# STUDY OF THE PERFORMANCE OF EXISTING IRON REMOVAL PLANT DEVELOPED BY UNICEF

A Thesis

by

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## DICLARATION

It is here by declared that neither this thesis nor any part there of has been submitted or is being concurrently submitted any where else for the award of any degree or diploma or for publication.

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Candidate

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# ABSTRACT

This study investigates the effectiveness of the existing iron removal plants developed by UNICEF in Sirajgonj in reducing the iron concentration to the acceptable limit, the appropriateness of this technology with regard to maintenance by the beneficiary group and to suggest necessary improvements on the way to successful implemnetation of iron removal plants.

The yield capacity and the filter run of the existing plants were also measured. A survey was carried out among the bneneficiaries to investigate their attitude towards the existing iron removal plants. Various Data on the existing iron removal plants were collected from UNICEF and WHO officials. A field study was also carried out to investigate the operational and maintenance difficulties of the existing iron removal plants in Sirajgonj.

After pointing out the problems of the existing plants, a modified iron removal plant was developed at Kalampur near Dhamrai, which would overcome the problems of the existing plants. Rearranging the unit treatment processes, the performance of the modified plant was investigated and compared with the performance of the existing plants.

# CHAPTER 1

# INTRODUCTION



## 1.1. General

The hydrology of Bangladesh is characterized by the major cross border rivers and by abundant annual rainfall of which about 80 percent falls between June and October. Of the annual rain fall about one third evaporates and another 15 percent percolates under ground (1). In the dry season, flood water recedes and pond and ground water level drops, but generally water availability remains high in most parts of the country.

In Bangladesh thedry season is very dry and the wet season very wet. Rivers, ponds, ditches and canals are traditional sources of water for domestic use and are spread widely throughout the country. Because of poor sanitary conditions in the rural areas, water from these sources is dangerously contaminated. The country thus faces acute problems not only in terms of sufficient water supplies, but also in terms of water quality and diseases related to sanitation. It is found that 40% of the children, before reaching the age of ten are partially disabled either mentally or physically due to attacks of various water borne diseases and consequent malnutrition (24). It is also estimated by WHO that more than 50 percent of cases of mortality among infants in Bangladesh are due to diarrhoeal diseases (24).

At present hand pump tubewells are regarded as the only means for collecting ground water in the rural areas of Bangladesh because of numerous socio-economical and technical reasons. Though at present one tubewell for 133 people has been installed, a recent survey reveals that only 52% of the rural population use tubewell water for drinking and few use it for other domestic purposes(1).

Ground waters collected through hand pump tubewells in Bangladesh show in general a high concentration of iron and in many locations the concentration is much higher than the acceptable limit. This is probably because of the fact that most of the places of Bangladesh are underlain by alluvial deposits containing trace of iron compounds and shallow hand pump tubewells are drilled in such deposits to collect water(22).

Ground water Exploration and Development Division of the Department of Public Health Engineering prepared a map in 1973 showing probable iron problem areas. This map, shown in Fig. 1.1 indicates that ground water of about 65% of the area of Bangladesh has average iron content greater than 2 mg/l, which is much higher than maximum allowable limit of .25 mg/l recommended by the World Health Organization for drinking water. There are some pockets where iron concentration is much higher than the average concentration shown in the map. Acute iron problem areas with iron content more than 5 mg/l have also been identified in the map.

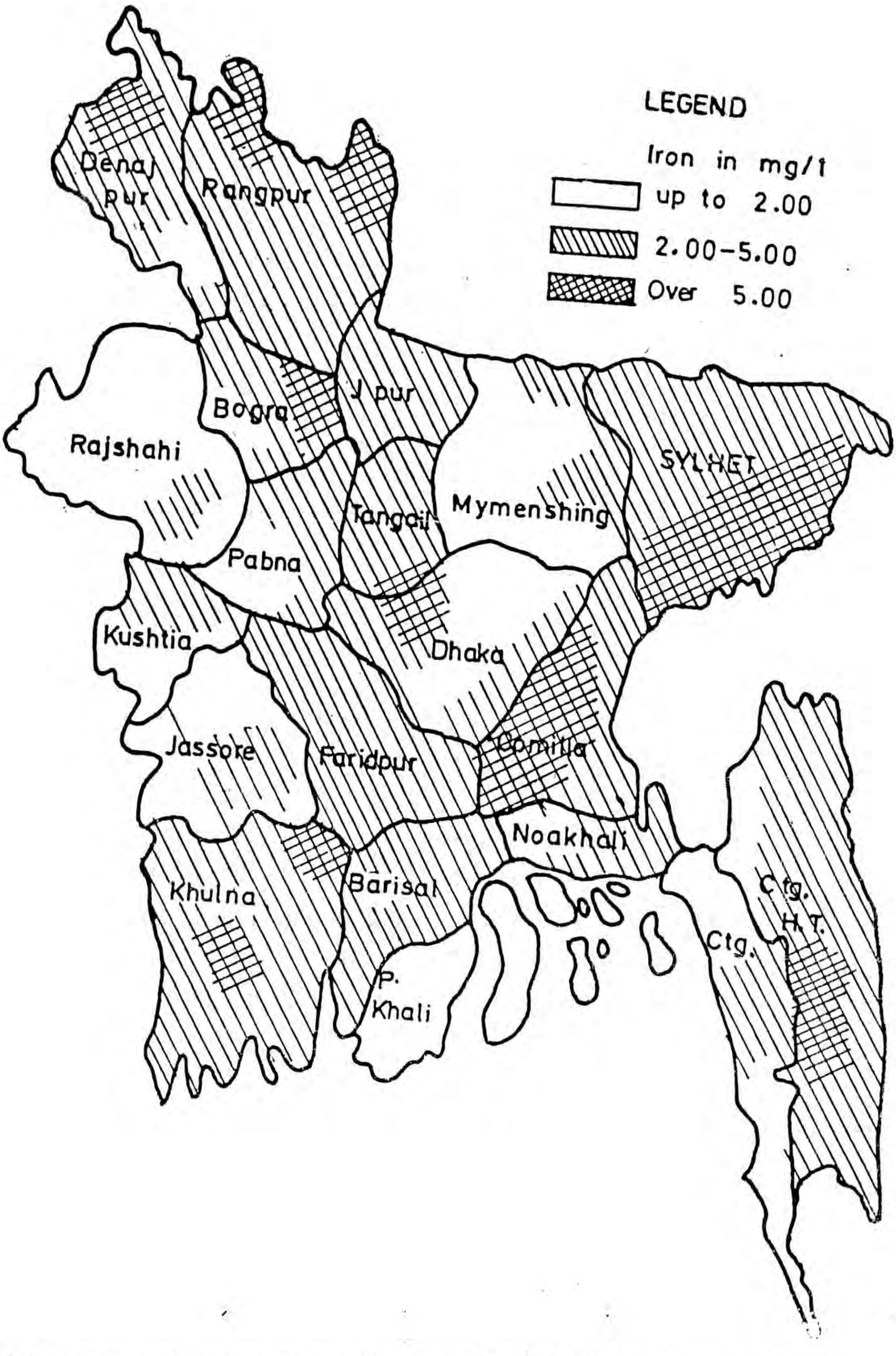



Fig. 1.1 Average iron content in ground water in Bangladesh based on hand pump tubewell water analysis. ( Ground water exploration and development Divn, DPHE ) (22)

## 1.2. Statement of the Problem

The presence of iron in water is objectionable primarily because the precipitation of iron alter the appearance of the water, turning it a turbid yellow brown to black. In addition, the deposition of these precipitates will cause staining of plumbing fixtures and laundry. Another condition which is associated with the presence of iron in water supplies is the growth of micro-organisms in distribution system. Accumulation of microbial growths can lead to reduction in the pipe line carrying capacity and the clogging of meters and valves (17).

Iron impart a taste to water which is described as metallic or medicinal. The precipitations of iron may lead to difficulty with water treatment processes such as ion exchange.

In iron problem areas, people generally refuse to take water from tubewells. If there is no other good water source, people mainly collect tubewell water for drinking and sanitary purposes only. For other purposes like cooking, washing cloths and utensils and for bathing, surface water sources are being used. Where there are ring wells, people use unprotected water from ring well for drinking purpose. Taste, odour and turbidity in tube well water due to slow precipitation of oxidized insoluble iron compounds in Presence of air discourage the people from using tubewell water (22). In a study (22) on water use pattern in some iron problem areas of Jessore, Kushtia and Khulna districts, the water use pattern of the people was observed and have been presented in the

Table 1 of Appendix A. Table 2 of Appendix A. represents the causes of nonusage of tubewell water in iron problem areas.

1.3. Rational of the Study :

Various organizations have so far developed many iron removal plants in Bangladesh. But most of the plants have failed because of poor maintenance and construction faults. During 1983-85, 250 iron removal plants were constructed throughout Bangladesh by UNICEF under a UNICEF-DPHE and Danida research and development programme. But the project failed due to operational and maintenance problems. Then in 1985-86, 50 iron removal plants were built by UNICEF in Sirajgonj under a crash programme. But the programme was also failed.

The causes of failure were due to (3)

1) little or no beneficiarys participation during construction,
2) bad construction; lack of proper supervision and understanding of the plant operation,
3) lack of continued support and technical advice from DPHE/UNICEF to solve minor technical problems,
4) short filter run and
5) difficulties in cleaning the plants.

In 1986 a research and development programme was taken by UNICEF to increase the filter run and make cleaning easier with out increasing the overall cost. Since 1987 about 193 improved iron removal plants have been installed in different areas of sirajganj and Pabna.

The present research is aimed at studying the performance of the existing plants and suggest further modification for improvement.

## 1.4 Objectives of the Study

The main objectives of the research are-

- to investigate the iron removal efficiency of the existing iron removal plants developed by UNICEF in Sirajganj.
- to investigate the operational and maintenance difficulties of the existing iron removal plants.
- to develop a modified iron removal plant and observe its performance.

## 1.5 Methodology used in the Study

To study the working principle and investigate the performance and condition of the existing plants in Sirajgong built by UNICEF, it was decided to visit the IRPs. During the visit the existing condition of the plant was observed. Water samples were collected form five plants and later tested in the laboratory. A survey was also carried out among the beneficiaries about their opinion toward the IRPs and their participation in the cleaning of the IRPs. The yield capacity and filter run of the existing plants were also measured. WHO has recently surveyed the iron

# CHAPTER 2

# LITERATURE RIVIEW

## 2.1 History of the Practice of Iron Removal

In 1874, the first iron removal plant was constracted at charlo Herburg, Germany. In 1893, the first iron removal plant in the united states was placed in operation at Atlantic highlands, New Jersey. The earliest plants employed aeration and filtration, sometimes supplimented by the addition of lime, to treat ground water. The same method of treatment predominates today(20).

In some places of India and Bangladesh, Iron removal at household level were attempted by using 4 pitchers placed one above the other. Raw water from the top pitcher dripped through a hole and passed through the pitchers filled with burned charcoal and sand. The treated water was collected in the bottom pitcher. Although it is a low cost treatment process, it is not feasible because it requires large head and it has slow discharge rate(20).

In some places(31) Galvanized Iron barrels partially filled with filtering media were placed below the spout of hand pump tube well. Treated water was collected through tap fixed at the barrel bottom. A force and lift pump was employed at some regions to spray the iron bearing ground water onto a filter bed in an elevated chamber and then allowed, to pass through the filter bed under drainage system. The treated water was collected slightly above the ground. But it has high initial cost and requires high head(20).

A number of iron removal plants have been designed and operated by various organisations like NEERI, AIIH, besides package water treatment plant by M/s Richardson and Cruddas (1972) Ltd. Madras, to suit individual house hold need and community water supply as well. A few of the units developed by NEERI and the package treatment plant by M/s Richardson and Cruddas (1972) Ltd. is described below.

Hand operated domestic Aeration /Filtration unit(23) internationally designated as Domestic Iron Removal Unit (DIRU) was developed by NEERI to suit rural conditions, and can be built with the help of locally available skill. In this unit aeration of the raw water accomplished in a series of coke, movable/calcite beds and is followed by slow sand filtration. Catalytic oxidation hasten the removal process. No chemical is needed. The unit can be operated by an elevated hand pump. Raw water, containing 1-6 mg/l of iron can be treated by this method at a rate of 200 - l/hr (Fig.2.1).

The estimated cost for rural water supply schemes as worked out by NEERI is given in the Table-1 of Appendix-B . Operation and maintenance cost includes (i) Man Power (ii) Chemical cost (iii) Depreciation @ 5% p.a. (iv) Annual interest on capital investment @ 12% p.a.

The table 2 of Appendix B reflects capital cost and operation and maintenance cost per unit flow and per day.

