation of average manganese concentration with operation period in different treatment unit processes of the MSFU -1 have been explained in figure 4-22. The initial concentration of manganese in the effluent of URF and DRF were found to be 0.7 and 0.29 mg/L indicating removal efficiency of 57 % and 82% respectively. With the passage of time the manganese concentration in the effluent of URF and DRF decreased upto 0.58 mg /L and 0.11 mg/L indicating removal efficiency of 64 % and respectively 93%. This was because there were gradually adsorption of precipitated iron flocs on the coarse media surfaces and gradually deposition of the same in the interstices and these iron particles along with other metal oxy-hydroxides provided increased adsorption surfaces for the manganese ions to be adsorbed. However, after 3 to 4 weeks of run the manganese concentrations in the effluent of DRF again started to increase. This was because when the coarse media pores were clogged the increased pore velocities caused shearing / sloughing of precipitated iron particles which resulted less adsorption site available for arsenic ions and ultimately appeared with the effluent water.

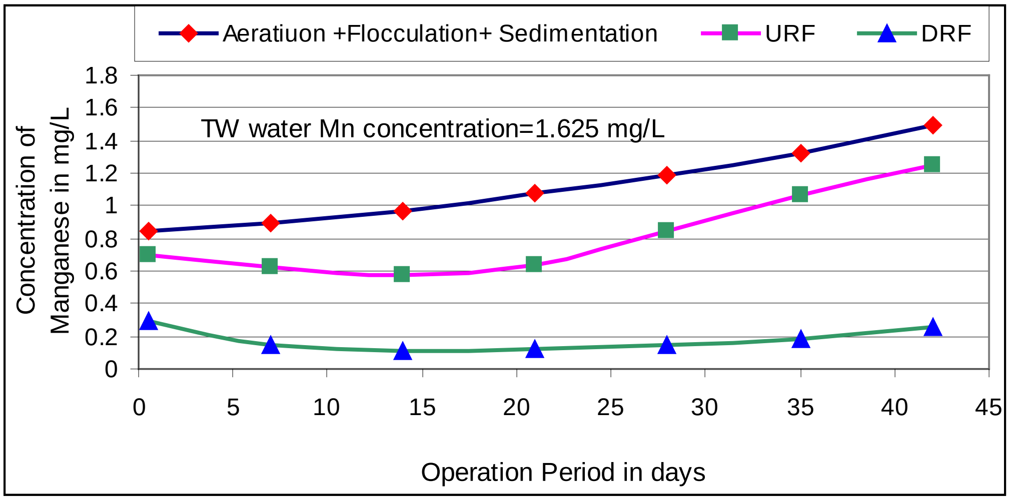


Figure 4-22. Variation of average manganese concentration with operation period in different treatment unit process (Kodda, Sirajgonj)

From the beginning of the filter run a continuous increasing trend of arsenic concentration in the effluent of sedimentation chamber have been observed .Because with the passage of time gradually accumulated iron flocs at the bottom of sedimentation chamber along with adsorbed manganese ions were carried over and ultimately appeared in the effluent of this chamber.

This figure indicates that DRF process process have significant effect on manganese removal. Manganese concentrations in the effluent of sedimentation chamber and URF chamber were much above the WHO health based guideline value for manganese (0.4 mg/L) to protect against neurological damage. On the other hand ,manganese concentration in the effluent of DRF was observed less than 0.4 mg/L.

This was due to the fact that detention time of pre-DRF chamber did not meet the time requirement of manganese oxidation ---because manganese is much more slowly oxidised through aeration than iron and not only that Mn oxidation through chlorine requires 2-4 hours to react completely.

MSFU-2(Chala,Sirajgonj

Figure 4-23 represents the variation of average manganese concentration with operation period in different treatment unit processes of the MSFU-2 .The initial concentration of manganese in the effluent of URF and DRF were found to be 0.35 and 0.16 mg/L indicating removal efficiency o 52 % and 77 % respectively. With the passage of time manganese concentration in the effluent of URF and DRF decreased upto 0.288 mg /L and 0.1 mg/L indicating removal efficiency of 60 % and respectively 86 % . The figure 4.11.1 and 4.11.2 shows that manganese removal efficiency of MSFU-2 was not as effective as MSFU-1. One reason is manganese removal is a function of raw water manganese concentration. i.e higher the Mn concentration, greater is the removal performance .Since tube well water manganese concentration of MSFU-2 is less than MSFU-1,so manganese removal efficiency of MSFU-2 was< MSFU-1. Another reason is total number of users of MSFU-2 > total number of users of MSFU-1.So detention time available for manganese oxidation in all the chambers of MSFU-2 was less than that of MSFU-1. This figure indicates that residual Mn concentration in the effluent of DRF successfully satisfied the WHO health based guideline value (0.4 mg/L) to protect against neurological damage. Due to less detention time and more use of the plant, pre DRF processes was unable to maintain the WHO health based guideline value for manganese (0.4 mg/L) in the effluent.

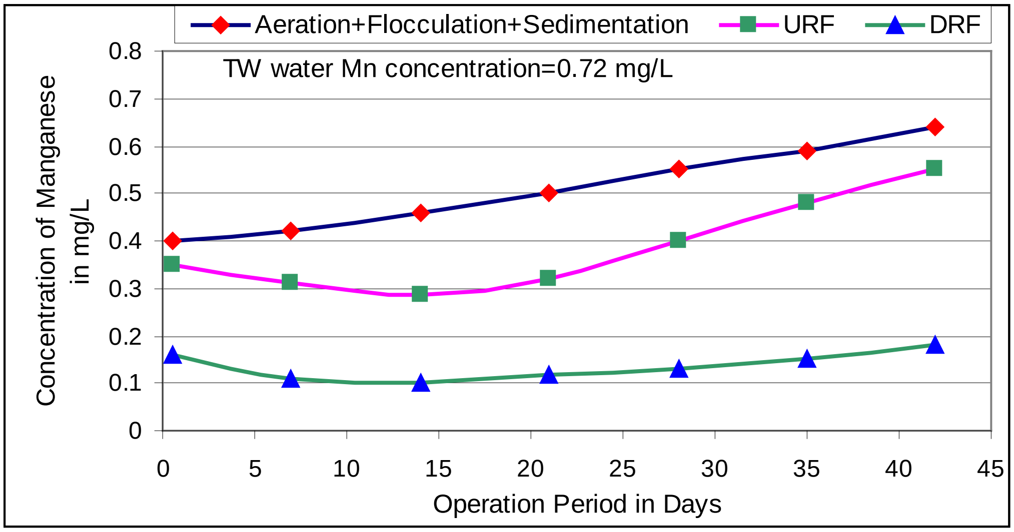


Figure 4-23.Variation of average manganese concentration with operation period in different treatment unit process (Chala, Sirajgonj)

MSFU-3 (Digholkandi,Sirajgonj)

Variation of average manganese concentration in the effluent of different treatment unit processes of the MSFU-3 have been shown in figure 4-24. The tube well water manganese concentration of this unit is higher than the other two units installed at Sirajgonj but the size of URF chamber of MSFU-3 was around 33% smaller than the previous two units MSFU-1 and MSFU-2 which resulted increased face velocity.

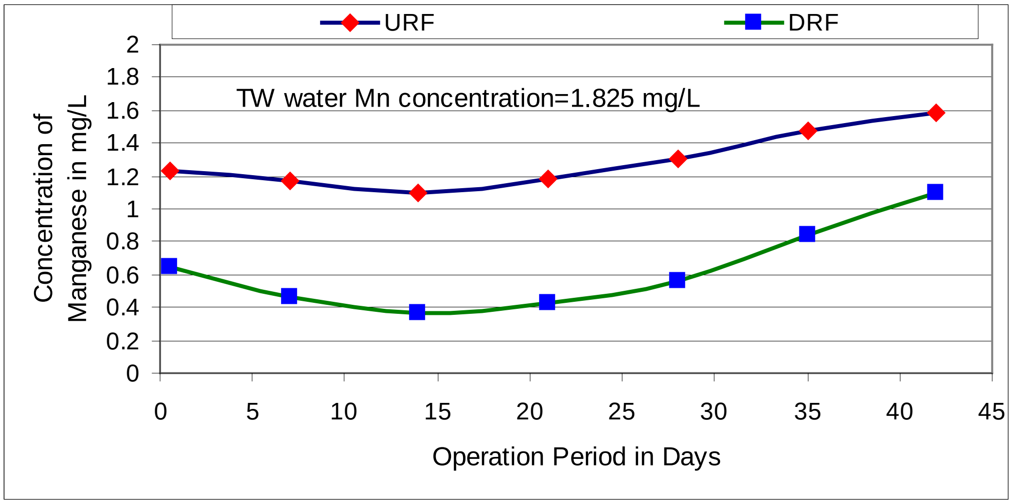


Figure 4-24. Variation of average manganese concentration with operation period in different treatment unit process (Digholkandi, Sirajgonj)

So the manganese removal efficiency of this unit was not as efficient as the previous two units and residual manganese concentration in the effluent of DRF did not satisfy the WHO health based guideline value (0.4 mg/L) to protect against neurological damage.