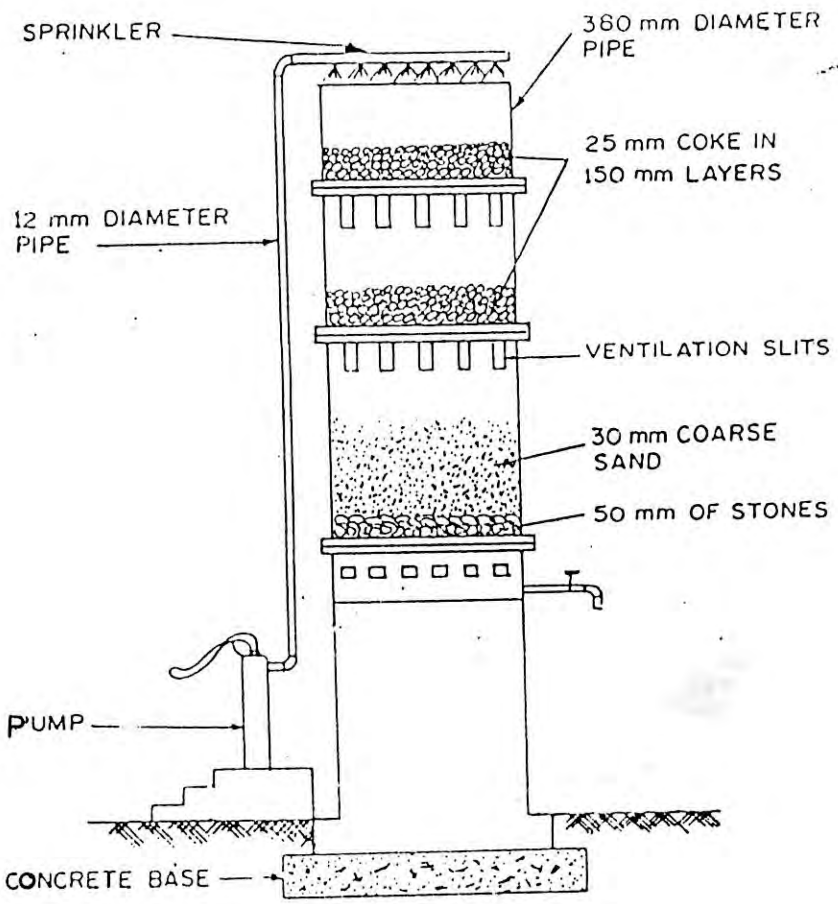



FIG 2.1 HAND OPERATED DOMESTIC AERATION/FILTRATION UNIT(23)

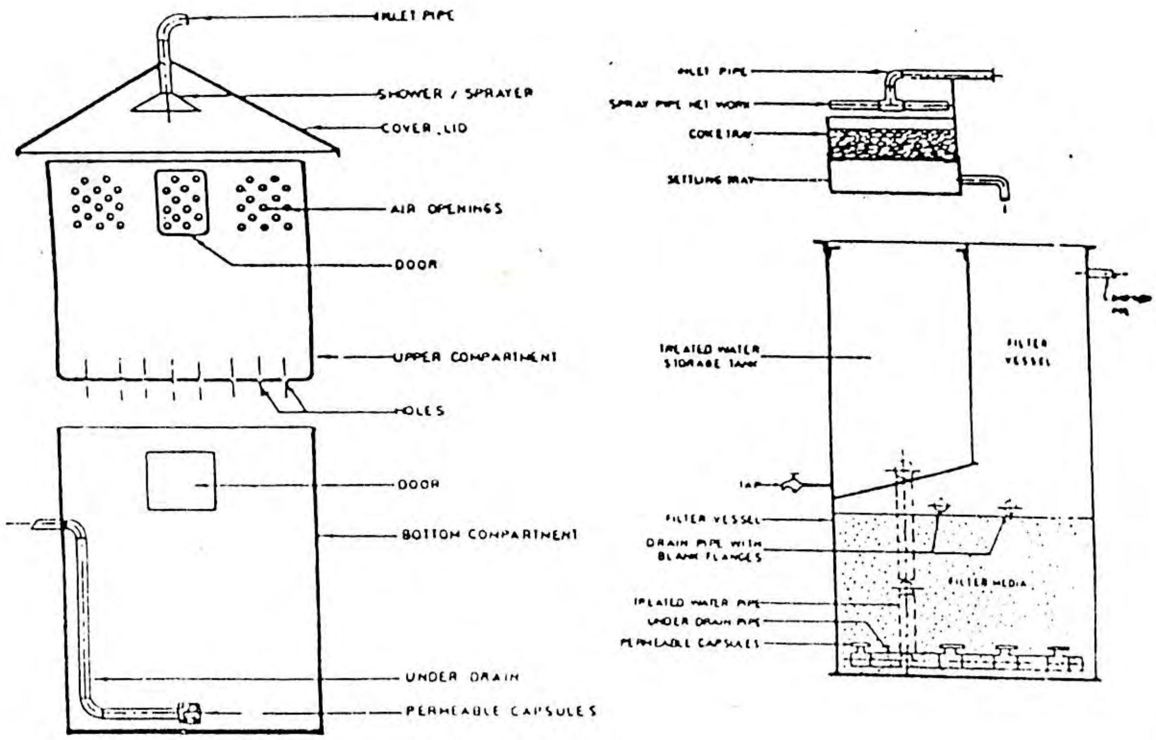
In order to ensure safe potable water to the rural population, M/s Richardson cruddas (1972) Ltd. developed two types of package plants(23) in different ranges. The type I plants are intended for hand pumps installation and have a treatment capacity of 450 l/hr. the type II plants intended for power pumps and are of two ranges, one to serve a population of 500 persons and the other for 1500 persons. The lay out plan for type I and II plants are shown in Fig. 2.2.

The type I units consist of three parts; the bottom compartment, the upper compartment and the lid. The bottom compartment is the filter. The upper compartment houses coke medium to support the oxidized iron flocs produced by the spray aeration which achieved by means of the shower fitted in the inlet feed pipe. The third part is the cover lid. The unit is fitted with polluted permeable capsule under drain system (24).

The type II package plants include the main filter vessel containing filter medium with pVC laterals and polluted underdrain permeable capsules. The plants are also provided with inbuilt treated water storage tanks. The raw water is pumped and sprayed over the coke medium and there after settled in the lower compartment before filtration in the main filter compartment. The purified water from the storage tank is drawn through taps provided for the purpose.

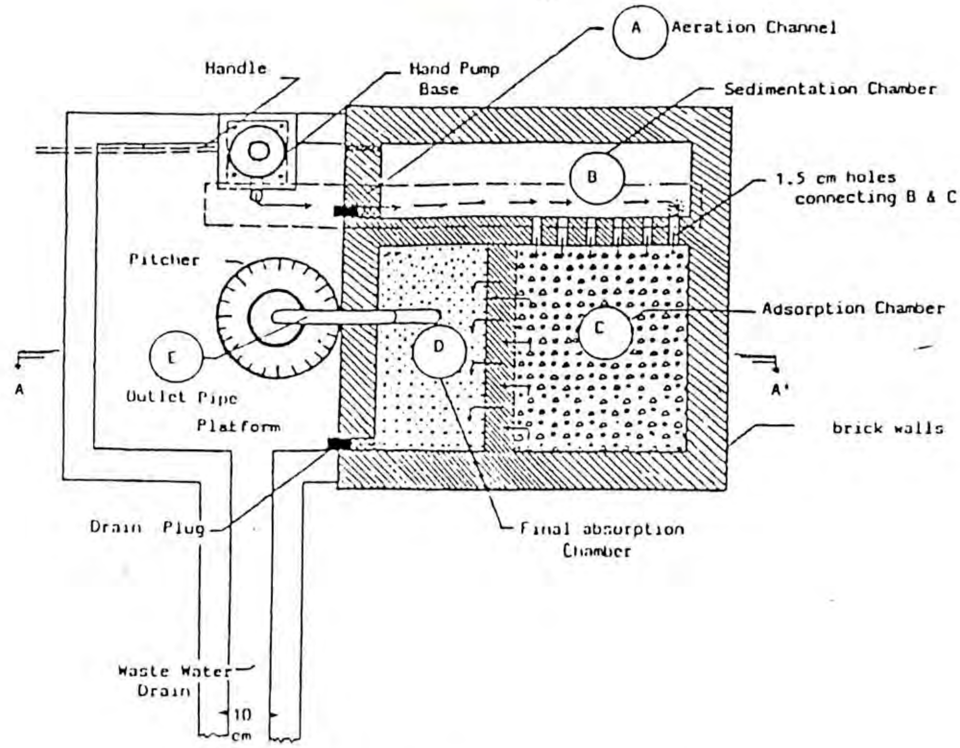
For the elemination of iron from handpump tubewell water, Aowal (31) proposed to introduce a spray aeration, a settling tank and a plain sand filter, all housed in a single chamber of 1.2 x 1.2 x 1.5m size. In his plant the settling effect is obtained by having a constant pool of water above the filter bed and allowing the sprayed water to fall on this pool of water. Then it passes through a scum of flocculant iron suspension formed at the surface of the pool of water. After that the water is passed through a two layer sand filter and a substructure of graded gravel. Although an effective removal is 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 so easy.

The performance and operational difficulties of the previous plants led to think that a simple iron removal plant with easy operation and maintenance facilities shall be acceptable to the rural people. Keeping the above factors in mind, a community type iron removal plant has been designed. The plant shown in Fig.2.3 consists of four units, aeration channel, sedimentation, adsorption and filtration chamber. Water discharged through the spout of a tubewell, directly inters into a pvc pipe partially filled with brickchips and flows horijontally over it and then drips into a sedimentation chamber. After a detention time of a minimum of 8 minutes, the water enters into the adjacent adsorption chamber through small holes near the bottom and finally flows over a weir into the final adsorption chamber before coming out of the plant.

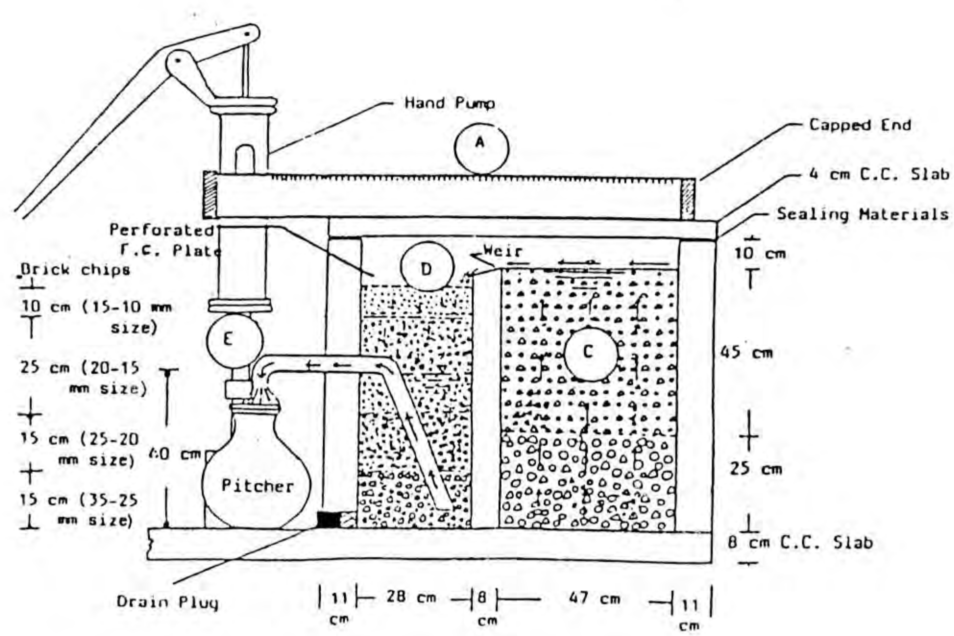



TYPE I TYPE II

FIG2.2 PACKAGE WATER TREATMENT PLANT(23)




PLAN




SECTION A.A'

FIGURE 2.3 COMMUNITY TYPE IRON REMOVAL PLANT (31)

This plant has been installed over 250 locations in rural Bangladesh and field investigations on over 100 of these plants show an iron removal in excess of 90 percent (31).

On the basis of aeration filtration principles, removal of iron from tubewell water supply was tried in different places. UNICEF water section Dhaka (22) constructed an experimental plant spending about Tk. 3,000 in Manikgonj. Force pump was used to lift the water to a height of 8 ft. from the ground for spraying the water on a filter bed placed in G.I. sheet enclosure. Efficient removal of iron was achieved, but such type of plant involved a high initial cost and the maintenance of force pump, cleaning of filter bed were not very easy. Iron removal studies at household level by using 4 Nos pitchers placed on tripod stand have been started at Tangail, Manikgonj and other places. As mentioned earlier, the raw water from the top pitcher drips through a bottom hole and passed through two pitchers filled with charcoal and sand. Treated water is collected form the bottom pitcher. Although it is very low cost system, long time is required to get one pitcher of treated water(22). During field observation it was found that in some places, about 55% of the total requirement of water is being utilized at tubewell site for bathing washing utensils and cloths, cleaning hands and face. Since in many places water with high iron content is used at least for drinking, construction of this type of plant will not bring any major change in per capita water use(22).

As a part of the study at BUET, several house hold type iron removal plants were constructed in 1982, with cement concrete ring, containing filter materials and aeration holes. But few weeks after installation, the plant was found inoperative. The main reasons for non usage of the plant as given by the users were that, the discharge through the delivery tap was very low and they did not like to do the two fold labour i.e. collection from the tubewell, pouring it on the filter bed and again collection from bottom tap (22).

As mentioned earlier, in 1983-85, 250 iron removal plants were constructed throughout Bangladesh by UNICEF under a UNICEF - DPHE and Danida research and development programme. But the project failed due to operational and maintenance problem. Than in 1985-86, 50 iron removal plants were built by UNICEF in Sirajganj under a crash programme. But the programme was also failed. The research and development activities continued to evolve appropriate technology and methodology for implementation, operaiton and maintenance of iron removal plants. Then the improved iron removal plants installation began in 1987-88 in Sirajganj and Pabna district.

## 2.2 Occurrence of Iron in Natural Water

Iron is likely to be present in all waters but especially in ground waters. There are two different types of iron found in water supplies and the methods used to remove them are entirely different. For convenience one is known as inorganic iron and refers to the clear and sparkling well waters that turn turbid on exposure to air, the other may be called organic iron, which is colored with humic acids. Organic iron may be present in colored well waters as well as colored surface waters. The first thing to do when examining a water that contains iron is to find out if it is ordinary iron (in organic) or the organic variety; that is to say, the molecules of iron are held in solution by the organic humic substances present in the water. This organic iron is also known as chelated iron(16).

The presence of iron in ground water is generally attributed to the solution of rocks and minerals, chiefly oxides, sulfides, carbonates and silicates containing these metals. Iron occurs in the silicate minerals of igneous rocks. Pyroxenes, amphiboles and some micas generally contain iron. It also occurs in the form of various oxides, such as magnetite ($Fe_3O4$) hematite ($Fe_2 0_3$) and limonite ($2Fe_20_3 . 3H_20$). The sulfide and carbonate minerals are also important sources of iron. These include Pyrite ($Fes_2$) and siderite ($Feco_3$)(18).

Iron bearing minerals are more abundant than manganese bearing minerals in part accounts for the fact that iron is found more frequently in ground water.

## 2.3 Chemistry of Iron Removal

The chemistry of iron removal in natural water system involves a number of factors like solubility of iron in natural water oxidation and precipitation of iron, impact of organic complexing agents. etc.

### 2.3.1. Solubility of iron in natural water

Ferrous iron as $Fe(OH)_2$ can dissolve upto 100 ppm at a pH of 8 and upto 10,000 ppm at a pH of 7. In the presence of $Co_2$ the solubility of ferrous carbonate governs and is 1 to 10 ppm for pH between 7 and 8 though it may be upto 100 ppm for pH 6 to 7. Organic substances i.e.; humic or tannic acids can create complexes with iron (II) ion holding them in the soluble state to higher pH levels. If a large concentration of organic matter is present, iron can be held in solution at pH levels upto 9.5.

The solution of iron bearing minerals is often attributed to the action of $co_2$ in ground water. Most of the $Co_2$ is presumably generated by the bacterial decomposition of organic matter leached from the soil. The solution of these mineral may take place under anaerobic condition and in the presence of reducing agents capable of reducing the higher oxides of iron to the ferrous state.

In the pH range encountered in natural water, the iron in solution consist primarily of hydrated ion $Fe^{++}$, $FeoH^{+}$. While greatly limited in solubility at neutral pH, the aqueous ferric ions consist predominantly of $Fe(oH)^{+}_{2}$ and $Fe(OH)^{-}_{4}$.