4.4.2 Manganese Removal Performance of Different Treatment Unit Processes

Figure 4-25 on the next page elaborates the average manganese removal performance of the different treatment unit processes of the multi-stage filtration units of Sirajgonj (Kodda & Chala). Appreciable amount of manganese reduction have been occurred through Aeration cum Flocculation cum Sedimentation Processes (33%).Effect of DRF process alone in removing manganese was found very significant (37%).Role of URF process in reducing manganese was observed moderate (15%).

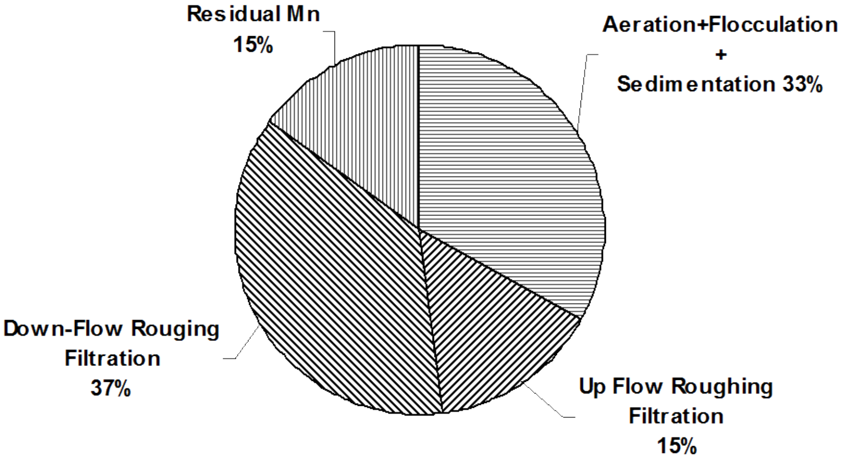


Figure 4-25. Manganese removal performance of different treatment unit processes Sirajgonj (average of Kodda & Chala)

4.4.3 Variation of Manganese Removal Performance with Initial Manganese Concentration

Effect of initial manganese concentration on manganese removal performance of the MSFUs of Sirajgonj (Kodda & Chala) have been furnished in figure 4-26. It indicates that in Kodda, where manganese concentration was 1.625 mg/L and iron concentration was 16 mg/L, then residual manganese concentration was detected around 11% (0.178 mg/L) in the treated water and in Chala, where manganese concentration was 0.72 mg/L and iron concentration was 15 mg/L, then residual manganese concentration was detected around 20% (0.144 mg/L) in the treated water. From this it can be concluded that manganese removal performance is a function of initial manganese concentration i.e. higher the initial manganese concentration, the more is the manganese removal performance.

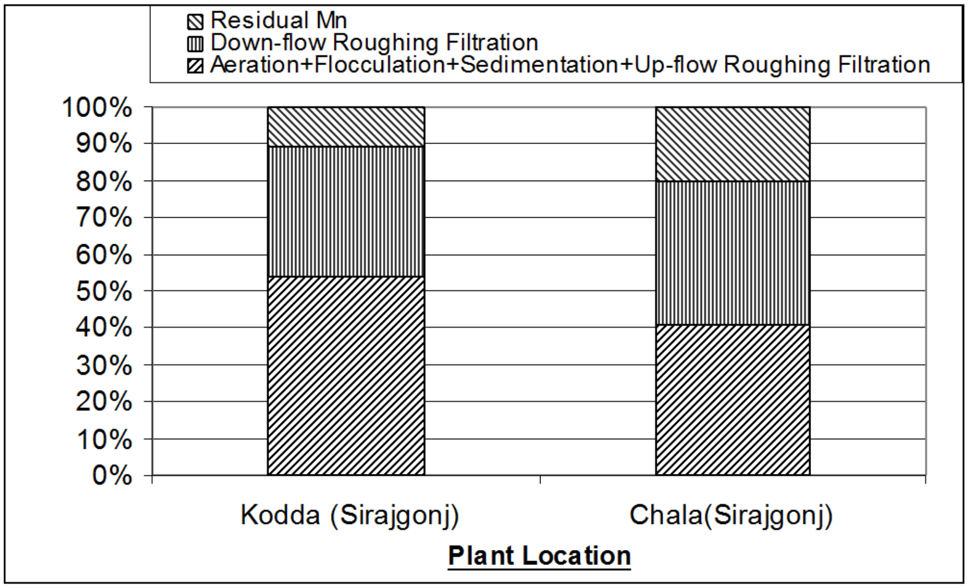


Figure.4-26. Variation of Manganese Removal Performance with Initial Manganese Concentration at Sirajgonj (Kodda & Chala)

4.4.4 Variation of Residual Manganese Concentration with Operation Period in the Treated Water after Down-Flow Roughing Filter (DRF) and Iron Chips Column (ICC)

Variation of residual manganese concentration with operation period in the effluent of DRF and ICC collected from the MSFU-1&2(Kodda & Chala, Sirajgonj) have been shown in figure 4-27. It is mentionable here that in the modification steps ICC was installed after URF chamber and DRF was installed in place of ICC.

Figure 4-27 indicates that residual concentration of manganese in the effluent of ICC didn't satisfy the minimum standard of WHO health based guideline value for manganese (0.4 mg/L) to protect against neurological damage particularly for high Mn concentration.

The above figure also reveals that residual concentration of manganese in the effluent of DRF was well below of 0.4 mg/L. This was because that detention time of DRF Process (around 80 minutes) is much higher than ICC and detention time of ICC (< 5 minutes) does not meet the requirement of complete Mn oxidation. It is also mentionable here that manganese is much more slowly oxidised through aeration than iron and not only that Mn oxidation through chlorine requires 2-4 hours to react completely.

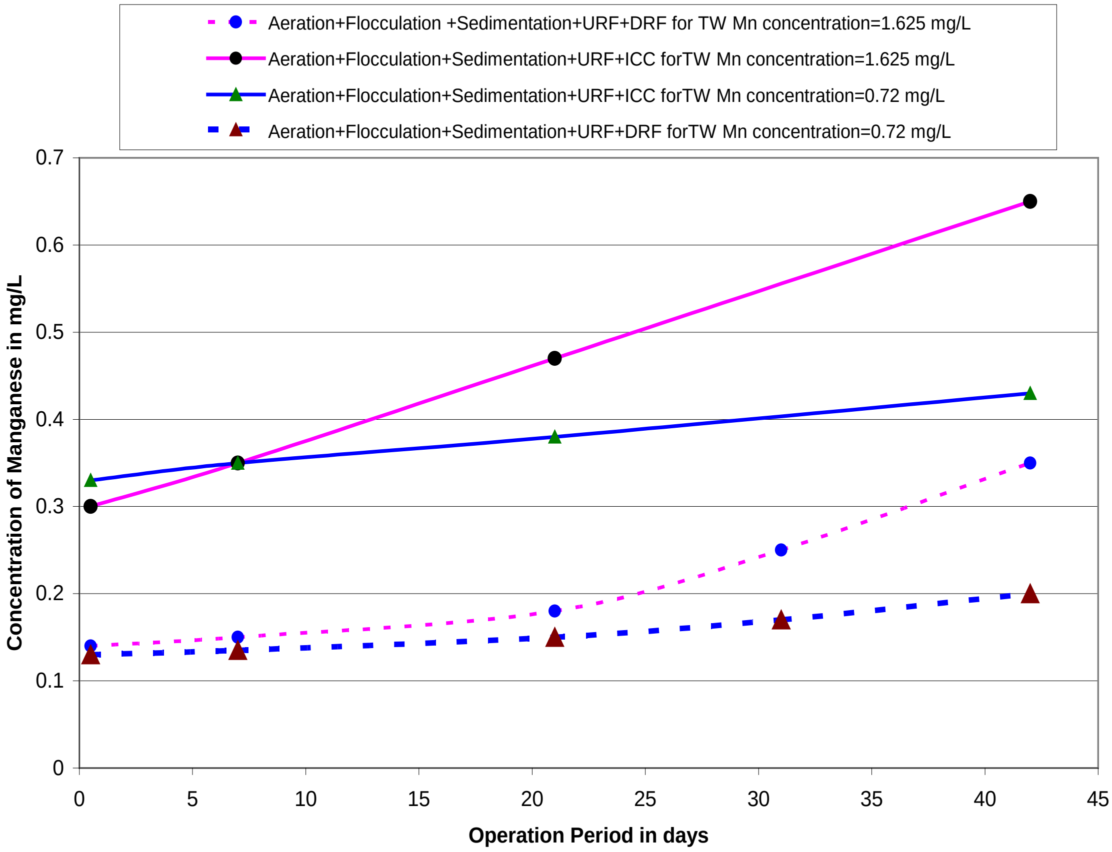


Figure 4-27.Variation of residual manganese concentration with operation period after down-flow roughing filter (DRF) and iron chips column (ICC).

4.4.5 Effectiveness of DRF in Comparison to ICC on Combined Removal Performance

Effectiveness of DRF in comparison to ICC on combined removal performance have been presented in figure 4-28. The above figure shows that that DRF process was found more effective than ICC, particularly for manganese removal. For As and Fe removal the difference between effectiveness of DRF and ICC was found negligible**.** However, As removal was found better in case of ICC use and Iron removal was found better in case of DRF use.

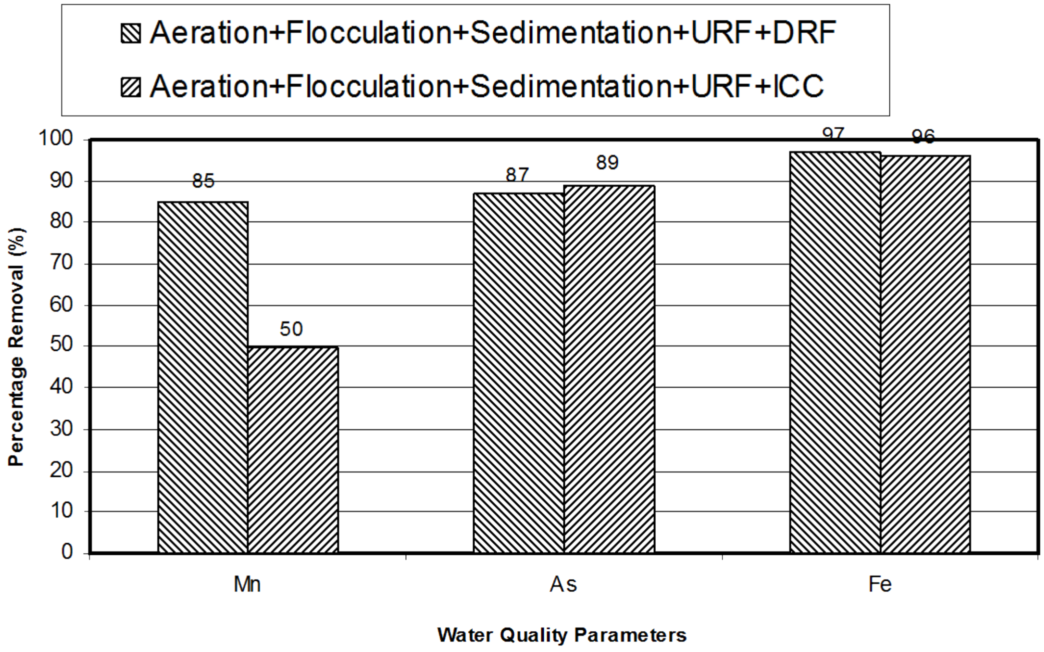


Figure 4-28. Effectiveness of Down-Flow Roughing Filter (DRF) in Comparison to Iron Chips Column (ICC) on Combined Removal Performance of Mn, As & Fe (Kodda & Chala, Sirajgonj)

4.5 DETERMINATION OF VARIATION OF FLOW

4.5.1 Variation of Flow with Operation Period

Rate of flow from the tube well and treatment plants were measured through a known volume of bucket and counting time over the period .The variation of flow after URF with operation period and successive cleaning cycles have been furnished in the following figures.

Figure 4-29 represents the variation of average flow after URF with operation period of the MSFU-1 and 2 (Kodda & Chala). This figure indicates that Tube Well Flow of this unit was 20L/min .The initial effluent flow from the Up-flow Roughing Filter (URF) was 16 L/min (80 % of the influent flow). The effluent water flow then reduced gradually due to deposition of iron flocs on the surfaces of coarse media and in the interstices of the filter bed and reached to 30% of its influent flow within 6 weeks of filter run. Cleaning operation was done at this stage and the flow again recovered up to 75% of the tube well water (influent) flow. The above figure shows first three cycles of filter run through URF which indicates that the length of filter runs between cleaning were not uniform and reduced in successive cycles.

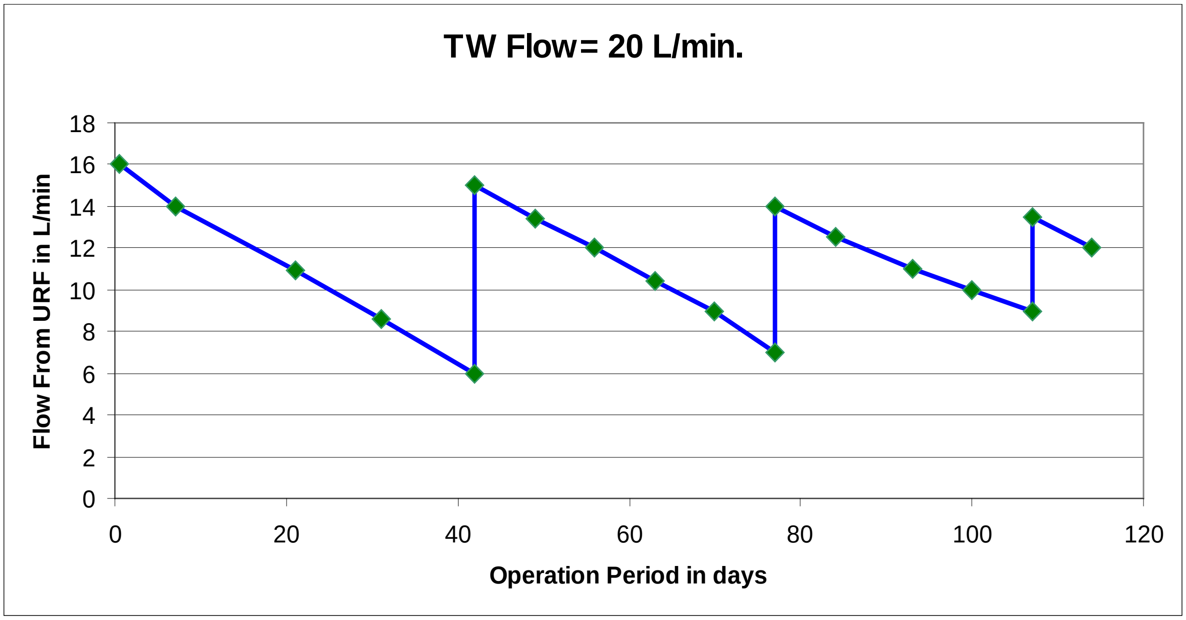


Figure 4-29. Variation of average flow after urf with operation period (average of Kodda & Chala)

The variation of average flow after URF with operation period of the MSFU-4 (Homna, Comilla) have been presented in figure 4-30 .The initial effluent flow from the Up-flow Roughing Filter (URF) of this unit was also 6 L/min (80 % of the influent flow). The effluent water flow then gradually reduced to 40% of its influent flow within 6 weeks of filter run. At this stage cleaning operation was done and the flow again recovered up to 75% of the tube well water flow. First three cycles of filter run through URFof this unit indicates that the length of filter runs between cleaning were not uniform and reduced in successive cycles.

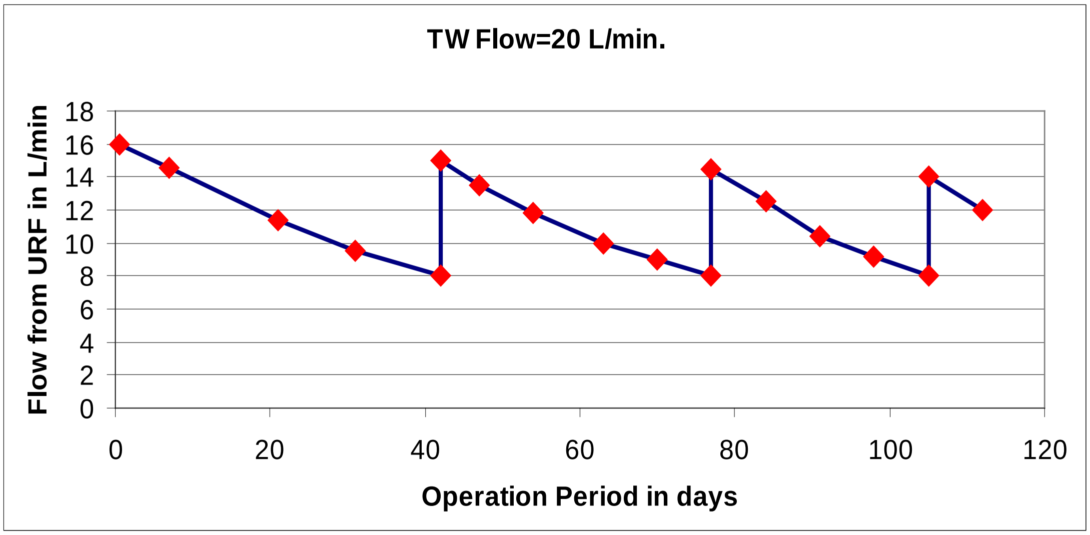


Figure 4-30. variation of average flow with operation period (Homna,Comilla)

Figure 4-31 shows the variation of average flow after URF with operation period of the MSFU-5,6 & 7 (Polua, Sadipur & Sonakur). At the beginning of the filter run 17 L/min flow (85 % of the influent flow) was achieved through URF. The flow then reduced to 55% of its influent flow within 6 weeks of filter run.