In addition to the hydroxide complexes, the inorganic complexes may form where water contain substantial amount of bicarbonate, sulphate, phosphate, cyanide or halides. The formation of such complexes would tend to increase the concentration of iron found in solution. The formation of organic complexes and chelates may also increase the solubility of iron(17).

### 2.3.2. Oxidation and Precipitation of Iron

Iron can be precipitated as carbonates in carbonate bearing water by addition of lime or soda ash. These precipitation take place under anaerobic condition. Appendix C shows plots of the solubility of Fe (II) and $M_n$ (II) in water having a concentration of total carbonic species(17).

Examination of the plots indicates that under these condition ferrous carbonate may be expected to precipitate almost completely at pH values above 8 and 8.5 respectively. Precipitation of ferrous hydroxide requires that the pH be increased to about 11. Mixtures of these precipitates may be formed during lime soda softening.

Most frequently for the precipitation of iron, advantage is taken of the fact that ferric hydroxide are far less soluble then the hydroxides and carbonates of Fe(II). Therefore Fe(II) are oxidized most commonly by oxygen, chlorine, potassium permanganate or in rare cases by ozone. Fig of Appendix A indicates that oxidation of Fe (II) to Fe(III) will greatly reduce the solubility of iron over a very broad pH range 4 to 12(17).

### 2.3.3. Kinetics of Oxidation

The rate of oxidation of Fe(II) by oxygen is slow under condition of low pH as shown in Fig of Appendix D. In such cases pH is increased by stripping $Co_2$ or adding lime. Alternately the rate of oxygenation may be increased by the use of aerators and contact filters have long been used to accelerate iron oxidation(17).

Measurements of the rates of Fe(II) oxidation in natural water are beset by analytic problems because of the difficulty in determining ferrous ion in the presence of reducing agents and incipient precipitates of ferric oxide. However, measurements of the rate of conversion of Fe (II) to a filterable form in ground water indicate that the rates of iron precipitation and agglomeration are slower then those shown in Fig. of Appendix D. It has been suggested that the inhibition of iron oxidation may be the result of the reduction of Fe (III) by organic substances which behave in a manner similar to tannic, gallic or ascorbic acids. Until all these organic material is oxidized, the rates of iron oxidation may be inhibited and the precipitate formed may be stabilized. It is possible, therefore, that the widespread chlorination of many iron bearing waters results in the oxidation of the organic matter and other reducing agents present rather than in the direct oxidation of Fe(II)(17).

### 2.3.4. Effect of alkalinity

The concentration of iron found in solution in natural water are frequently limited by the solubility of its carbonate. Waters of high alkalinity often therefore have lower iron content than the waters of low alkalinity. For a given pH the solubility of iron carbonate in natural water is inversely proportional to the bicarbonate ion concentration or for most water the alkalinity(17).

Stumm and Lee (25) reported that the reaction rates obtained in solutions of lower alkalinities tend to be of smaller magnitude and more scattered than those obtained in solutions of higher alkalinities.

Robinson and Dixon(25) mentioned that in order to obtain complete oxidation of the ferrous iron, the bicarbonate alkalinity of the water should be in excess of 100 mg/l as $CaCO_3$. Generally, if the concentration of alkalinity reaches 130 mg/l as $caco_3$all of the ferrous iron will be oxidized almost immediately, and any further addition of chemicals would appear to be unnecessary. Low alkaline water needs some oxidizing agent ($KMnO_4$) without raising pH and alkalinity or some chemical additive ($Na_2CO_3$) to raise both pH and alkalinity.

Gosh et al(27) observed that within a pH range of 7.49 to 7.78, an increase of alkalinity from 335 to 610 mg/l as $CaCO_3$, causes a 10 fold decrease in half-time.

## 2.3.5. Effect of pH

In any alkaline natural water the solubility of ferrous iron is limited by the solubility of ferrous carbonate to a pH of 9, above which solubility equilibria of ferrous hydroxide become limiting again(17).

Theoretically, iron that precipitates from a super saturated solution of this type would be either ferrous carbonate or ferrous hydroxide depending on the pH. Under practical condition, however, the precipitation of basic carbonates, e.g. $Fe(OH)_2$, $FeCO_3$, with some what different solubility characteristics is probable, especially in the pH range of 8 to 11.(17)

On aeration, or by the addition of oxidizing agent, iron is oxidized from the ferrous to the ferric form. Once oxidized, the solubility of iron is limited over a wide pH range (4 to 13) by the solubility of ferric hydroxide. To take advantage of this solubility restriction, the basic step in the removal of iron is the oxidation of ferrous iron to the ferric form.

$$Fe\ (II)^{++} + 1/4O_2 + 2OH^- + 1/2\ H_2O = Fe\ (OH)_3$$

The oxidation may occur under certain condition, especially in buffer solution with pH values greater than 6, in a stepwise fashion over the mixed iron (II) - (III) hydroxide and magnetite. The rate of oxidation is first order and independent of the Fe(III) concentration.

### 2.3.6 Effect of Temperature:

The reaction rate is dependent on temperature. For a given pH value, the rate increases about 10 fold for a $15^{o}C$ increase in temperature, which is mainly caused by the change in (OH) concentration due to temperature dependence of the ionization constant of water(25).

### 2.3.7. Effect of Ionic Strength

Sung and Forbes(28) showed that the rate constant K is also a function of ionic strength and the presence of complex forming anions. They observed a linear variation (decrease) of the rate constant up to an ionic strength of 0.25 M in their study. At values greater than this, increasing ionic strength actually increases the rate constant.

### 2.3.8. Effect of Chloride :

Sung and Morgan(29) observed that chloride and sulphate ions have a significant retarding influence on the rate constant in the pH range from 6.5 to 7.2. Later Sung and Forbes(29) mentioned that for typical fresh water iron removal, chloro-complexes of iron could probably be ignored, because the effect of ionic strength and chloro-complexation may not be as important as the effects of temperature and pH.

2.3.9. Effect of Organic Matter :

Ferrous iron is capable of forming complexes with organic matter and, as such, is resistant to oxidation even in the presence of dissolved oxygen. The relative strength of such complexes that has a stability constant of approximately $10^4$(25).

2.3.10. Catalytic Effects

For a given pH value and oxygen concentration the addition of as little as 0.02 mg/1 of $Cu^{2+}$, reduces the oxygenation time by a factor of 5(25).

Sung and Morgan(29) studied the effect of ferric hydroxide on the oxygenation of ferrous iron and stated that auto catalysis is noticeable only for pH around 7 and above Cox(29) has described the use of contact bed oxidation in iron removal. The purpose of contact bed according to him, is to facilitate oxidation of iron or manganese through the catalylic action of previously precipitated oxides of these minerals on the gravel.

2.3.11. Rate of Iron Precipitation

Theoretically solubility product of ferrous carbonate is 2.11 x $10^{-11}$ moles per litre at 25$^{o}$C. When alkaline groundwaters supersaturated with respect of ferrous carbonate are aerated, the pH increases becuase of the loss of carbon dioxide, thereby further increasing the degree of supersaturation. As a result, the precipitate formed may be expected to contain both ferrous carbonate and ferric hydroxide. The rate of precipitation of iron would therefore be determined by the rate of oxidation of ferrous iron plus the rate of ferrous carbonate precipitation as shown in Fig. of Appendix E.

In water having low alkalinities and, hence, low buffer capacities, the pH will decrease gradually as the iron hydrolyses resulting in an increase in acidity of the water(11). In such cases it has been suggested to use soda ash, lime or caustic soda to raise the bicarbonate alkalinities to 100-130 mg/l as $CaCo_3$. Potassium permanganate can be used as an oxidant to oxidize ferrous iron in natural water without raising the pH or the alkalinity.

## 2.4. IRON OXIDIXING BACTERIA

A group of organisms collectively designated 'iron bacteria' which is neither morphologically nor physiologically homogenous, yet it may be characterized by the ability to transform or deposit significant amounts of iron, usually in the form of objectionable slimes. However, iron bacteria are not the sole producers of bacterial slimes. The organisms of this group may be fillamentous or single-celled, autotrophic or heterotrophic, aerobic or anaerobic.

### 2.4.1. Autotrophic Condition and Neutral pH

Gallionella ferruginea is undoubtedly an autotroph which obtians its energy from oxidizing ferrous salts to ferric salt, its carbon from carbonates or carbon dioxide, and which synthesizes its proteins from amonium chloride. It can therefore, exist in waters devoid of organic matter and at neutral pH. Twisted stalk fragments of Gallionella enable them to be recognized in water supply equipments or in cultivating the organisms(30).

### 2.4.2. Autotrophic Condition and Low pH

Thiobacillus Ferrooxidans and Ferrobacillus ferrooxidans, which contribute to the problem of acid mine drainage, can be identified by tests for transformaiton of ferrous to ferric iron. They are categorised as facultative autotrophes rather than obligate autotrophes (30).

### 2.4.3. Heterotrophic Condition and Neutral pH

Sphaerotilus natans is commonly associated with polluted streams and sewage rather than with water supply operations. It develops only in an approximately neutral environment in which chemical oxidation of ferrous iron is rapid and extensive (30).

## 2.5. Unit Processes of Treatment

The unit processes of the water treatment to reduce iron content are,

- i) aeration
- ii) flocculation
- iii) sedimentation and
- iv) filtration

### 2.5.1. Aeration

Aeration is the treatment process whereby water is brought into intimate contact with air for the purpose of (a) increasing the oxygen content (b) reducing the carbondioxide content and (c) removing various volatile organic compounds responsible for taste and odour.

Aeration is widely used for treatment of ground water having too high in iron and manganese content. The atmospheric oxygen brought into the water through aeration will react with the dissolved ferrous compounds, changing them into insoluble ferric hydrate. These can then be removed by sedimentation and filtration. There are various types of aerators used in water treatment. They are mechanical aerators gravity type cascade aerator, spray aerator, nozzled spray aerator etc. The aims of aerators is supported by the most common gas transfer equation.

$$C_t = C_o + ( C_s - C_o) \{ 1 - \exp [-kg ( A/C)t]\}$$

where $C_t$ = Concentration of gas at time t.

$C_o$ = Concentration of gas at t = 0

$C_s$ = Saturated concentration

Kg = Proportionality factor

A/c = area of inter face per unit volume of liquid

The transfer can be optimized

1) by generating largest interfacial area
2) by preventing the build up of thick interfacial film
3) by inducing as long a time of exposure as possible.
4) by ventilating the aerator to maintain the highest possible driving force or concentration difference ( $C - C_o$ ).

2.5.2. Flocculation

Flocculation is the process of gentle and continuous stirring of coagulated water for the purpose of forming floc through the aggregation of the minute particles in the water. It is thus the conditioning of water to form flocs that can be readily removed by sedimentation or filtration.

The period of retention and the degree of agitation are critical factors in the operation of flocculation. Too much mixing can break the floc into unsettleable colloids. Higher velocity are required where the suspended matter is relatively heavy. In various design, horizontal or vertical revolving paddles are used. In one design reciprocating paddles move up and down in the flocculating chamber. The objective is to cause as many gentle collisions as possible between the already formed flocs with the intention of making them adhere together to form large conglomerates.

Flocculation can be done by either mechanically or by using coarse media flocculator.

Flocculation depends on the number of particles and the probability of collision. Collision may result from variable velocity of suspended particles and from micropulsation generated by mixing. The intensity of mixing can be defined by the variation in the velocity vector of fluid motion, which is described in terms of average velocity gradient. Its magnitude is a function of the useful power input, P. relative to the volume, C, of the fluid and a proportionality factor, $\mu$ , the absolute viscosity. The average velocity gradient,G,is thus expressed as-

$$G = \sqrt{\frac{P}{C\mu}}$$

Micropulsation generated during mixing not only contributes to floc formation but causes floc damage as well. Extended mixing also multiplies the recurrance of floc formation and damage, leads to the screening of active centres, decreases the flocculation rate and reduces the size of floc. CAMP has developed the flocculation criteria for optimum floc formation by combining the average velocity gradient with the mean or displacement time, which is expressed as dimentionless CAMP number.

$$G \times td = \sqrt{\frac{P}{C\mu}} \times \frac{C}{Q} \quad \text{or} \quad \sqrt{\frac{PC}{\mu}} \times \frac{1}{Q}$$

A specific range of values is maintained for a particular condition. Thus the design and performance of a flocculator can be related to the term G x td.

In coarse media flocculator an expression for mean velocity gradient G is given by (31).

$$G = 8.38 \quad \frac{Q}{a} \quad \times \frac{S}{d}$$

where Q = rate of flow.

a = cross sectional area of bed

s = shape factor = $6/\psi$

d = diameter of coarse media

and CAMP No Gtd = 3.354 S/d x L

Where L = depth of bed

## 2.5.3. Sedimentation

The purpose of sedimentation is to remove the suspended particles form aqueous solutions when it stands still or flows slowly through a basin. In raw water and reclaimed water treatment a wide variety of suspensions ranging from a very low concentration of nearly discrete particles to a high concentration of flocculent solids can be treated by the sedimentation process.

Due to the low velocity of flow, turbulance will generally be absent or negligible and particles having a mass density higher than that of the water will be allowed to settle. These particles will ultimately be deposited on the bottom of the tank forming a sludge layer. The water reaching the tank outlet will be in a clarified condition.

The fraction of particles removed by sedimentation is given by

$$x_r = (1 - x_c) + \int_0^{x_c} v/vc \; dx$$

where $(1 - x_c)$ = fraction of particles with velocity greater then critical velocity, $V_c$.

$\int_0^{x_c} V/V_c \; dx$ = fraction of particles removed with velocities less than $V_c$.

The factors that effect sedimentation are, density of particle, density of water, size of particle, velocity of settling particle, drag coefficient, acceleration due to gravity 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.

### 2.5.4. Filtration

Filtration is the process whereby water is purified by passing it through a porous material. For filters in which thin media are used, such as screens or membrane, the principle mechanism of particulate removal is straining, where some characteristic size of particulates is larger than the opening in the filter medium.

Larger floc particles can be removed by simple straining at the bed surface, but much of the flocculated matter will pass into the bed and lodge within it.

In the case of granular deep bed filters, particulates can penetrate into the depth of the filter medium, and the mechanisms of removal are more complex. Generally the particulate matter must be transported from the fluid streamline to the surface of the media or collector. Particles will deviate from fluid streamline due to gravitations forces, diffusion gradients and interfacial effect of momentum. Particles removed in filters are much smaller than the passages between adjacent grains, so the process of filtratio is not straining only. Following phenomena have been considered by various investigators as being part of the mechanism of filtration :

1. Straining- Particles larger than the pore space of the filtering medium are strained out mechanically and particles smaller than the pore space are trapped within the filter by chance contact.