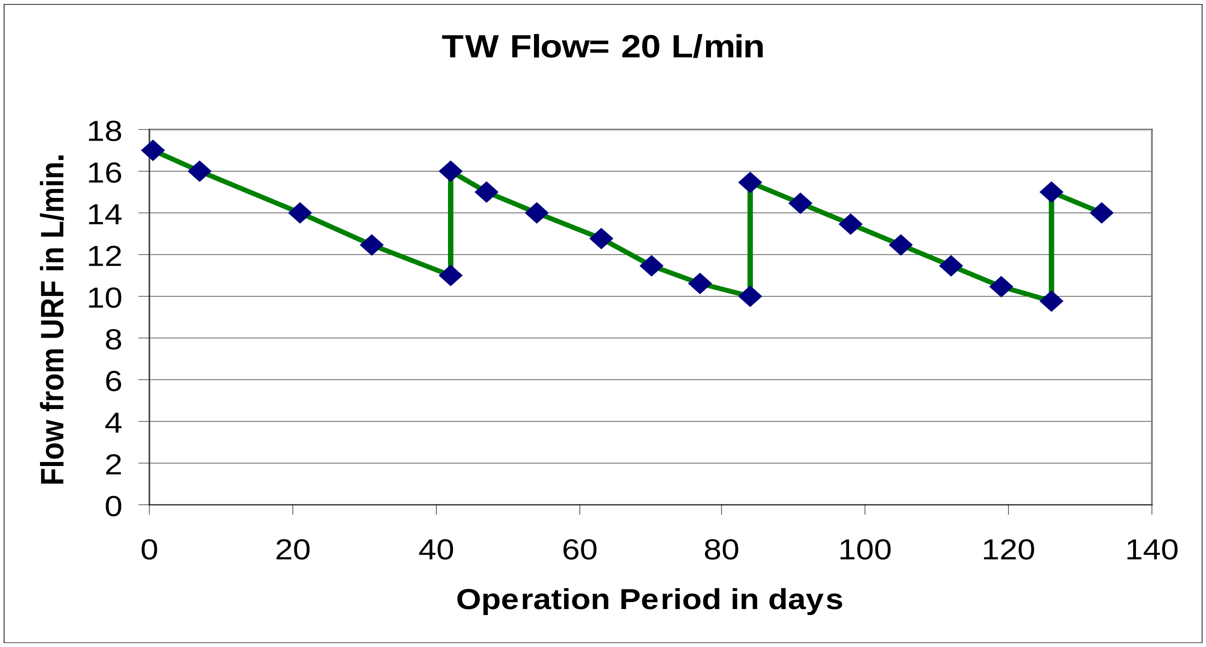


Figure 4-31. Variation of average flow with operation period (Polua,Sadipur&Sonakur)

The flow was recovered up to 80% of influent flow due to cleaning. First three cycles of filter run through URF which indicates that the length of filter runs between cleaning were not uniform and reduced in successive cycles.

4.5.2 Variation of Flow Recovery with Successive Cycle of Cleaning Operation

The tube well water flow and effluent water flow from URF were measured through a known volume of bucket and counting time over the period . The initial effluent flow from the Up-flow Roughing Filter (URF) were 16 L/min, 16 L/min and 17 L/min i.e.80%,80 % and 85 % of the influent flow were achieved in the units Kodda,Homna and Polua respectively. The effluent flow then reduced gradually due to deposition of iron flocs on the surfaces of brick chips and in the interstices of the filter bed and reached to 30%,40 % and 55% of its influent flow respectively within 6 weeks of filter run. Cleaning operation was done at this stage and the flow again recovered up to 75 %,75 % and 80% of the tube well water (influent) flow respectively .Figure 4-32 shows variation of average flow recovery after URF with successive cycle of cleaning operation (as a % of initial URF flow). Cleaning was performed without removing the course media and simply through opening the gate valve at the bottom layer of the sedimentation chamber & at the top layer of coarse media of the URF bed and flushing out the settled sludge within the interstices of the coarse media through back washing by hydro-static pressure.

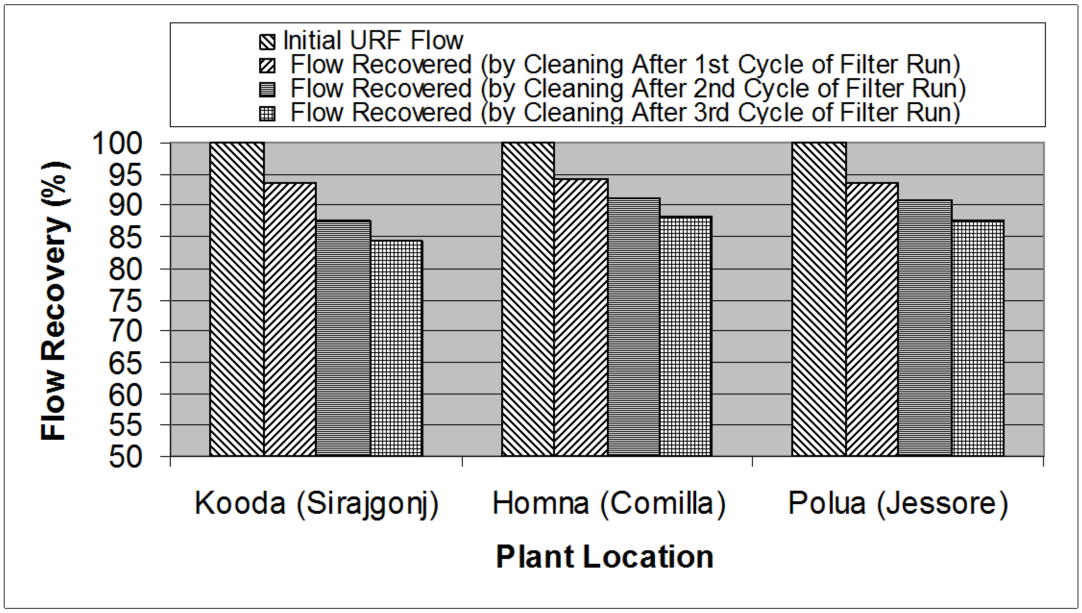


Figure 4-32.Variation of average flow recovery with successive cycle of cleaning operation (as a % of initial URF flow)

The above figure indicates that on an average 94%,90% and 87 % flow recovery of the initial URF flow has been observed respectively in the cleaning operation after 1st ,2nd and 3rd cycle of filter run (from the clogging condition of 40--50% URF flow) at Kodda, Homna and Polua unit respectively. This figure also indicates that flow recovery were not uniform and reduced in successive cycles due to the presence of previously deposited iron precipitates which was not cleaned completely. It is mentionable here variation of average flow recovery with successive cycle of cleaning operation of Kodda unit are similar to Chala unit. Average flow recovery of Sadipur unit and Sonakur units were found similar to Polua unit .

4.5.3 Reduction of average flow from the URF chamber with operation period and determination of cleaning interval.

The effluent flow from URF reduced gradually due to deposition of iron flocs on the surfaces of brick chips and in the interstices of the filter bed. The variation of measured flow (average of Kodda & Chala) with operation period and recommended cleaning interval have been presented in figure 4-33.

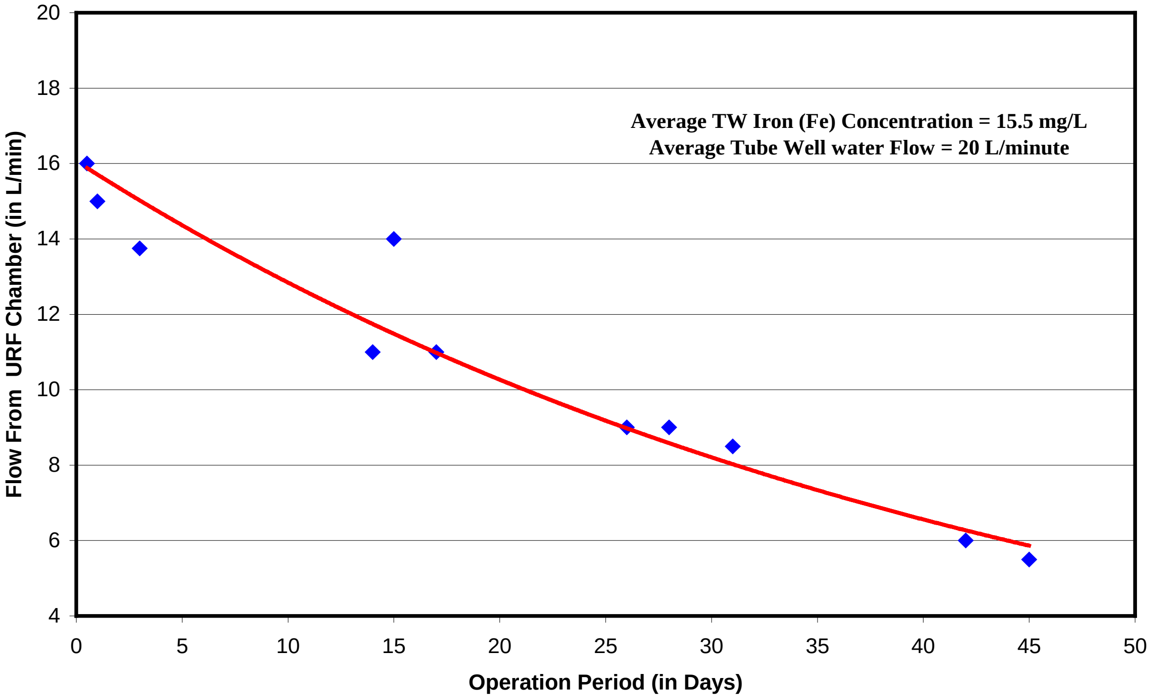


Figure 4-33. Reduction of average flow from the URF chamber with operation period (Kodda & Chala, Sirajgonj)