2. Sedimentation-Interstices of filter media act as minute sedimentation basins with comparatively large surface area.

3. Interception - Many particles, that move along in the streamline are removed when they come in contact with the surface of the filtering media.

4. Impaction-Heavy particles will not follow the flow streamline.

5. Chemical and Physical adsorption-Once a particle has been brought in contact with the surface of the filter medium, bonding, chemical interaction or various surface forces may be responsible for holding it there.

6. Flocculation - Large particles overtake smaller particles, join them, and form still larger particles.

7. Adhesion- Flocculant particles become attached to the surface of the filtering medium, some materials are sheared away before it becomes firmly attached and is pushed deeper into the filter bed. Interstices of the filtering medium are gradually narrowed down by accumulating deposits which further carry out mechanical straining action moreover, some chemical flocs have good adsorbing properties which can even remove microprecipitates.

8. Biological Growth - Biological growth within the filter also can reduce the pore volume. These mechanism indicate the possibility of use of a coarse filter medium in place of fine filter medium.

## 2.6 Methods of the removal of Iron

There are three general methods used for the control of iron in public water supplies at the present time(18). The first method involves precipitation followed by filtration. The second method involves ion exchange and the third method involves stabilization of the iron in suspensions using dispersing agents to prevent the deposition of these metals.

More specifically, the treatment processes employed in the control of iron include :

1. Precipitation and filtration.

   a) Aeration, sedimentation and filtration
   b) Aeration, chemical oxidation by $cl_2$, $KMno_4$, $Cl_2O$ followed by filtration.
   c) Chlorination - filtration
   d) Calcined manganese - diatomaceous earth filtration.

2. Ion exchange.
   The manganese - Zeolite process

3. Stabilization with polyphosphates.

## 2.6.1. Precipitation and filtration

### (a) Aeration- Sedimentation - filtration

The simplest form of iron oxidation in treatment of well water is plain aeration. A typical tray type aerator has a vertical riser pipe that distributes water on top of a series of trays from which it then drips and splatters down through the stack. The trays frequently contain coke or stone contact beds that develop and support oxide coatings that speed up the oxidation reaction soluble iron is readily oxidized by the following reaction.

$$2F_e\ (HCO_3)_2 + .5O_2 + H_2O = 2Fe\ (OH)_3 + 4CO_2$$

In plants using the aeration sedimentation filtration process most of the oxidized iron is removed by a sand filter. Flocculent metal oxides are not heavy enough to settle out in the settling basin. The main function of the basin is to allow sufficient reaction time for oxidation to proceed to near completion. This process is generally recommended for water with high concentrations (>5.0 mg/L) of iron to save chemical costs.

(b) Aeration-chemical oxidation-sedimentation-filtration

It is a common method for removing iron from well water without softening treatment. Preliminary aeration strips out disolved gases and adds oxygen. Iron is chemically oxidized by free Chlorine residual (equation 1) or by $KMNO_4$ (equation 2 and 3) at rates of oxidation much greater than dissolved oxygen. When chlorine is used, a free available residual is maintained throughout the treatment process. The specific dosage required depends on the concentration of metal ions, pH, mixing conditions and other factors. Theoretically 1 mg/l of $KMno_4$ oxides 1.06 mg/l of iron. In actual practice the amount needed is often less than this theoretical requirement. Permanganate oxidation may be advantageous for certain water, since its rate of reaction is relatively independent of pH.

$$Fe^{++} + Mn^{++} \text{ oxygen} \xrightarrow[\text{residual}]{\text{free chlorine}} FeO_x\downarrow + MnO_2\downarrow \quad \ldots. (1)$$

$$Fe(HCO_3)_2 + KMno_4 \longrightarrow Fe(OH)_3\downarrow + Mno_2\downarrow \quad \ldots\ldots(2)$$

$$Mn(HCo_3)_2 + KMno_4 \longrightarrow Mno_2\downarrow \quad \ldots\ldots\ldots\ldots (3)$$

Effective filtration following chemical oxidation is essential, since a significant amount of the flocculant metal oxides are not heavy enough to settle by gravity(18).

(c) Chlorination filtration

Chlorination filtration process equipment is simple in that it normally consists of a chemical feed system, and filters. Sometimes a small retention tank and a pH adjustment system to feed soda ash, caustic soda or lime are required. Either gaseous chlorine or hypochlorite can be used as the oxidizing agent. The theoretical amount of chlorine required to oxidize a soluble iron concentration of 1 mg/l is 0.62 mg/l(18). The filter used in this process are similar to those in the aeration sedimentation

filtration process. This process is recommended for removal of low iron concentration (< 2.0 mg/l).

(d) Calcined manganese-diatomaceous Earth Filtration

A method of iron removal recently finding application employing calcined magnesite and diatomaceous earth filtration. Calcined magnesite (Mgo) and diatomaceous earth are fed to a rapid mix tank which provided 5 to 10 minute of contact during which Fe(II) are oxidized in contact with the Mgo, There after the water is filtered through a diatomaceous earth filter. An advantage of this system is that, the filter medium is discarded after each filtration cycle, thereby avoiding any accumulation of precipitates or bacterial growths on the filter medium(18).

### 2.6.2. Manganese Zeolite Process

Manganese Zeolite is a natural greensand coated with manganese dioxide that removes soluble iron from solution. After the zeolite becomes saturated with metal ions, it is regenerated using potassium permanganate. Permanganate solution is applied to the water ahead of a pressure filter that contains a dual media anthracite and manganese zeolite bed. The iron and manganese oxidized by the permanganate feed is removed by the upper filter layer. Any ions not oxidized are captured by the underlying manganese zeolite layer. If surplus permanganate is inadvertently applied to the water, it passes through the coal medium and regenerates the greensand. When the bed becomes saturated with metal oxides, it is backwashed to remove particulate matter from the surface layer and to regenerate the zeolite with potassium permanganate. This process is recommended for removal of low to moderate concentrations (0-5.0 mg/L ) of iron(4).

### 2.6.3. Stabilization with Poly phosphates

The alternative to iron removal is stabilization or dispersion. Sodium hexameta phosphates at dosages of 5 mg per mg of Fe have been used for this purpose. While this treatment will stabilize iron in suspension, it reportedly is not suitable where metal concentration of 1 mg/L are exceeded. Moreover when the water is heated, the polyphosphate will revert to orthophosphate and lose its dispersing properties. The application of the polyphosphate must take place prior to aeration or chlorination because the polyphosphates 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. Where polyphosphates are used to maintain colloidal dispersions of iron or to prevent calcium carbonate deposition, chlorine residuals must be sufficient to control bacterial slime growth(18).

## 2.7. Selection of appropriate technology

An iron removal technique appropriate to the rural community should be determined considering the following three major factors :

i) water quality
ii) water use pattern and socio-economic conditions
iii) condition of the source.

In the absence of organic matter, for alkaline ground water supersaturated with carbon dioxide, aeration for gas transfer is the simplest way of oxygen addition and carbon dioxide removal. Field data indicates that there was an increase in pH value above 7.0 even without any effective aeration of water (31). In such conditions there is no need of any chemical addition for further pH adjustment and oxidation. Moreover, for iron concentration above 5 mg/l, aeration is the cheapest oxidation process(31). For a normal handpump tubewell water supply where maximum available head of water is only 90-100 cm, neither external power aided aerators nor high head cascades, perforated trays are feasible or practicable. Manually operated force pump is not adviseable for operational and maintenance problems. A low head gravity flow aerator is the most appropriate option for these handpump tubewells(31).

The oxidised and precipitated iron particles after aeration process are so small in size that it is very difficult to seperate them through sedimentation. Flocculation is the process by which these small particles are allowed to grow or flocculate to sizes that settle at satisfactory velocities. For the same reason neither chemical coagulants nor mechanical mixing devices are feasible and practicable in small community water supply systems. A new solution to the flocculation process may be the one involving single or double media gravel bed with up or downflow.

The sedimentation process in iron removal provides for the settling and removal of heavier and larger flocculated particles of the effluent from the flocculator prior to filtration. The removal efficiency in the sedimentation basin determines the subsequent loadings on the filters and, accordingly, has a marked influence on their capacity, the length of the filter runs, and the quality of the filtered water. Rectangular horizontal-flow clarifiers without mechanical sludge removal are advantageous for communities in developing countries because of their simplicity and abilty to adapt to various raw water conditions.

Frequent cleaning of sand bed is the major problem in an iron removal process that has been experienced in all most all previous studies. Rapid sand filters are completely unsuitable for small installations due to backwashing and operation difficulties. Sometimes high turbid iron content water from the sedimentation tank may be carried over to a filter due to inefficient maintenance of the plant which may easily clog a slow sand filter after a few hours of run (31).

Therefore it is adviseable to find out an alternative treatment process like roughing gravel filter in place of a sand filter.

### 2.8. Acceptable Limit of Iron in tubewell water

United states public health service and world health organisation have recommended the maximum allowable limit of .25 mg/l iron for drinking water. This limit can hardly be attained in our country, since iron free water is rarely available from tubewells in Bangladesh. To maintain the above limit of iron, chemical treatment is required which is not practicable and feasible in rural water supply based handpump tubewells. For the above reasons, Water Pollution Control (Bangladesh) has recommended the desirable limit of 1 mg/l in drinking water, but in the case of hand pump tubewells in rural areas, the maximum tolerable limit may be upto 5 mg/l in the absence of better sources. This local standard is also being followed by the Department of public health engineering in their tubewell sinking programme(22).

The term 1 mg/l or 5 mg/l is meaningless to the rural people who are the main users of hand pump tubewells. Since the presence of iron in water normally does not involve any health risk and strain of plumbing fixtures is not a problem in rural water supply, peoples opinion should be the only criterion in fixing the acceptable limit of iron in hand pump tubewell water in Bangladesh.

In different iron problem areas of Jessore Khulna and Kushtia, some households were interviewed about their general opinion on over all water quality. The opinion is plotted in Fig.2.4 against the iron content of the tubewell water they use. It was observed that rural people use hand pump tubewell water having iron content less than 2 mg/l without raising any specific objection and they consider such water as good quality water. Therefore, if iron content in tubewell water is maintained within 2 mg/l, it can be expected that such water will be acceptable to all most all consumers(22).

This limit may vary from place to place. It has been reported that in some places rural people use water with 4 mg/l to 5 mg/l of iron without much hesitation. Therefore, it is not essential to maintain the interactional standard for iron in rural water supply and to maintain a concentration below 2 mg/l may be considered adequate in rural areas of Bangladesh(22).

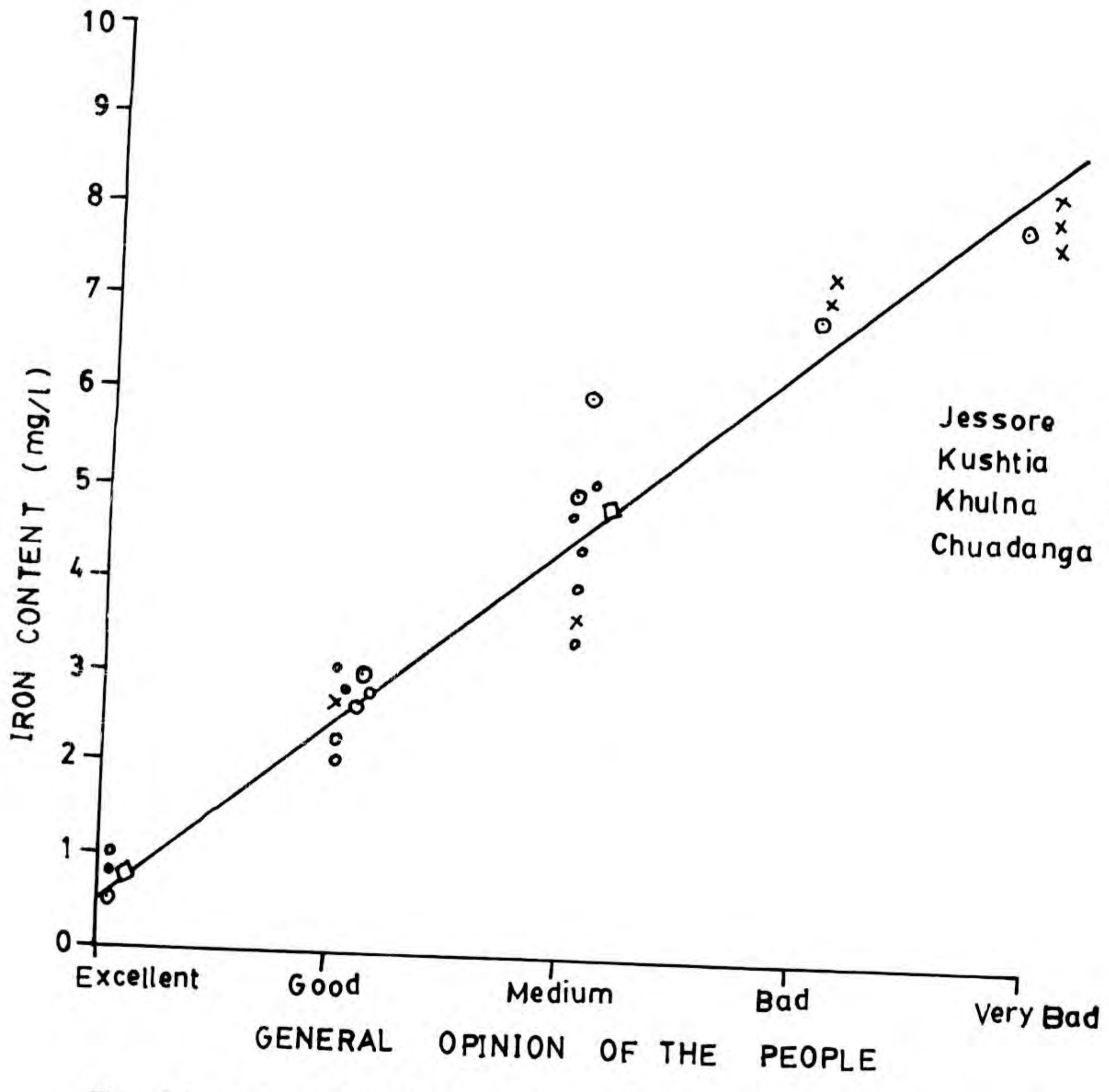



Fig. 2.4 Iron content and people's general opinion about water quality (31)

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# CHAPTER 3

# FIELD INVESTIGATION OF THE EXISTING PLANT

## 3.1 INTRODUCTION

As mentioned earlier, the improved iron removal plants are under implementation since 1987-88. The latest phase of research and development work was aimed to increase the filter run and make cleaning easier while at the same time simplifying the design without increasing the overall cost.

To study the working principle and investigate the performance of the existing plants it was decided to visit the IRPs in Sirajgonj. During the visit, samples were collected from the plants and a survey was carried out among the beneficiaries about their opinion toward the IRPs and their participation in the maintenance of the IRPs. The yield capacity of the existing plants were also measured. WHO has also recently surveyed the iron removal plants in Sirajgonj. The results of the survey were collected from the officials of WHO.

As the level of maintenance of IRP is influenced by so many factors including level of iron concentration, socio-economy, culture, tradition, hygiene education, technology, alternative source of water etc. the findings of survey may vary from area to area.

## 3.2 Details of the Plants

The existing iron removal plant consists of two compartments. First compartment is meant for sedimentation and the second for filtration. Water passes from the handpump into a ferrocement channel. This was made at site from a mould and has a ferrocement cover at the handpump end. The water drops through the perforations at the base of the channel into the sedimentation tank.

The filter is 8" deep, 23" wide and 33" long. The brick chips sieved to sizes from 1/8" to 5/8" were placed in the filtration chamber. Same grade of material was used throughout for simplicity. The brick chips can be removed and replaced without worrying about grading. The filter media rests upon a perforated ferrocement plate supported over a sump to ensure that the entire filter area is used and to make drainage and cleaning easier.

After passing through the filter the water delivered through a 1/2" diameter G.I pipe. Two 1.5" G.I pipes with caps were used as drian pipe and a 1.5" diameter PVC pipe was used for overflow. The IRP is covered with a corrugated sheet on wood frame. Finally a platform 4′ x 7′ was constructed to facilitate water collection and cleaning of IRP. Fig. 3.1 shows the details of the existing plant in sirajgonj. Plate 3.1 shows the top view of existing iron removal plant and plate 3.2 shows the side view of the existing plant in Sirajgonj.

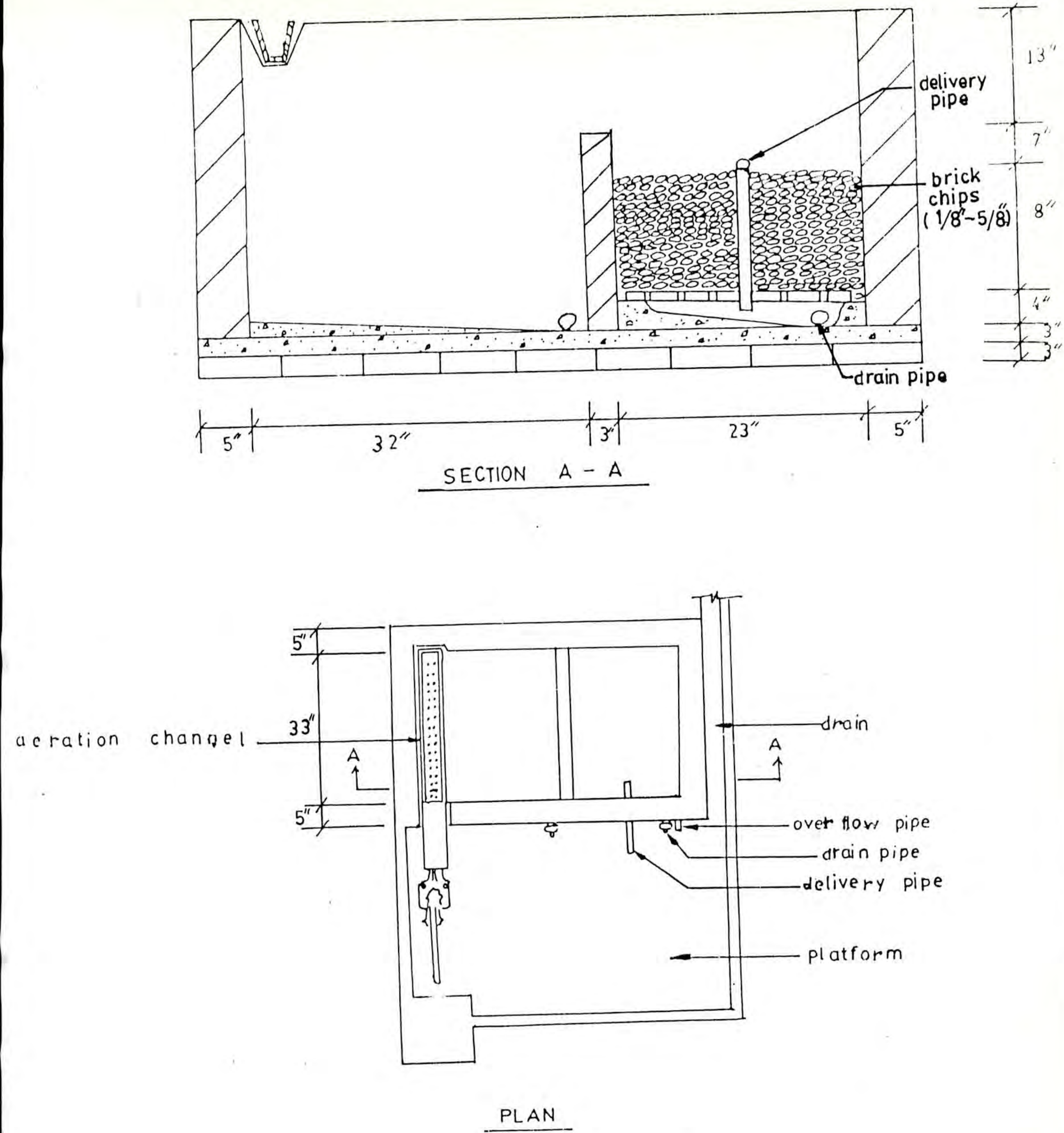



Fig. 3.1 Details of existing iron removal plant

Plate 3.1 Top view of existing iron removal plant.

Plate 3.2 Side view of the existing plant at Sirajgonj.

### 3.3 Working Principle of existing iron removal plants

In the existing plant raw water passes from the handpump into a ferrocement channel. There are perforations at the base of the ferrocement channel. As the water drops through the perforations of the channel into the sedimentation tank, the interfacial area of water in contact with air is increased and thus aeration is achieved. The aeration causes soluble iron to precipitate out of solution. As the water flows across the sedimentation tank, some of the precipitated iron are removed either by sedimentation or by adhesion to the interior wall.

The water then passes over a dividing wall and down through the filter. The particulates penetrate into the depth of the filter medium. The particles are transported from the fluid stream line to the surface of the media or collector due to gravitational forces and thus removed.

Aster passing through the filter the treated water is delivered through the delivery pipe. This is fitted with a tappered wooden bung to prevent leaks. Fig. 3.2 shows the flow diagram of existing iron removal plant.

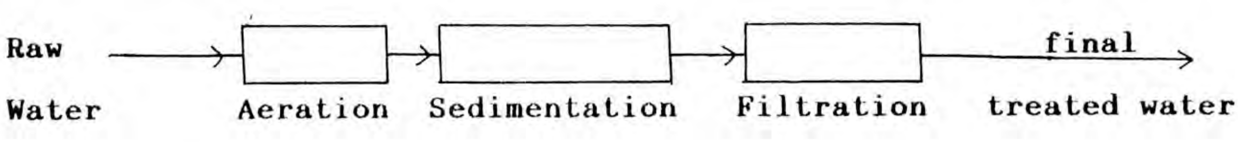



Fig. 3.2 Flow diagram of existing iron removal plant.

## 3.4 Iron removal efficiency of the plants and the filter run

Table 3.1a shows the performance of 92 existing plants. The iron removal is satisfactory with an average cleaning interval of 12 days. The raw water iron concentration varies from 11.4 to 15.29 ppm, where treated water iron concentration varies from 1.3 to 1.8 ppm. The percent removal is approximately 90%.

During field visit at Sirajgonj, samples were collected from five existing plants and later tested in the laboratory. Table 3.1b shows the performance of 5 existing plants. The samples were collected form three points. It was observed that raw water iron concentration varies from 14 to 16 ppm where the treated water iron concentration varies from 1.4 to 2.5 ppm. Average iron concentration after sedimentation varies from 8.2 to 10 ppm. Therefore 40% iron is removed in the sedimentation process and 45% iron is removed in filtration process. The average % iron removal varies from 84.375 to 90.66. The filter run varies from 7 to 15 days depending on iron concentration and usage of water. The filter run was taken as the time when yield of IRP becomes very low, less then 6l/min. The no of beneficiaries per tube well is 50 to 100.

Table 3.1a Performance of the IRPs in use(2).

| Name of district | Name of Upazila | No.of IRP surveyed | Average iron concentration ppm. | | Average interval of cleaning days |
|---|---|---|---|---|---|
| | | | Raw water | Treated water | |
| Siraj-gonj | Belkuchi | 5 | 11.4 | 1.8 | - |
| | Shahjadpur | 37 | 14.43 | 1.6 | 14 |
| | Sirajgonj | 34 | 15.29 | 1.3 | 11 |
| | Ullapara | 16 | 13.0 | - | 11 |
| District total | | 92 | | | 12 |

Table 3.1b Performance of the IRPs in use (field survey).

| Sl. No. | Avg raw water iron content ppm | Avg.iron content after sedimentation ppm | Avg.treated water iron content ppm | Avg. % iron removal | Avg. filter run days | Approx. No.of beneficiaries |
|---|---|---|---|---|---|---|
| 1. | 14 | 8.2 | 1.4 | 90.00 | 10 | 50 |
| 2. | 15 | 9.3 | 2.0 | 86.66 | 15 | 75 |
| 3. | 16 | 9.7 | 2.5 | 84.375 | 12 | 80 |
| 4. | 15 | 9.4 | 1.4 | 90.66 | 12 | 80 |
| 5. | 16 | 10.0 | 2.0 | 87.5 | 7 | 100 |

## 3.5 Yield capacity of the existing plants

The yield capacity of the existing plant and the tubewell was measured during field visit. To determine the yield capacity of the tubewell, it was pumped at uniform rate. The discharge through the spout per minute was measured. This discharge, 17.35 l/min represents the yield capacity of the tube well. To determine the yield capacity of the existing plant, tubewell was pumped at uniform rate. Since the rate at which water entered the filtration chamber is higher than the rate at which water discharged through the delivery pipe, water level in the filtration chamber started to rise. Water discharged due to this head. Tubewell was pumped at such a rate that the head remains constant. The constant head was found to be 3.2 inch. The discharge through the delivery pipe per minute was measured. This discharge per minute represents the yield capacity of the existing plant. The yield capacity of the existing plant was found to be 13.15 l/min. Therefore the yield loss is 24.20% with respect to the tubewell yield.

## 3.6 Water Quality parameters of the existing plant

Water quality parameters of the existing plant, like pH, $Co_2$ concentration and dissolved oxygen concentration were measured in the laboratory. The samples were collected from inlet, after aeration and out let. The results have been enumerated in the Table 3.2. It has been observed that due to aeration dissolved oxygen concentration increased from 0.1 ppm to 2.1 ppm. The pH increased from 6.5 to 7.1 and $Co_2$ concentration decreased from 112 ppm to 31 ppm.

Table 3.2 Water Quality parameters of the existing plant.

| Sampling points | pH | $Co_2$ concentration ppm | dissolved oxygen concentration ppm. |
|---|---|---|---|
| inlet | 6.5 | 112 | 0.1 |
| after aeration | - | - | 2.1 |
| outlet | 7.1 | 31 | - |

3.7 Beneficiaries opinion

During the field study at Sirajgonj a number of beneficiaries of a certain IRP were interviewed. The No.of people interviewed was 31 where total No.of beneficiaries of that IRP was about 60. The results of the interview have been shown in the Table 3.3. It was observed that 100 percent people are satisfied with the effluent water quality where 35.48% people are satisfied with the yield capacity. 64.52% people complained about its low yield and only 19.35% people actively participated in the cleaning of IRP. Fig. 3.3 Shows the beneficiaries opinion toward the existing plant.

Table 3.3 Beneficiaries opinion toward IRP (Field survey).

| Satisfied with yield | | Satisfied with effluent water quality | | Participated in the cleaning of IRP | |
|---|---|---|---|---|---|
| Yes | No | Yes | No | Yes | No |
| 11 (35.48%) | 20 (64.52%) | 31 (100% ) | 0 (0%) | 6 (19.35%) | 25 (80.65) |

3.8 Existing condition of IRPs

A total of 114 Nos. of IRPs have been surveyed in Sirajganj, out of which 92 Nos. (80.7%) were found to be operative and 22 Nos (19.3%) found to be abandoned. The results of the survey have been shown in Table 3-4

Table 3-4 Existing condition of IRPs(2).

| Name of district | Name of Upazila | No.of IRP | | |
|---|---|---|---|---|
| | | Installed | Surveyed | |
| | | | in use | Abandoned |
| Sirajgonj | Belkuchi | 5 | 5 | - |
| | Shahjadpur | 46 | 37 | 9 |
| | Sirajgonj Sadar | 43 | 34 | 9 |
| | Ullahpara | 20 | 16 | 4 |
| District total % | | 114 (100%) | 92 (80.70%) | 22 (19.3%) |