Figure 4-33 indicates that reduction of flow after URF is directly proportional to the length of the operation period of the MSFU. . MSFU should be cleaned when flow from the outlet of URF chamber will reduce by 45 -- 50 % of the TW flow (flow from the URF chamber = 9 -- 10 L/min). So length of run between cleaning should be maximum 4 weeks

4.6 EFFECT OF THE MSFU ON WATER USE

Presence of high concentration iron, arsenic and manganese in the tube well water discouraged the beneficiaries to use it for all domestic purposes. It was reported that before the construction of the MSFU(s) the tube wells were used only for toilet and cleaning purposes. After the construction of the MSFU(s), the local people were attracted by the treated water quality and consequently the number of users increased depending on the existing local environmental conditions. In case of MSFU at Kodda (Sirajgonj),Chala (Sirajgonj) and Homna (Comilla) appreciable number of users were found from the very beginning of the commissioning of the unit and this condition was prevailing till the last report was reached. In Kodda and Chala the concentration of iron, manganese and arsenic in the treated water well below the acceptable limit of WHO guideline Value and Bangladesh Drinking Water Standard Value. As a result people from the vicinity were inclined to use the treated water from the MSFUs and day by day number users were increasing since peoples from distant places started to use the treated water. In Homna (Comilla) the concentration of iron and arsenic in the treated water well below the acceptable limit of Bangladesh Drinking Water Standard Value.

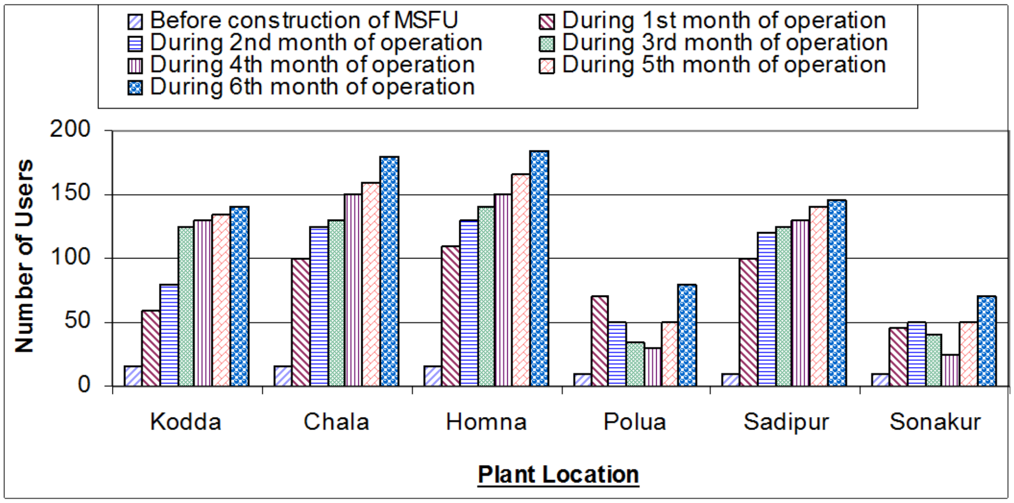


Figure 4-34. Variation of MSFU users with operation period (in month)

As a result people from the vicinity were inclined to use the treated water from the MSFU and day by day number users were increasing since peoples from distant places stated to use the treated water . In Sadipur (Jessore) the concentration of iron and arsenic in the treated water well below the acceptable limit of Bangladesh Drinking Water Standard Value and people from the vicinity were inclined to use the treated water from the MSFU . At the very begining due to low concentration of iron in the treated water in Polua (Jessore) and Sonakur (Jessore) the local people were attracted to the MSFU but when it came to notice that the treated water quality from the MSFU didn’t satisfy the minimum level for arsenic, they began to use water from other alternative sources of safe drinking water in the locality .

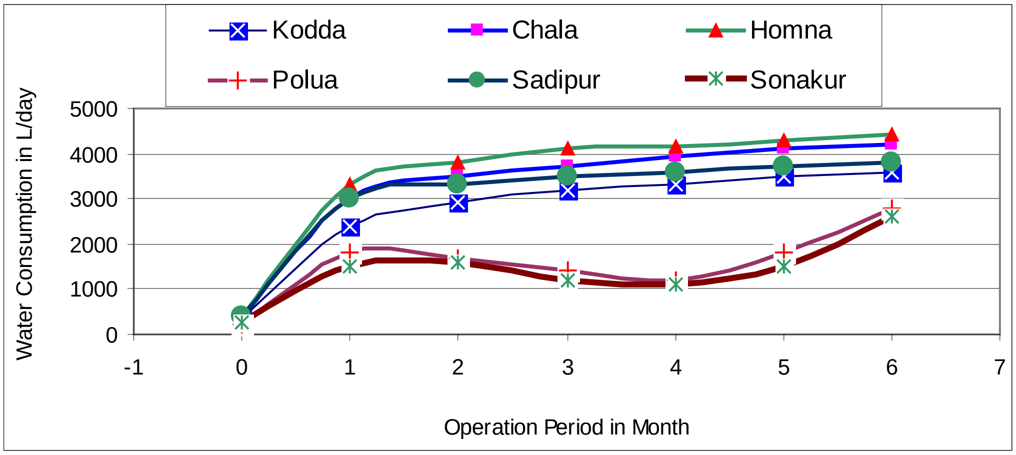


Figure 4-35. Variation of water consumption with operation period (in month)

But after the improvement of water quality (by the installation of ICC) the numbers of beneficiaries were increased in both the places. Figure 4-34 and Figure 4-35 represents the overall effect of MSFU on water use.

4.7 BACTERIOLOGICAL ANALYSIS

Samples, for analysis of bacteriological water quality, were collected in especial sample bags and immediately put in ice box for transportation to the laboratory. Bacteriological analysis was commenced within 8 hours (maximum) of sample collection. Bacteriological analysis was performed in the Environmental Engineering Laboratory ,Department of Civil Engineering, BUET, Dhaka, Bangladesh using membrane filtration unit. Table 4-1 represents the results of bacteriological analysis.

Table 4-1. Results of bacteriological analysis

Location of MSFU	Discharge Point	Analysis on 15.04.2009		Analysis on 15.05.2009	
		TC	FC	TC	FC
Kodda, Sirajgonj	Tube Well	2	0	2	0
	After DRF	TNTC	54	17	Nil
Chala, Sirajgonj	Tube Well	2	2	2	2
	After DRF	TNTC	166	48	27

TC= Total coliform,FC= Fecal coliform, TNTC=Too numerous to count

Table indicates that both total coliform (TC) and fecal coliform(FC) were detected more in the treated water than the raw water. It is likely that bacteriological contamination occurred within the DRF due to placement of filter material without addition of bleaching powder.

4.8 USERS OPINION REGARDING THE MSFU

A questionnaire as shown in the Annex-1 was used for the collection of household details and beneficiaries opinion.. The Users expressed their opinions whether they were satisfied with the effluent water quality, plant yield and the operations and maintenance. Operations of MSFU(S) were not very much difficult, however, reduction of flow with time was a concern. They were capable to clean the unit through opening the bottom valves of the MSFU(S). Users are very much interested about the residual concentration of iron and arsenic in the treated water . They are not anxious about the manganese issue. It was observed that water having iron concentration less than 2.0 mg/L was of no objection to the people and they called such water as good. According to them water having residual iron concentration <1 mg/L is excellent and water having residual iron concentration >3 mg/L is bad . Users opinions are such that when they are satisfied with the residual iron concentrations, at the same time they are also satisfied with the residual concentrations of arsenic and manganese. That means if they are satisfied with the residual iron concentrations, then they believe that water quality (iron,manganese & arsenic) has been improved .According to them yield of the plant is excellent or good or bad ,if they get effluent flow from URF chamber > 14 L/min or in between 9 to 14 L/min or < 9 L/min respectively. Operation & maintenance is excellent to those users who get enough effluent flow from URF as well as DRF without pumping the tube well. Operation & maintenance is good to those users who get enough effluent flow from URF as well as DRF with spending little effort for pumping the tube well. According to some users operation & maintenance is bad because(1) there is no motorized pumping facilities,(2) there is no arrangement for regular cleaning, (3)frequent clogging of filter bed occurs, (4) interval between successive cleaning is not so long, etc. The following table represents beneficiaries' Opinion.