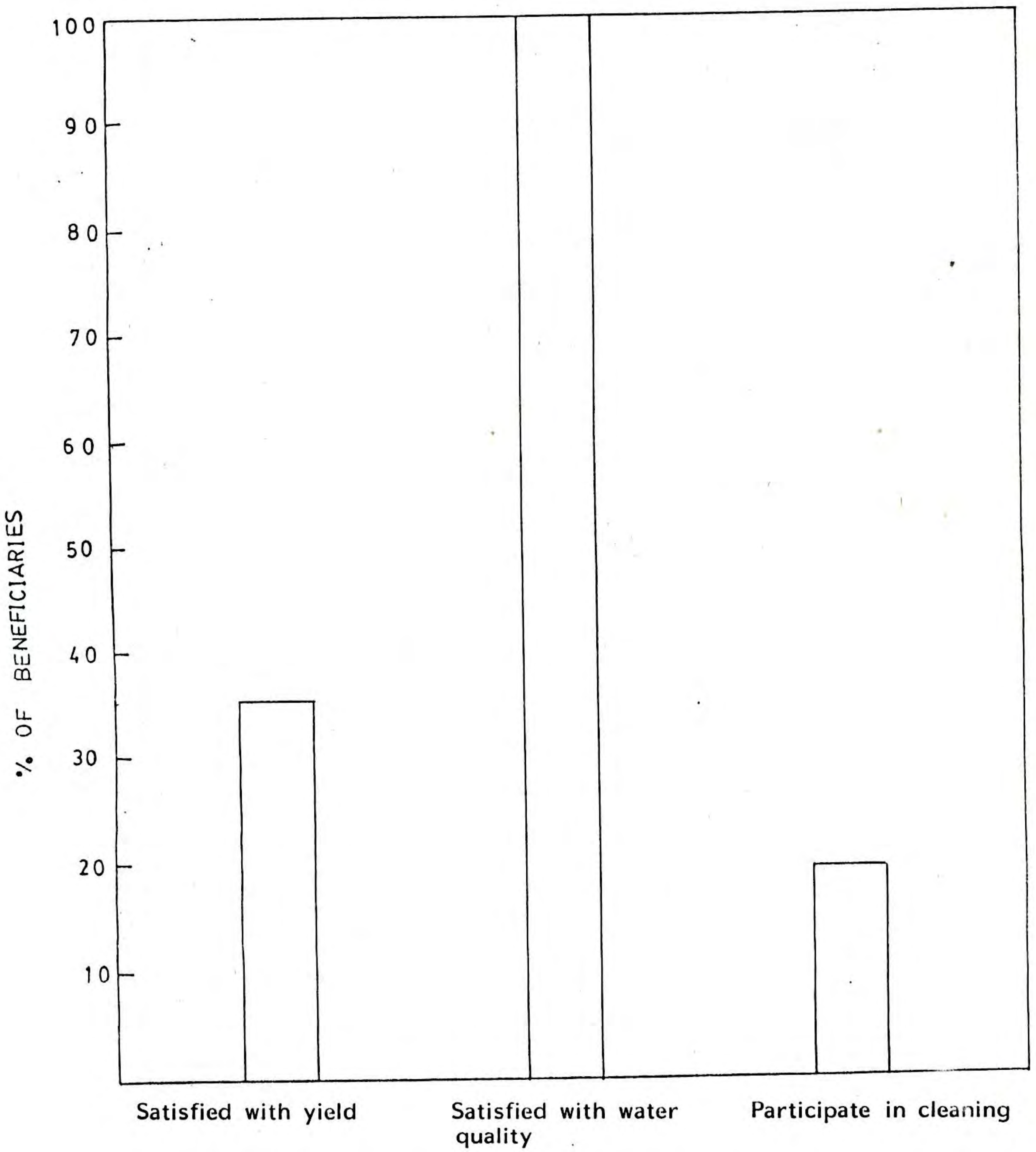



Fig. 3.3 Beneficiaries opinion toward the existing plant.

## 3.9 Reasons of the abandoning of IRPs

The reasons for abandoning the plants have been enumerated in Table 3.5. 45% of the abandoned IRPs were found subject to breakdown and non availability of IRP spare parts. 18.2% IRPs were abandoned due to lack of interest and motivation of the beneficiaries. Another 18% were abandoned because it was not felt needed. Only one IRP was abandoned due to damage during flood and two due to easy access of insects.

Table 3.5 : Reasons of the abandoning of IRPs(2).

| Name of District | Name of Upazila | No.of IRP Not in use | No. of IRP Not in use because of | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | breakage & non availab-ility of spare parts | lack of interest/ motiva-tion | easy access of in-sects | break down of tube well | not felt nee-ded | damaged during flood |
| Sirajgonj | Shahjadpur | 9 | 8 | 1 | 0 | 0 | 0 | 0 |
| | Sirajgonj Sadar | 9 | 1 | 2 | 1 | 1 | 3 | 1 |
| | Ullahpara | 4 | 1 | 1 | 1 | 0 | 1 | 0 |
| District Total | | 22 | 10 | 4 | 2 | 1 | 4 | 1 |
| % | | 100.00) | (45.00) | (18.2) | (9.2) | (4.5) | (18.0) | (4.5) |

### 3.10 Condition of the IRPs in use

The condition of the IRPs have been enumerated in Tables 3.6a and 3.6b. All the plants surveyed have good platform, intact cover and sound structure. The structural construction is satisfactory except in a few cases (4.3%) where it deserves more attention to the dressing of earth around the plant. 91.3% IRPs have been visited at least once during the last three months by DPHE officials. Out of 92 IRPs surveyed 91 were found with clean perforated channel and 72 with clean interior. No IRPs was found with clean net. 87 IRPs have clean overflow pipe where 60 IRPs have clean Brick chips.

Table 3.6a Condition of the IRPs in use(2).

| Name of District | Name of Upazila | No.of IRP in use and surveyed | No. of IRP with | | | | | No.of IRPs visited by DPHE official at least once during last 3 months. |
|---|---|---|---|---|---|---|---|---|
| | | | Sound structure | cover intact | water ponding around platform | Good platform | Good drain plug | |
| Sirajgonj | Belkuchi | 5 | 5 | 5 | 0 | 5 | 5 | 5 |
| | Shahjadpur | 37 | 37 | 37 | 2 | 37 | 37 | 36 |
| | Sirajgonj Sadar | 34 | 34 | 34 | 2 | 34 | 34 | 31 |
| | Ullahpara | 16 | 16 | 16 | 0 | 16 | 16 | 12 |
| District Total | | 92 | 92 | 92 | 4 | 92 | 92 | 84 |
| % | | (100.00) | 100.00) | (100.00) | (4.3) | 100.00) | (100) | (91.3) |

Table 3.6b : Condition of the IRPs in use.(2)

| Name of District | Name of Upazila | No.of IRP Surv-eyed | No. of Units with clean | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Interior | Perfor-ated channel | Settling chamber | Brick chips | Net | Over flow pipe |
| Sirajgonj | Belkuchi | 5 | 3 | 5 | 5 | 5 | 0 | 4 |
| | Shahjadpur | 37 | 29 | 37 | 13 | 29 | 0 | 34 |
| | Sirajgonj Sadar | 34 | 30 | 34 | 16 | 16 | 0 | 34 |
| | Ullahpara | 16 | 10 | 15 | 13 | 10 | 0 | 15 |
| District Total | | 92 | 72 | 91 | 47 | 60 | 0 | 87 |
| % | | (100.0 | (78.3) | (98.9) | (51.1) | (65.2) | (0.0) | (94.6) |

## 3.11 Caretakers role in maintenance and operation

Care takers of the IRPs were also interviewed. Out of 92 care takers interviewed, 88 were trained, know the job and their family members know about maintenance procedure. The plants are cleaned at an average interval of 12 days. All the care takers claimed that they will approach DPHE Officials for restoration in case of any major break down. The results of the interview have been enumerated in Table 3.7.

Table 3.7 : Care takers role in the maintenance and operation(2).

| Name of District | Name of Upazila | No.of care taker inter-viewed | No. of Care Takers | | | Inter-vel of clea-ning days (Avg) | No.of care takers who will appr-oach DPHE/ others for advice. |
|---|---|---|---|---|---|---|---|
| | | | Trained | Know the job | Having family member fami-liar with main-tenance proce-dure | | |
| Sirajgonj | Belkuchi | 5 | 1 | 1 | 1 | 0 | 5 |
| | Shahjadpur | 37 | 37 | 37 | 37 | (14) | 37 |
| | Sirajgonj Sadar | 34 | 34 | 34 | 34 | (11) | 34 |
| | Ullahpara | 16 | 16 | 16 | 16 | (11) | 16 |
| District Total | | 92 | 88 | 88 | 88 | (12) | 92 |
| % | | (100.00) | (95.7) | (95.7) | (95.7) | | (100.00) |

## 3.12 Use of water for different purpose

Use of water of IRPs for different purposes have been enumerated in Table 3-8. 28.3% beneficiaries use water for all purpose where 45.71% use for drinking and cooking. 2.3% use water for drinking only. 100.0% beneficiaries believe that IRP treated water is better. Fig 3.4 shows the % of beneficiaries water use for different purposes.

Though all the interviewed beneficiaries admitted that IRP treated water is better, its use had not been encouraging. The users do not hesitate to take the fresh water with invisible dissolved iron from handpump spout. Awareness development on IRP and mass mobilization should be intensified.

Table 3.8 : Use of water for different purposes(2).

| Name of District | Name of Upazila | No.of Households near IRP visited | No.of household use water for | | | | No.of Households believe that IRP water is better |
|---|---|---|---|---|---|---|---|
| | | | All purpose | All purpose except drinking | only drinking | Drinking & cooking | |
| Sirajgonj | Belkuchi | 5 | 0 | 0 | 0 | 5 | 5 |
| | Shahjadpur | 37 | 9 | 11 | 0 | 17 | 37 |
| | Sirajgonj Sadar | 34 | 18 | 8 | 2 | 13 | 34 |
| | Ullahpara | 16 | 7 | 2 | 0 | 7 | 16 |
| District total | | 92 | 26 | 21 | 2 | 42 | 92 |
| % | | (100.0) | (28.3) | (22.8) | (2.3) | (45.7) | (100.00) |

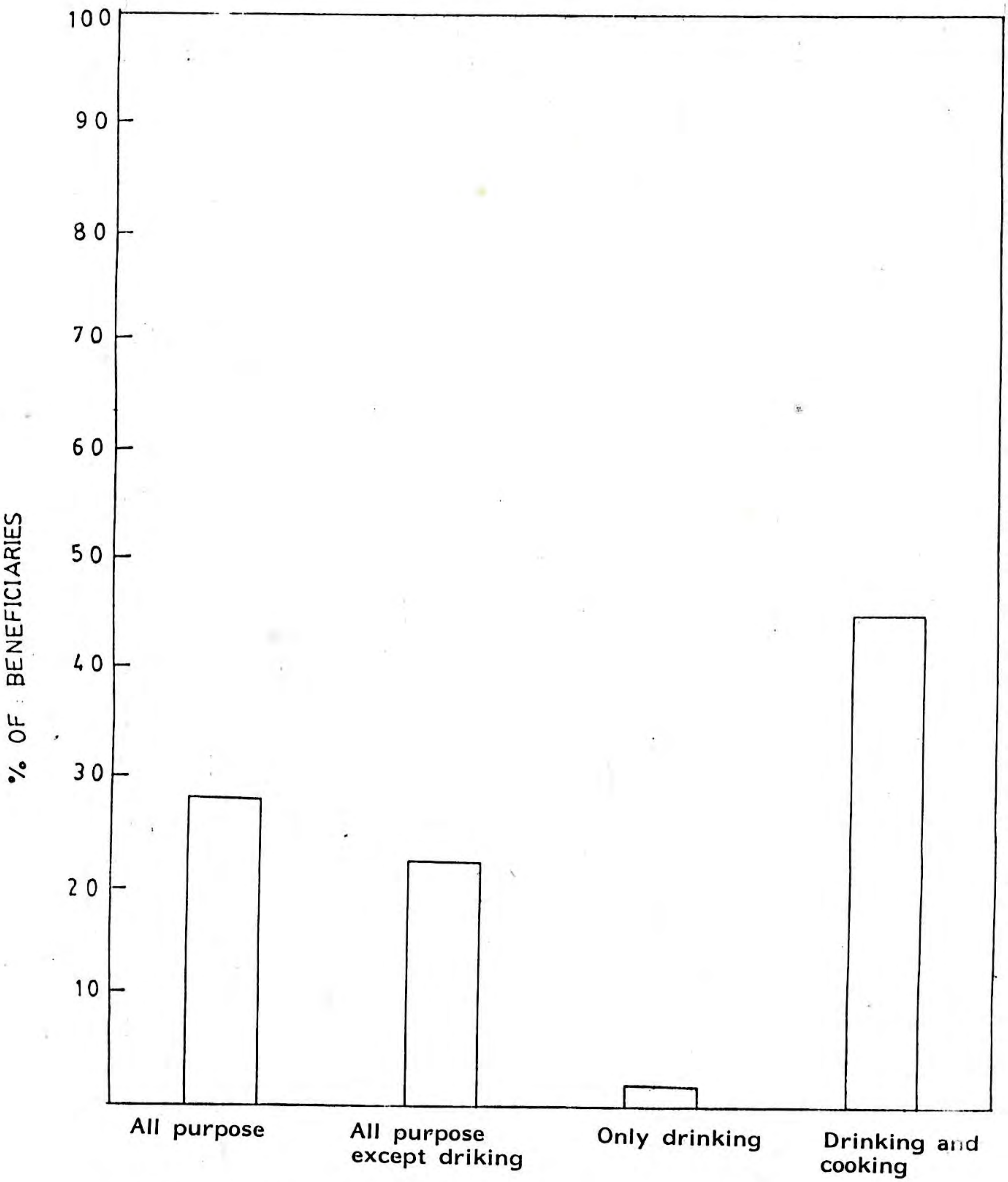



Fig. 3.4 % of beneficiaries use water for different purpose.

### 3.13. Cleaning and maintenance

The IRP is designed to be operated, cleaned and maintained by the beneficiaries themselves. The beneficiaries are involved in the construction to help them understand the IRP and how to look after it. They are also trained in how to use the IRP. The IRPs were cleaned whenever the treated water became too cloudy, had lumps of iron floc or the flow is too low.

The cleaning procedure is as follows :

a) The lid is opened and aeration channel is removed to allow water to be drawn by bucket directly from the hand pump.

b) Filter drain cap is removed.

c) Using a bucket, the filter is flushed with tubewell water, until the filter drain water is fairly clean.

d) The Sedimentation chamber drain cap is removed and flushed with clean water from the tubewell, until all the deposited iron flocs are drained out.

e) The drain caps are replaced using jute or cloth on the threads to prevent leaks.

f) The aeration channel is placed in position and the plant is covered with Lid.

If the IRP has been properly constructed, the only items likely to need repair are the movable parts i.e. the ferrocement channel, ferrocement perforated plates and the lid. The repair of the lid is within the competence of any local carpenter.
The pump handle fulcrum pins are oiled regularly. This prevents the handle from wearing out and makes pumping easy.

## 3.14. Problems encountered : reasons and discussion

In the existing iron removal plants, aeration is done by means of a perforated rectangular channel. This channel is very narrow (4") and short (33") producing a thick film (2") of water. Since the detention time is short and renewal of inter facial area is not effective, efficient aeration is not done.

For effective aeration and oxidation of soluble iron, longer detention time, larger and frequent renewal of inter facial area are required. Although the existing plant consists of a large sedimentation basin, very small precipitates of iron, which are very small ( colloidal range) in size can not be settled during its detention time which is ultimately deposited on the coarse media in the following chamber causing a rapid clogging of pores. Very often, immediately after cleaning, the effluent water from the plant looks turbid and contains lumps of iron, which are sloughed off from the coarse media. As the pores of the filtrate materials are clogged very rapidly, the plants are required to be cleaned very frequently (12 days interval).

Yields of the plant reduce very quickly due to the clogging of coarse media. The no of beneficiaries are about 70 to 100 per tubewell. But the yield capacity of the IRP is so low that it can not meet the requirement of the beneficiaries which ultimately discourage them to use IRP water.