Table 4-2 . Users opinion regarding water quality, yield and operation & maintenance

Plant Location	Water Quality			Yield			Operation & Maintenance		
	E	G	B	E	G	B	E	G	B
Kodda	90	10	-	20	50	30	10	60	30
Chala	90	10	-	20	50	30	10	60	30
Homna	90	10	-	20	40	40	5	65	30
Polua	-	65	35	40	40	20	30	65	5
Sadipur	20	70	10	40	40	20	30	65	5
Sonakur	-	70	30	40	40	20	30	65	5

N:B: E=Excellent, G=Good, B= Bad

4.9 MAINTENANCE & OPERATION

The MSFUs are designed to be operated, cleaned and maintained by the beneficiaries themselves. The beneficiaries are involved in the construction. They are also trained in how to use the MSFU. Length of filter run between cleaning should be maximum 3 - 4 weeks. The MSFUs will be cleaned before the break through curve reached the maximum concentration level and when flow from the outlet of URF chamber will reduce by 45-50% of the TW water flow i.e. flow from the URF Chamber = 9-10 L/min. During the cleaning operation tube well should be pumped continuously and following steps should be followed.

a) Water collecting fittings /taps should be closed.
b) Wash-out valve from the top of URF should be opened to flash out partially deposited sludge.
c) After finishing step (2) wash-out valve should be closed and water level should be raised at least 4 above the top layer of coarse media of the URF bed.
d) Wash-out valve from the bottom of sedimentation chamber should be opened to flash out the gradually accumulated sludge (at the bottom of this chamber and within the interstices of the coarse media) through back washing by hydro-static pressure. Wash-out valve should be closed as soon as the clear water appeared with the effluent and in no case the water level should not be brought down to the top layer of coarse media of the URF bed.
e) Tube well should be pumped enough to raise the water level above the top of the DRF bed and wash-out valve from the top of DRF bed should be opened to flash out partially deposited sludge.

f) After completing step (5) top wash-out valve should be closed and bottom wash out valve of DRF bed should be opened for flashing out the settled sludge within the interstices of the coarse media and at the bottom of this chamber.

<u>Important points on maintenance and operation</u>

a) Length of filter run between cleaning should be maximum 3 - 4 weeks.
b) MSFU will be cleaned when flow from the outlet of URF chamber will reduce by 45-50% of the TW flow i.e. flow from the URF Chamber = 9-10 L/min.
c) Weekly chlorination should be done to control biological growth on filter media through mixing BP solution with tubewell water.
d) Flow from the outlet of DRF should be controlled through using special flow restricted (2 - 2.5 L/min) gate valve.
e) Periodical (after 5-6 months) cleaning of filter materials should be done through removing & complete washing of filter materials and cleaning of filter chambers.
f) Approximate cost of construction of the MSFU is around TK.19000/=.
g) Operation & Maintenance cost is around TK. 150/- per month (including cost of Bleaching Powder).

4.10 SUMMARY OF REMOVAL PERFORMANCE

4.10.1 Summary of Iron Removal Performance

a)Around 97 % of iron removal i.e a residual iron concentration below maximum permissible limit of 1 m g/L.could be achieved easily through the MSFU.
b) Major removal of iron (78%)occurred through aeration cum flocculation cum sedimentation Processes.
c)URF process plays significant role in removing iron (16%).
d)Performance of DRF for iron removal was not significant.(only 3%)
e)Iron removal was a function of initial iron concentration. The more the initial iron concentration, the more was the iron removal performance. The effect of tube well water iron concentration on iron removal performance can be expressed through the equation $y = 8.7714\mathrm{Log}_e(x) + 73.116$,Where, y =Percentage of Iron Removal, x = Tube well water Iron Concentration (mg/L). Using this equation it will be easy to determine the residual iron concentration in the final effluent achieved through properly designed MSFU treating tube well water of different initial iron concentration (range from 4.6 mg/L to 16 mg/L).

4.10.2 Summary of Arsenic Removal Performance

a) Appreciable percentage of arsenic reduction could be achieved through the MSFU, provided that TW water iron concentration is reasonably high and DRF process is incorporated with the MSFU.
b) Both URF and Pre-URF (Aeration cum Flocculation cum Sedimentation) Processes contributed significantly (respectively34% and 53%) in Arsenic removal.
c) Arsenic removal is a function of initial Iron. The trend of the arsenic removal performance with respect to initial iron concentration of tube well water achieved through the MSFU

have been expressed through the equation $y = 8.8742 \, Log_e(x)+65.86$, **w**here, y =percentage of arsenic removal, x = tube well water iron concentration (mg/L). Using the above equation it will be easy to determine the residual arsenic concentration in the final effluent achieved through properly designed MSFU treating tube well water of different initial iron and arsenic concentration (iron concentrations range from 4.6 to 16 mg/L and arsenic concentration range from 70 to 410 ppb).

d) For As and Fe removal the difference between effectiveness of DRF and ICC was found negligible**.** However, As removal was found better in case of ICC use and Iron removal was found better in case of DRF use.
e) For arsenic concentration > 300 & <350 ppb and iron concentration < 8 mg/L an additional attachment of ICC after DRF is essential to achieve arsenic concentration in the treated water below maximum permissible limit of 50 ppb.
f) For tube well water having arsenic concentration around >350 ppb and iron concentration < 11 mg/L an additional attachment of ICC after DRF is essential to achieve arsenic concentration in the treated water below maximum permissible limit of 50 ppb.
g) For arsenic concentration > 400 ppb and iron concentration < 15 mg/L an additional attachment of ICC after DRF is essential to achieve arsenic concentration in the treated water below maximum permissible limit of 50 ppb.

4.10.3 Summary of Manganese Removal Performance

a) Manganese removal is a function of raw water manganese concentration. Higher the Mn concentration, greater is the removal performance.
b) Up to 85 % manganese removal performance was achieved through the MSFU.
c) Contribution of DRF alone in removing manganese was observed very significant (around 37%).
d) Contribution of URF in removing manganese is moderate(around15%).
e) For TW water Manganese concentration around 1.5 mg/l and Iron concentration around 15 mg/l, a residual Mn concentration below maximum permissible limit (WHO health risk guide line value for Mn) of 0.4 mg/L could be maintained through the MSFU.
f) DRF process was found more effective than ICC for manganese removal.

4.11 Comparison between ITN-AIRU and MSFU

Multi-Stage Filtration Units (MSFUs) are the stepwise modification of ITN-AIRU. So a comparison between ITN-AIRU and MSFU regarding the overall removal efficiency, users' acceptability , cost effectiveness, etc. are important to know the real improvements. Plant yield, Length of filter run between cleaning and cleaning procedures of ITN-AIRU are almost similar to those of MSFU. However ,MSFU provides more comprehensive recommendation on operation & maintenance than ITN-AIRU . The ITN-AIRU and MSFU can be compared in the following ways:

a) There was single water collection point for all purposes in case of ITN-AIRU whereas separate water collection point for drinking and cooking purposes have been introduced in MSFU. So the MSFU is more acceptable to get better quality water.
b) Only overall removal efficiency have been determined in case of ITN-AIRU. Different treatment unit process wise iron ,arsenic and manganese removal efficiency as well as overall removal efficiency have been determined in case of MSFU. So the latter is more acceptable to get the true picture of removal efficiency.
c) Iron removal efficiency of 90% was achieved through the ITN-AIRU. Iron removal efficiency of 97% was achieved through the MSFU. So the latter is more acceptable to get better quality water.
d) Average arsenic removal efficiency around 75% was achieved through the ITN-AIRU without using any chemicals. Average arsenic removal efficiency around 87% was achieved through the MSFU without using any chemicals. So the latter is more acceptable to get better quality water.
e) Manganese removal efficiency upto 85% was achieved through the MSFU. Manganese removal efficiency was not observed in case of ITN-AIRU. So the MSFU is more acceptable considering the manganese issue.
f) The effect of tube well water iron concentration on iron removal performance achieved through the MSFU have been expressed through the equation $y = 8.7714\mathrm{Log}_e(x) + 73.116$,Where, y =percentage of iron removal, x = tube well water iron concentration (mg/L). Using the above equation it will be easy to determine the residual iron concentration in the final effluent achieved through properly designed MSFU treating tube well water of different initial iron concentration (iron concentration range from 4.6 to 16 mg/L). No such co-relation has been developed for ITN-AIRU. So MSFU will provide more input than ITN-AIRU for future study regarding iron removal performance.
g) The trend of the arsenic removal performance with respect to initial iron concentration of tube well water achieved through the MSFU have been expressed through the equation $y = 8.8742\ \mathrm{Log}_e(x)+65.86$, **w**here, y =percentage of arsenic removal, x = tube well water iron concentration (mg/L). Using the above equation it will be easy to determine the residual arsenic concentration in the final effluent achieved through properly designed MSFU treating tube well water of different initial iron (4.6 to 16 mg/L) and arsenic concentration (70 ppb to 410 ppb). No such co-relation has been developed for ITN-AIRU.So MSFU will provide more input than ITN-AIRU for future study.