The IRP is covered with corrugated sheet. If the iron removal plant is not shaded, water will be slightly warm in the late afternoon and unpalatable. The beneficiaries have to take full responsibility for maintenance and repair of the IRPs, which lead to various problems because of their lack of knowledge.

Field investigation reveals that some of the IRPs contain frogs, fishes and various water born insects. It is objectionable both from aesthetic point of view and for hygienic reason. These insects enters through the openings in the corrugated sheet that covers the IRP. More over, the corrugated sheet can not prevent evaporation loss of water. Using a ferrocement cover slab instead of corrugated sheet would prevent the entrance of insects and evaporation loss of water.

3.15 Estimated cost of the existing Plant :

The cost of the materials used in the existing plant are listed in Table 3.9. The price of different components were fixed on the basis of present (1990) market price(3)

Table 3.9 : Estimated cost of the existing Plant.

| Item | Quantity | Rate (Tk.) | Cost (Tk.) |
|---|---|---|---|
| Brick | 250 Nos. | 2200/1000 | 770 |
| Cement | 6 bags | 210/bag | 1050 |
| Sand | 20 cft | 400/100 cft | 80 |
| Khoa making | 10 cft | 6/cft | 60 |
| 1/8-5/8" khoa | 5 cft | 20/cft | 100 |
| Wood | .6 cft | 150/cft | 90 |
| CGI Sheet | 2 Nos. | 120 | 240 |
| GI drain pipe | 2 Nos. | 15 | 30 |
| 1.5" GI cap | 2 Nos. | 10 | 20 |
| 0.5" GI delivery pipe with bung & chain | 1 No | 20 | 20 |
| 0.5" dia GI elbow | 1 No | 7 | 7 |
| 1.5" PVC overflow pipe | 1 No. | 5 | 5 |
| Lid hinges | 2 Nos. | 15 | 30 |
| Bolt, nut & washers | 4 Nos. | 2.5 | 10 |
| 4" bamboo Lid prop | 1 No. | 10 | 10 |
| hinge for lid prop | 1 No. | 5 | 5 |
| hook for lid prop. | 1 No. | 3 | 3 |
| Coal tar paint | 1 Kg. | 15 | 15 |
| Wire mesh | 12 sft | 5 | 60 |
| Mosquito netting | Rs reqd. | - | 25 |
| Mason | 5 days | 100 | 500 |
| Helper | 5 days | 60 | 300 |
| Carpenter | 1 day | 100 | 100 |
| Carriage | - | - | 180 |
| Contingencies | - | - | 208 |
| Total Cost Tk. | | | 3918 |

# CHAPTER 4

# DEVELOPMENT OF MODIFIED IRON REMOVAL PLANT

## 4.1 Introduction

As mentioned earlier in the existing plant, aeration is done by means of a perforated ractangular channel. Water flows along the channel producing a thick film of water. Since the renewal of interfacial area is not possible, effitient aeration is not done. For effective aeration and oxidation of soluble iron, renewal of interfacial area is required.

It has an ordinary sedimentation tank. Some investigators(31) have pointed out that when iron solution with initial concentration, 2 to 5 mg/l is oxygenated, the precipitate is roughly concentrated to submicron size range. Such particles would have very low settling velocity. So the typical sedimentation tank would remove only a small fraction of the precipitated iron.

The remaining particles ultimately deposit on the coarse media in the following chamber causing a rapid clogging of pores. Provition of a flocculation chamber before sedimentation can minimize this problem.

Yield capacity of the plant reduce very quickly due to the clogging of coarse media which needs very frequent cleaning. Also yield capacity of the IRP can not meet the requirement of the beneficiaries which ultimately discourage them to use IRP treated water. On the basis of theoretical information and field observation of the problems, the following modifications were made.

## 4.2 Details of modified design

In order to minimize the problems encountered in the existing plants in Sirajgonj, the plant was modified keeping the existing dimention same. The modified plant also consists of two compartments. The First compartment is a flocculation chamber and the second compartment is meant for sedimentation. In the flocculation chamber, coarse media flocculator were used so that the floc are removed by adhesion. Two chambers are separated by a baffle wall with perforations at the bottom. So that water enters the sedimentation chamber after flocculation. The details of the modified plant is shown in Fig. 4.1. Plate 4.1 shows the top view of the modified iron removal plant. The iron removal plant consists of following components :

1. Inlet pipe
2. Aeration plate
3. flocculation chamber
4. Sedimentation chamber
5. Delivery pipe
6. Back wash pipe
7. Drain pipe
8. Ventilators

### 4.2.1. Inlet Pipe

The flexible inlet hose pipe of diameter 2.5" connects the spout of the tubewell with the aeration plate. The hose pipe is fastened at the spout of the tubewell by means of a clip. Therefore the main purpose of inlet pipe is -

1) To connect the tubewell spout with aeration plate

### 4.2.2. Aeration plate

It is a precast ferrocement plate of thickness 1". It was cast from a mould. There are two undulation on the surface of the plate. Seven angular stone chips of size 1" to 1.5" are placed alternately in each channel as shown in the Fig. 4.2. The size of the aeration plate is 31" x 46".

### 4.2.3. Flocculation chamber

The most important task of an iron removal process is the seperation of oxidised and precipitated iron particles from water which are roughly concentrated in the submicron size range. These particles are very difficult to remove in typical sedimentation basin without prior flocculation. Direct sand filtration is not also adviseable due to high load of suspended particles and frequent clogging of the filters. To enhance the settling character it is proposed to promote coagulation/flocculation before settling. For an alkaline water having pH value above 7.0, it is suggested to mix the aerated water. This mixing procedure agglomerates the ferric hydroxide flocs formed after aeration, which serves to destabilize and flocculate the microprecipitate substances through interparticle contact.

Neither chemical coagulation nor mechanical mixing devices are feasible and practicable in a small community water supply system. Simple techniques should be developed on the basis of available field conditions.

The mechanical flocculators are not used as they require extra power. Baffle flocculators require large number of baffles which are costly and difficult to construct. Rotating paddles or impellers need electricity which is not feasible in the rural areas. So a coarse media flocculator was considered before sedimentation. Locally available brick chips (1"-1.5") were used as coarse media.

The size of flocculation chamber is 19" x 33". The brick chips were supported by a precast perforated plate placed 6" above the base of the plant.

### 4.2.4 Sedimentation chamber

The sedimentation basins are mainly of two types :

1. Horizontal flow type
2. Upflow type

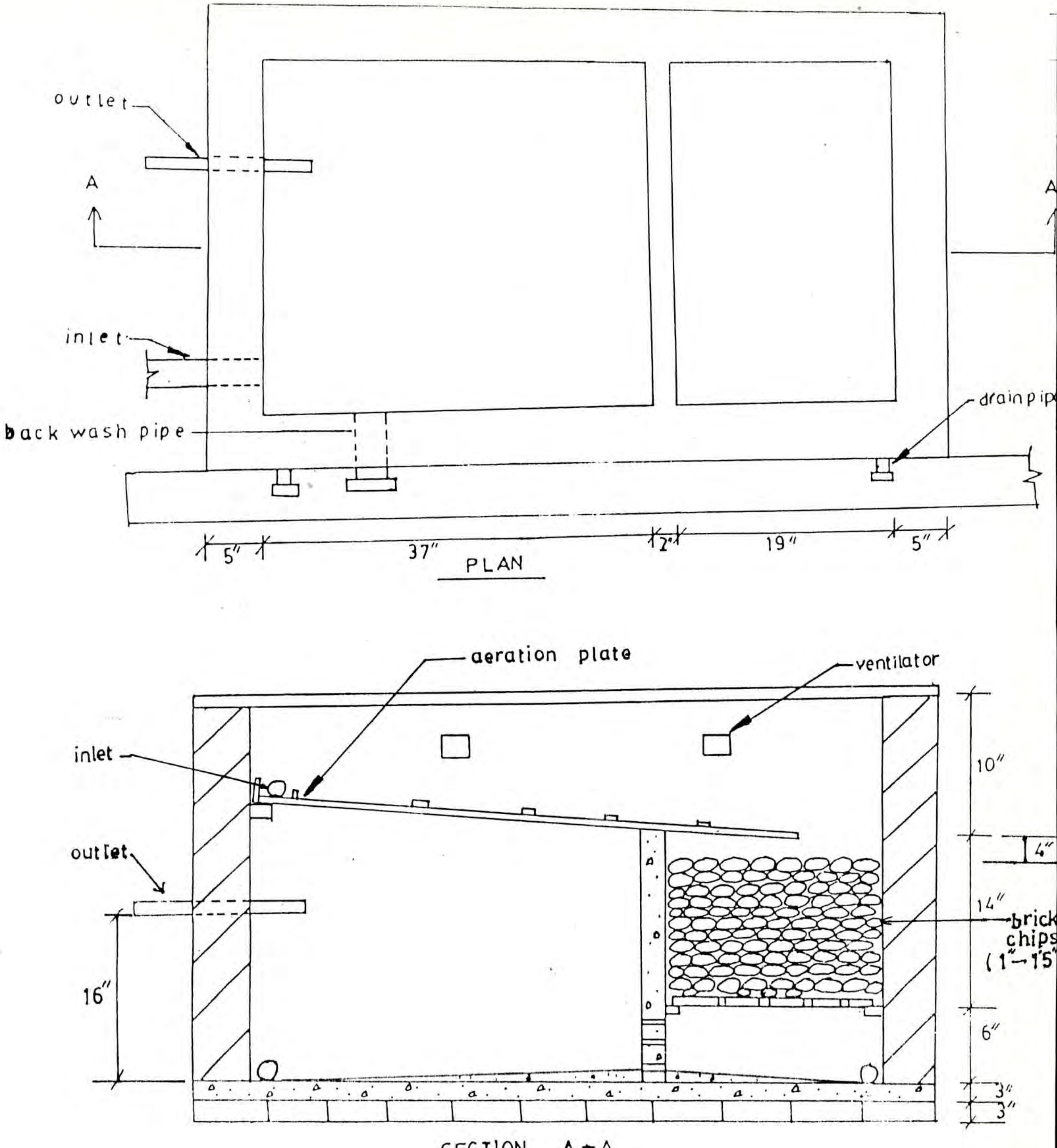
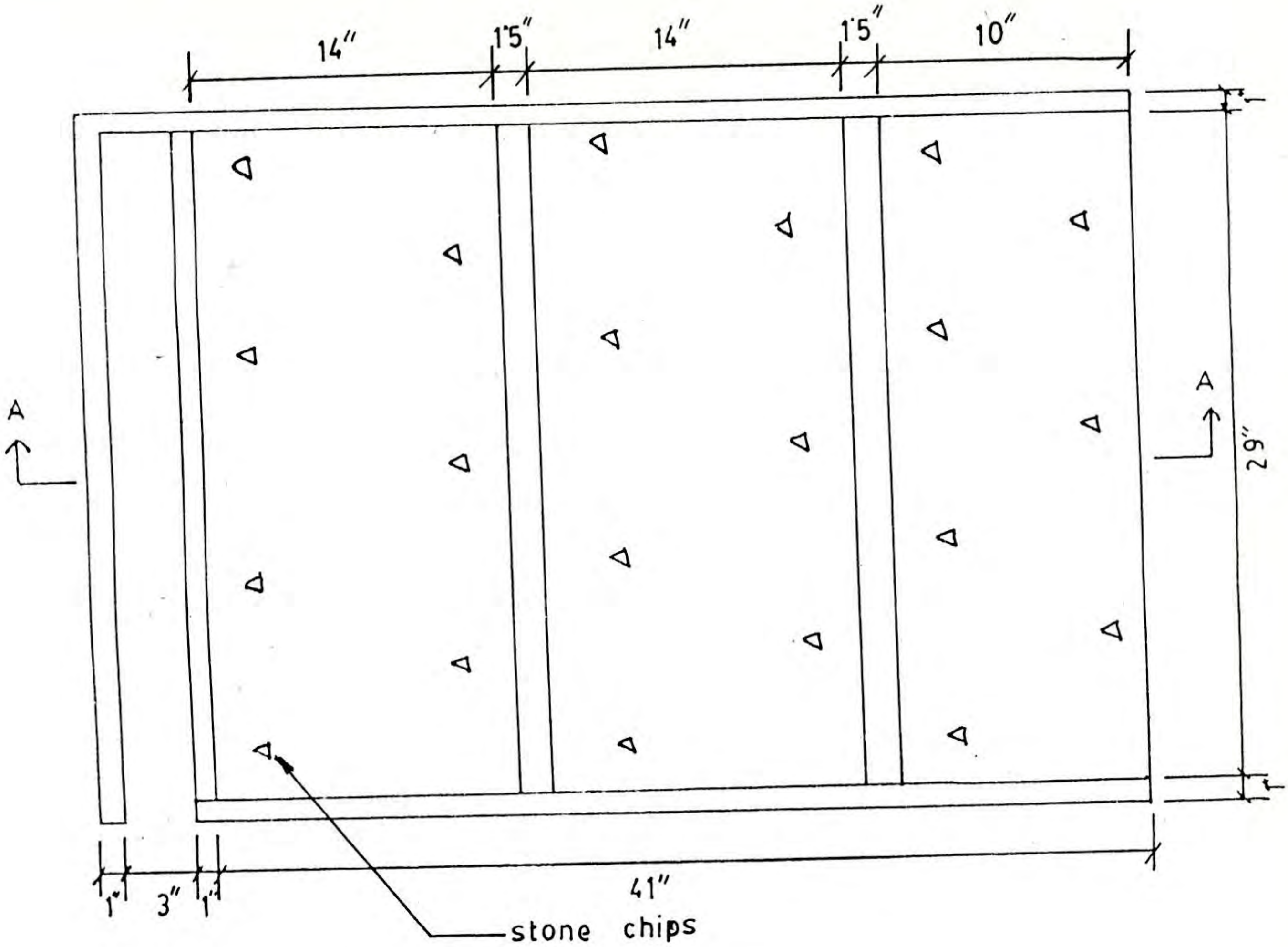



Fig. 4.1 Details of the modified iron removal plant

Plate 4.1 Top view of the modified iron removal plant

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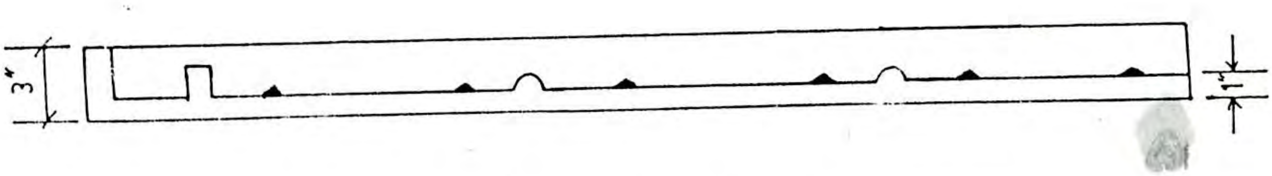



SECTION A - A

Fig. 4.2 Aeration plate

Since horizontal flow type requires larger area, an upflow sedimentation chamber was used. The size of sedimentation chamber is 33" x 37". It receives water from flocculation chamber, which contains substantial amount of flocs. These flocs settle down due to gravity in the sedimentation tank.