From the above comparison it can be concluded that MSFU is superior to (and more acceptable than) ITN-AIRU.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

Few years back, ITN-Bangladesh under a research program has developed a combined Iron-Arsenic Removal unit (AIRU) and made some recommendations for future study such as (i) to conduct extensive field tests of the AIRU to study both iron and arsenic removal performances and to determine maximum removal capacity under different water quality conditions,(ii) to study the comparative performances of variable adsorbents (activated alumina, iron coated sand, Read-F etc.) column attachment with the AIRU in acute arsenic problem areas and to find out the most suitable combination and (iii) to study the performance of using brick chips aggregate in stead of gravel for both flocculation and roughing filtration purpose. The present study has been performed on the basis of the above recommendations with additional attention on manganese issue.

5.2 CONCLUSIONS

a) Multistage filtration can be used effectively in removing iron, arsenic and manganese from groundwater of Bangladesh. Without using any chemicals around 97%, 91 % and 89 % removal performance of iron, arsenic and manganese respectively can be achieved easily through the treatment of multi-stage filtration unit (MSFU) provided that the raw water iron concentration is around 15 mg/L.

b) Multistage filtration can be used successfully to maintain the residual concentration of iron, arsenic and manganese in the treated water below maximum permissible limit of 1mg/L, 50µg/L and 0.4mg/L respectively.

c) Iron removal performance was observed to be a function of initial iron concentration. The more the initial iron concentration, the more was the iron removal performance. The effect of tube well water iron concentration on iron removal performance can be expressed through the equation $\mathbf{y = 8.7714 Log_e(x) + 73.116}$; where, y = percentage of iron removal, x = tube well water iron concentration (mg/L). Using this equation it will be easy to determine the residual iron concentration in the final effluent achieved through properly designed MSFU treating tube well water of different initial iron concentration (initial iron concentration range from 4.6 to 16 mg/L).

d) Arsenic removal performance was observed to be a function of initial iron concentration. The trend of the arsenic removal performance with respect to initial iron concentration of tube well water achieved through the MSFU have been expressed through the equation $\mathbf{y = 8.8742\ Log_e(x)+65.86}$, **w**here, y = percentage of arsenic removal, x = tube well water iron concentration (mg/L). Using this above equation it will be easy to determine the residual arsenic concentration in the final effluent achieved through properly designed MSFU treating tube well water of different initial iron and arsenic concentration (iron concentrations range from 4.6 to 16 mg/L and arsenic concentration range from 70 to 410 ppb).

e) Manganese removal performance was observed to be a function of raw water manganese concentration. Higher was the manganese concentration, greater was the removal performance.

f) Around 78%, 16 % and 3% iron removal have been occurred through pre-URF (aeration cum flocculation cum sedimentation) ,URF and DRF (post URF) processes respectively.

g) Around 53%, 34 % and 3% arsenic removal have been occurred through pre-URF (aeration cum flocculation cum sedimentation) , URF and DRF (post URF) processes respectively.

h) Around 33%, 15 % and 37 % manganese removal have been occurred through pre-URF (aeration cum flocculation cum sedimentation),URF and DRF (post URF) processes respectively.

i) If the calculated residual arsenic concentration (using equation **$y = 8.8742 \mathrm{Log}_e(x)+65.86$)** in the final effluent of MSFU treating tube well water containing high concentration of arsenic and low concentration of iron does not satisfy the maximum permissible limit of 50 µg/L, then an additional attachment of ICC after DRF is essential.

5.3 RECOMMENDATION ON OPERATION AND MAINTENANCE

a) Length of filter run between cleaning should be maximum 3 - 4 weeks. MSFU will be cleaned when flow from the outlet of URF chamber will reduce by 45-50% of the tube well flow i.e. flow from the URF Chamber = 9-10 L/min.

b) Just after each cleaning chlorination should be done to control biological growth on filter media through mixing bleaching powder solution with tube well water.

c) Flow from the outlet of DRF should be controlled through using special flow restricted (2 - 2.5 L/min) gate valve.

d) Periodical (after 5-6 months) cleaning of filter materials should be done through removing & complete washing of filter materials and cleaning of filter chambers.

5.4 RECOMMENDED DESIGN PARAMETER

The study reveals the following design parameters

Coarse media Flocculator
- Face Velocity = 3.24 – 4.05 m/hr
- Detention Time = 4.5 - 6 min

Sedimentation Chamber
- Surface Over Flow Rate = 9.7 -12.9 m^3/m^2-day
- Detention Time = 28 - 35 min

Up-flow Roughing Filter
- **Face Velocity = 0.32 – 0.40 m/hr**
- **Detention Time = 28 - 35 min**

Down-flow Roughing Filter

- Face Velocity = 0.22 – 0.27 m/hr
- Detention Time = 66 - 82 min

Additional attachment of ICC after DRF

If the calculated residual arsenic concentration (using equation **$y= 8.8742 \text{Log}_e(x)+65.86$)** in the final effluent of MSFU treating tube well water containing high concentration of arsenic and low concentration of iron does not satisfy the maximum permissible limit of 50 µg/L, then an additional attachment of ICC after DRF is essential

Flow Consideration

The rate of flow from Tubewell = 20 -25 L/min,
Flow across the Coarse Media Flocculator = 16 - 20 L/min,
Flow across the Up-flow Roughing Filter = 12 –15 L/min,
Flow across the Down-flow Roughing Filter = 2.0 - 2.5 L/min

5.5 RECOMMENDATION FOR FUTURE STUDY

Followings are the major recommendations for future study:

a) To conduct extensive field tests of the MSFU to study iron,manganese and arsenic removal performances and to determine maximum removal capacity under different water quality conditions.
b) To observe the influence of phosphate, silica, nitrate, chloride and other anions on the arsenic removal efficiency of this unit under variable water quality conditions of the country.
c) To study the performance of using increased number URF and DRF.
d) To develop a suitable and safe sludge collection and disposal system of the unit

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ANNEX-1A

QUESTIONAIRE FOR FIELD SURVEY

(Pre- construction Survey)

1.Village-----------------------------2. Date----------------------------------
3.House No.--------------------------4.Religion
5. Name of the informant and relation with househead---

6.Occupation:---
7.Level of education:
NothingPrimarySecondaryAbove Secondary
☐ ☐ ☐ ☐

8. Numbers of member in the house:

Sex	Below 12 years	12 to 60 years	Above 60 years
Male:			
Female:			

9. Reasons for non-usage of tube well water for all domestic purposes:

Reasons	Yes	No
Tube well water has a cloudy appearance		
Cooked food and clothes and utensils become coloured		
Tube well water has a bad taste and odor		
Hair becomes sticky		
Tube well water causes caustiveness		
Take more time in boiling rice and dal		
Other reasons (if any)		

10. Sources of water for domestic purposes:

Nature of consumption	Tube well	Other
Drinking		
Cooking		
Laundry		
Washing utensils		
Bathing		
Sanitary and other		

11.Water quality of the nearest tube well:

The tube well water is	Excellent	Good	Medium	Bad	Very Bad

ANNEX-1B

QUESTIONAIRE FOR FIELD SURVEY

(Post- construction Survey)

1.Village-----------------------------2. Date----------------------------------
3.House No.---------------------------4.Religion
5. Name of the informant and relation with househead---

6.Occupation:--
7.Level of education:
NothingPrimarySecondaryAbove Secondary
☐ ☐ ☐ ☐

8. Numbers of member in the house:

Sex	Below 12 years	12 to 60 years	Above 60 years
Male:			
Female:			

9.Water Use from MSFU

Container type	Small(<12 litres)	Medium(12 to 20 litres)	Big(above 20 litres)
Kolshi (No.)			
Bucket(No.)			
Others(No.)			
Total (litres)=			

10.Number of persons using MSFU for the purposes of

Drinking (3 L/persons)	Bathing (25 L/persons)	Cooking (4 L/ persons)	Washing Clothes (20 L/ persons)	Others (Litres)
Total (litres)=				

11. Beneficiaries opinion (No.)

Water Quality			Yield			Operation & Maintenance		
E	G	B	E	G	B	E	G	B

E= Excellent, G= Good, B= Bad

ANNEX-2

Construction cost of MSFU

Sl .No	Item	Sub-item	Quantity	Unit price (TK.)	Estimated Cost (TK.)
1	Bricks	Brick Flat Soling (BFS) 5" Brick wall	800 nos.	4.50	3600.00
2	Cement	Brick works,R.C.C. works,C.C. works,etc.	9 bag	360.00	3240.00
3	Sand	Brick works,R.C.C. works,C.C. works,BFS	80 cft	7	560.00
4	Khoa (# 1 bricks)	R.C.C. works,C.C. works	40 cft	60.00	2400.00
5	M.S. Rod	R.C.C. works	20 kg	45.00	900.00
6	Plumbing	3" P.V.C. pipe, G.I. pipe, G.I. gate valve, G.I. Sockect, 3" Flexible inlet pipe, Strainer, Delivery pipe fittings etc.	L.S.	-	2000.00
7	Burned Bricks chips (khoa)	Flocculator,URF, DRF	40 cft	60.00	2400.00
8	Labour	Mason and Helper	6days	(250+150)	2400.00
9	Local Carriage		L.S.	-	1000.00
10	Miscellaneous		L.S.	-	500.00
				Total TK./ UNIT=	19000.00

ANNEX-3

Photographs of the MSFU at the field Level


MSFU- 5 (Polua,Jessore) with single Column ICC attachment after URF


MSFU-1(Kodda, Sirajgonj) with double Column ICC attachment after URF


MSFU- 5 (Polua,Jessore) with double Column ICC attachment after DRF


MSFU-4 (Homna, Comilla)


MSFU-7 (Sonakur, Jessore)


MSFU-3 (Digholkandi, Sirajgonj)

ANNEX-4A

Iron Concentrations Data

In the effluent of	Iron Concentrations (mg/L) of Kodda with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
A+F+S	2.2	2.3	2.4	2.6	2.8	3.1	3.6
URF	1.4	1	0.67	0.4	0.5	0.7	1
DRF	0.8	0.53	0.29	0.2	0.25	0.4	0.6

In the effluent of	Iron Concentrations (mg/L) of Chala with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
A+F+S	3.8	3.9	4	4.22	4.53	4.9	5.5
URF	1.6	0.9	0.58	0.5	0.52	0.64	1
DRF	0.8	0.52	0.25	0.2	0.25	0.35	0.65

In the effluent of	Iron Concentrations (mg/L) of Digholkandi with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
URF	**3.2**	**2.6**	**2.1**	**2**	**2.2**	**2.5**	**2.9**
DRF	**2.12**	**1.33**	**0.92**	**0.8**	**0.95**	**1.2**	**1.58**
Chlorination	**0.05**	**0.1**	**0.2**	**0.3**	**0.4**		

In the effluent of	Iron Concentrations (mg/L) of Homna with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
URF	**1.8**	**1.3**	**0.9**	**0.7**	**0.62**	**0.72**	**1.2**
DRF	**0.8**	**0.4**	**0.25**	**0.22**	**0.22**	**0.3**	**0.6**

In the effluent of	Iron Concentrations (mg/L) of Polua with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
TW	**8**	**8**	**8**	**8**	**8**	**8**	**8**
URF	**1.9**	**1.4**	**1**	**0.9**	**0.85**	**0.85**	**1**
DRF	**1**	**0.8**	**0.65**	**0.55**	**0.5**	**0.55**	**0.6**

In the effluent of	Iron Concentrations (mg/L) of Sadipur with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
URF	**2.1**	**1.5**	**1.1**	**0.9**	**0.9**	**1.1**	**1.8**
ICC	**1**	**0.8**	**0.65**	**0.55**	**0.5**	**0.7**	**0.9**

In the effluent of	Iron Concentrations (mg/L) of Sonakur with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
URF	**1.5**	**1**	**0.78**	**0.73**	**0.75**	**0.8**	**1**
DRF	**0.97**	**0.77**	**0.55**	**0.35**	**0.39**	**0.57**	**0.75**

Arsenic Concentrations Data

In the effluent of	Arsenic Concentrations (ppb) of Kodda with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
TW	**70**	**70**	**70**	**70**	**70**	**70**	**70**
A+F+S	**25**	**27**	**29**	**31.3**	**34**	**41**	**48**
URF	**11**	**9**	**8**	**7**	**7**	**8**	**11**
DRF	**9**	**7**	**6**	**5**	**5**	**6**	**8**

In the effluent of	Arsenic Concentrations (ppb) of Chala with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
Raw	**120**	**120**	**120**	**120**	**120**	**120**	**120**
A+F+S	**42**	**44**	**47**	**52**	**60**	**68**	**75**
URF	**19**	**16**	**14**	**14**	**15**	**16**	**18**
DRF	**13**	**11**	**10**	**11**	**12**	**13**	**15**

In the effluent of	Arsenic Concentrations (ppb) of Homna with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
TW	**336**	**336**	**336**	**336**	**336**	**336**	**336**
URF	**110**	**95**	**80**	**72**	**75**	**81**	**98**
DRF	**45**	**34**	**28**	**25**	**26**	**34**	**41**

In the effluent of	Arsenic Concentrations (ppb) of Polua with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
TW	**410**	**410**	**410**	**410**	**410**	**410**	**410**
URF	**175**	**130**	**110**	**98**	**110**	**123**	**135**
DRF	**95**	**60**	**48**	**42**	**52**	**62**	**75**

In the effluent of	Arsenic Concentrations (ppb) of Sadipur with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
TW	**216**	**216**	**216**	**216**	**216**	**216**	**216**
URF	**69**	**54**	**50**	**51**	**55**	**61**	**70**
ICC	**42**	**31**	**25**	**26**	**30**	**39**	**46**

In the effluent of	Arsenic Concentrations (ppb) of Sonakur with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
TW	**337**	**337**	**337**	**337**	**337**	**337**	**337**
URF	**170**	**125**	**99**	**95**	**105**	**112**	**120**
DRF	**105**	**75**	**60**	**48**	**58**	**68**	**78**

Manganese Concentrations Data

In the effluent of	Manganese Concentrations (mg/L) of Kodda with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
TW	**1.625**	**1.625**	**1.625**	**1.625**	**1.625**	**1.625**	**1.625**
A+F+S	**0.85**	**0.9**	**0.972**	**1.08**	**1.193**	**1.326**	**1.5**
URF	**0.6**	**0.63**	**0.7**	**0.8**	**0.92**	**1.061**	**1.25**
DRF	**0.14**	**0.15**	**0.16**	**0.18**	**0.212**	**0.274**	**0.35**
Chlorination	**0.06**	**0.06**	**0.06**	**0.07**	**0.08**		

In the effluent of	Manganese Concentrations (mg/L) of Chala with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
Raw	**0.72**	**0.72**	**0.72**	**0.72**	**0.72**	**0.72**	**0.72**
A+F+S	**0.45**	**0.465**	**0.5**	**0.53**	**0.56**	**0.6**	**0.67**
URF	**0.37**	**0.385**	**0.407**	**0.44**	**0.47**	**0.515**	**0.6**
DRF	**0.13**	**0.135**	**0.14**	**0.15**	**0.16**	**0.17**	**0.2**

In the effluent of	Manganese Concentrations (mg/L) of Digholkandi with operation period of						
	0.5 days	7days	14days	21days	28days	35days	42days
Raw	**1.825**	**1.825**	**1.825**	**1.825**	**1.825**	**1.825**	**1.825**
A+F+S	**1.4**	**1.44**	**1.48**	**1.52**	**1.56**	**1.59**	**1.6**
URF	**1.1**	**1.169**	**1.235**	**1.31**	**1.4**	**1.47**	**1.59**
DRF	**0.4**	**0.43**	**0.46**	**0.53**	**0.62**	**0.753**	**1.1**

ANNEX-4D

Data on variation of URF flow

variation of URF flow (Kodda & Chala)

Day	0.5	7	21	31	42	42
Flow from URF (in L/min)	16	14	10.9	9	6	15
Day	49	56	63	70	77	77
Flow from URF (in L/min)	13.4	12	10.4	9	7	14
Day	84	93	100	107	107	114
Flow from URF (in L/min)	12.5	11	10	9	13.5	12

variation of URF flow (Homna)

Day	0.5	7	21	31	42	42
Flow from URF (in L/min)	16	14	10.9	9	6	15
Day	49	56	63	70	77	77
Flow from URF (in L/min)	13.4	12	10.4	9	7	14
Day	84	93	100	107	107	114
Flow from URF (in L/min)	12.5	11	10	9	13.5	12

variation of URF flow (Polua, Sadipur & Sonakur)

Day	0.5	7	21	31	42	42
Flow from URF (in L/min)	17	16	14	12.5	11	16
Day	47	54	63	70	77	84
Flow from URF (in L/min)	15	14	12.75	11.5	10.6	10
Day	91	98	105	112	119	126
Flow from URF (in L/min)	14.5	13.5	12.5	11.5	10.5	9.75

ANNEX-4E

Data on effect of MSFU on water use

variation of users pattern

Operation Period	Location of MSFU					
	Kodda	Chala	Homna	Polua	Sadipur	Sonakur
Before construction of MSFU	35	40	40	20	30	20
During 1st month of operation	60	100	110	70	100	45
During 2nd month of operation	80	125	130	50	120	50
During 3rd month of operation	125	130	140	35	125	40
During 4th month of operation	130	150	150	30	130	25
During 5th month of operation	135	160	165	50	140	50
During 6th month of operation	140	180	185	80	145	70

variation of water consumption pattern

	Location of MSFU					
Operation Period	Kodda	Chala	Homna	Polua	Sadipur	Sonakur
Before construction of MSFU	600	800	850	200	600	200
During 1st month of operation	2400	3000	3300	1800	3000	1500
During 2nd month of operation	2900	3500	3800	1700	3300	1600
During 3rd month of operation	3200	3700	4100	1400	3500	1200
During 4th month of operation	3300	3950	4180	1200	3600	1100
During 5th month of operation	3500	4100	4290	1800	3700	1500
During 6th month of operation	3600	4200	4420	2800	3800	2600