### 4.2.5 Delivery pipe

Delivery pipe is a 3/4" PVC pipe. Three such pipes were connected by elbows, through which treated water is discharged. A gate vsalve is attached at the end of the delivery pipe to regulate discharge and to minimize water losses. It is as hygienic as a tap and can easily be repaired or replaced. It gives a more acceptable flow rate.

### 4.2.6. Back wash pipe

Back wash pipe is a 3" pvc pipe. It is covered with a plastic cap. The main purpose of back wash pipe is to clean the plant at a certain interval. To do so the inlet hose pipe is inserted into the back wash pipe and the tubewell is pumped to clean the IRP.

### 4.2.7 Drain pipe

Drain pipes are 1.5" diameter PVC pipe with caps. During cleaning the caps are removed. Slope is provided in the direction of the drain pipes so that during cleaning water can easily be drained out.

### 4.2.8. Ventilators

Four ventilators above the aeration plate facilitate effective aeration as air flows continiously through the ventilators.The size of the ventilators are 3" x 3".

The plant also consist of a baffle wall (Fig. 4.3) of size 20" x 35". It separetes the flocculation chamber from sedimentation chamber. There are perforations at the bottom of the baffle wall. The perforated plate (Fig. 4.4) support the coarse media at the bottom of flocculation chamber. It is precast and made of ferrocement. The perforation were made by drill of 3/8" dia. The size of the perforated plate is 32" x 18".

## 4.3 Working principle of the modified plant

The plant consists of two compartments. The raw water flows from the tubewell onto a ferrocement aeration plate through a hose pipe. The top surface of the aeration plate is uneven. As the water flows over the surface, it spreads through the wide plate and form a thin film. At the same time renewal of interfacial area are achieved. The water flows over the aeration plate and drops into the flocculation chamber. The aeration causes soluble iron to precipitate out of solution. The water flows through the coarse media flocculator and the flocs are removed by ádhesion.

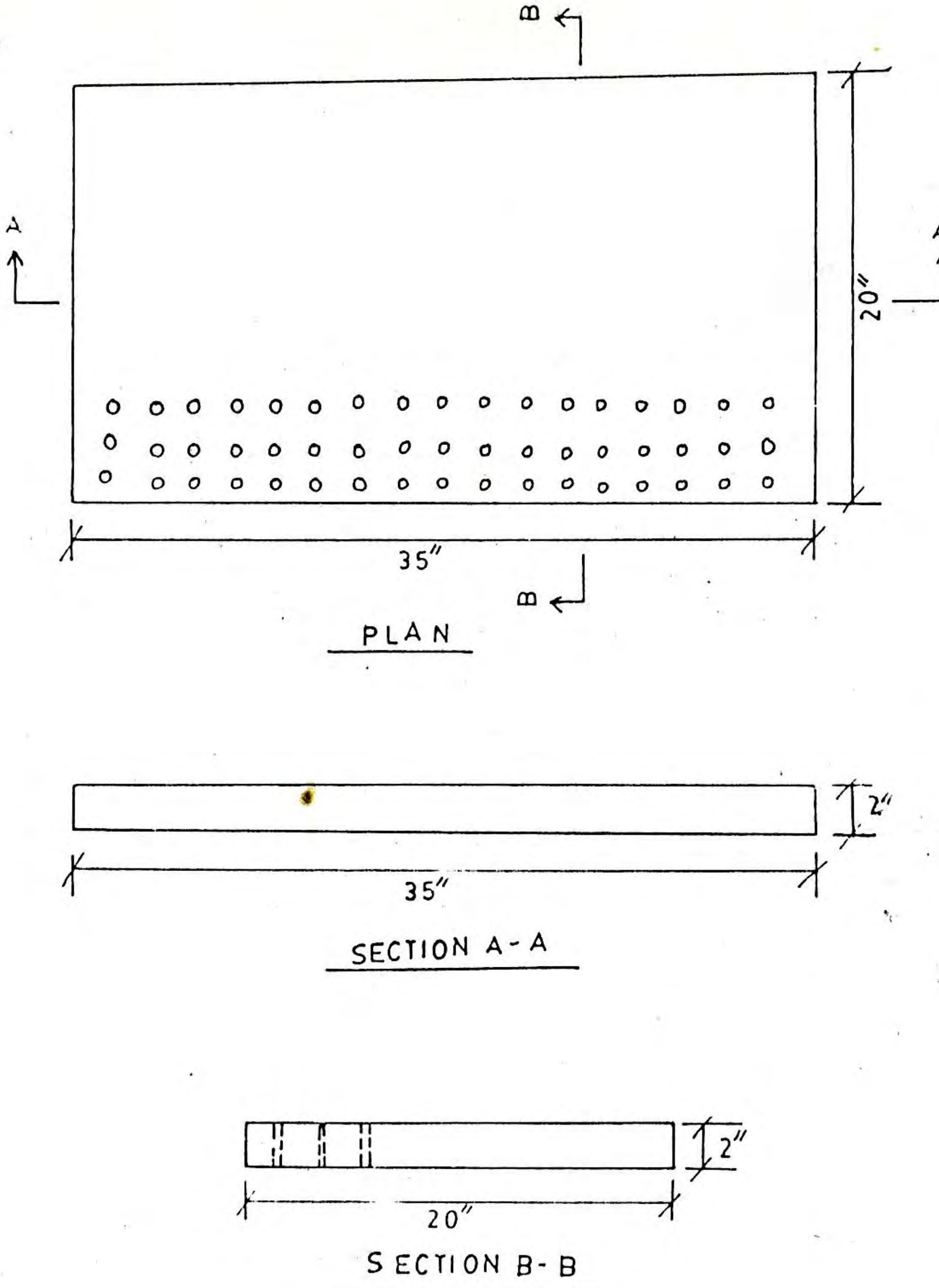



Fig. 4.3 Baffle wall

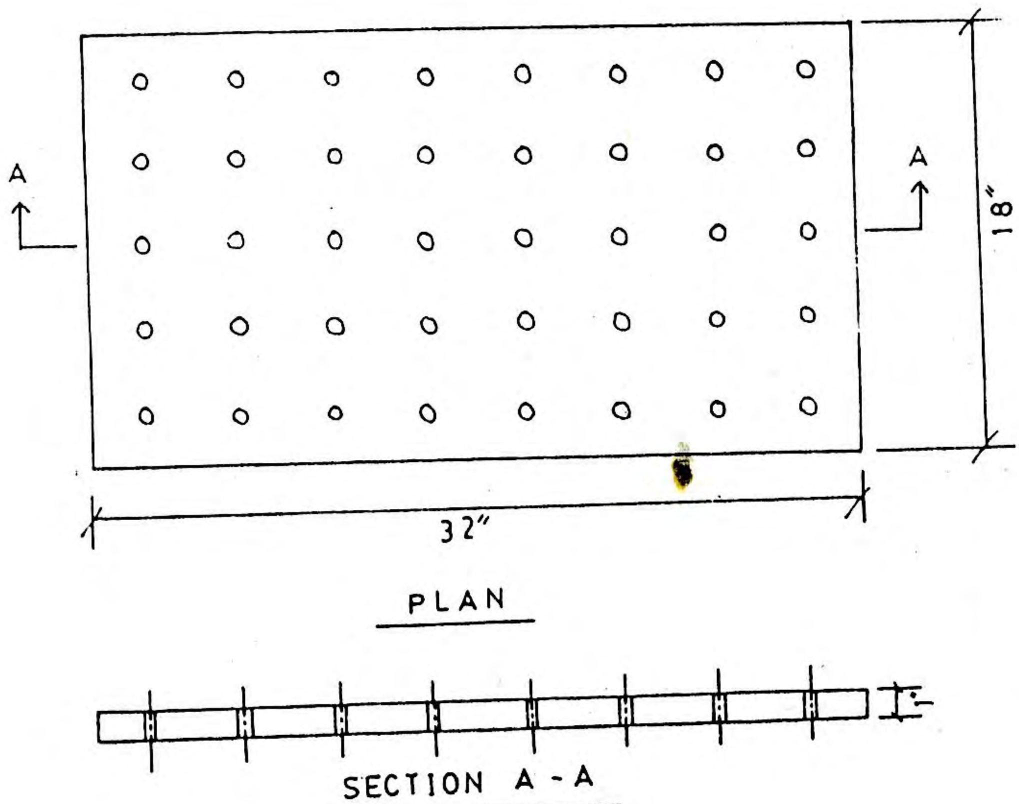



Fig. 4.4 Perforated plates.

After flocculation water enters the sedimentation chamber through the perforations at the bottom of the baffle wall that divides the two chambers. In the sedimentation tank a fraction of the precipitated iron is removed.

After sedimentation the treated water is delivered through a 1/2" diameter GI pipe. This is fitted with a gate valve which regulates the flow of water and prevents water losses.

Fig 4.5 shows the flow diagram of the modified plant.

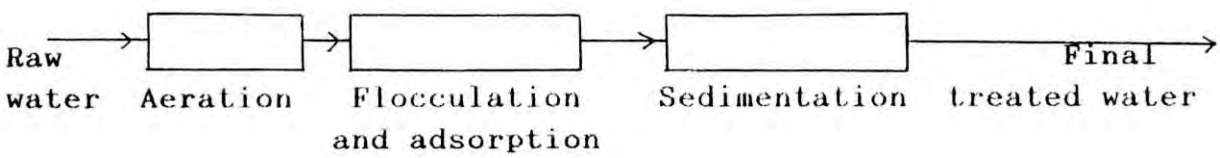



Fig. 4.5 : Flow diagram of the modified plant.

## 4.4 Method of sample collection

Water samples were collected from different points. Sampling points are such that, it reflects the efficiency of individual unit treatment processes.

The sampling points were -

1. Raw water
2. Effluent after flocculation chamber
3. Final treated water from IRP.

The samples were collected every day and tested in the laboratory. Fig. 4.6 shows the sampling points on the flow diagram and Plate 4.2 shows collection of samples from test tube.

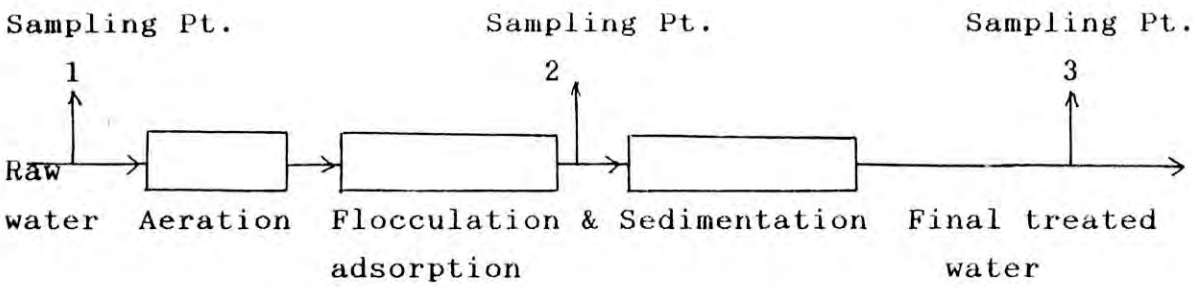



Fig. 4.6 : Sampling points on the flow diagram of modified plant.

4.5 Performance of the modified plant

The water samples were tested in the laboratory. Table 4.1 shows the iron concentration of sample at different points. Initially the iron concentration was high. Then it gradually decreased with time. On the fifth day iron concentration decreased from 19 ppm to 2 ppm and percent removal was 89.47%. The iron concentration of final effluent varies from 2 to 3.8 where after flocculation, iron concentration varies from 4.6 to 7.4. About 75% of iron are removed in the flocculation and adsorption process and 10 to 12 % of iron are removed in sedimentation process. Initially the iron concentration of final effluent was high because immediately

Plate 4.2 Collection of samples from test tube.

after operation the pores in the coarse media flocculator were open. So adsorption was not very effective. As the particles start to clog the pores, the adsorption and flocculation becomes effective and iron concentration of final effluent decreases with time. When the pores are clogged the iron floc sloughes off from the coarse media and ultimately settle in the sedimentation chamber. But some of the sloughed off particles escape the sedimentation chamber and ultimately discharge through the delivery pipe. So when the pores are clogged the iron concentration of final effluent increases with time.

After cleaning, again water samples were collected at different points. The iron concentration at different points after cleaning has been enumerated in Table 4.2.

Iron concentration after flocculation varies from 4 to 6.4 and that of final effluent varies from 1.6 to 3.2. The minimum concentration was found on the sixth day and the percent removal was 91.57%. Then again water quality starts to deteriorate. The data of Tables 4.1 and 4.2 are plotted on plain graph papers (Fig. 4.7 and 4.8).

Table - 4.1 : Variation of iron concentration with time before cleaning of IRP.

| Days | Initial concentration ppm | Iron concentration after flocculation ppm | Iron concentration of final effluent ppm | max. % removal |
|---|---|---|---|---|
| 1 | 19 | 7.4 | 3.8 | |
| 2 | 19 | 6 | 3 | |
| 3 | 19 | 5.4 | 2.4 | |
| 4 | 20 | 4.9 | 2.2 | |
| 5 | 19 | 4.6 | 2.0 | 89.47 |
| 6 | 19 | 4.8 | 2.1 | |
| 7 | 19 | 4.9 | 2.2 | |
| 8 | 18 | 5.0 | 2.4 | |
| 9 | 19 | 5.2 | 2.6 | |
| 10 | 19 | 5.6 | 2.8 | |
| 11 | 19 | 5.8 | 3.3 | |
| 12 | 19 | 6.0 | 3.4 | |

Table - 4.2 : Variation of iron concentration with time after cleaning of IRP

| Days | Initial concentration ppm | Iron concentration after flocculation ppm | Iron concentration of final effluent ppm | max. % removal |
|---|---|---|---|---|
| 1 | 19 | 6.4 | 3.2 | |
| 2 | 19 | 5.8 | 2.4 | |
| 3 | 18 | 4.7 | 2.1 | |
| 4 | 19 | 4.4 | 1.8 | |
| 5 | 19 | 4.2 | 1.6 | |
| 6 | 19 | 4.0 | 1.6 | 91.57 |
| 7 | 20 | 4.2 | 1.7 | |
| 8 | 19 | 4.3 | 2.0 | |
| 9 | 19 | 4.4 | 2.2 | |
| | 19 | 4.6 | 2.4 | |

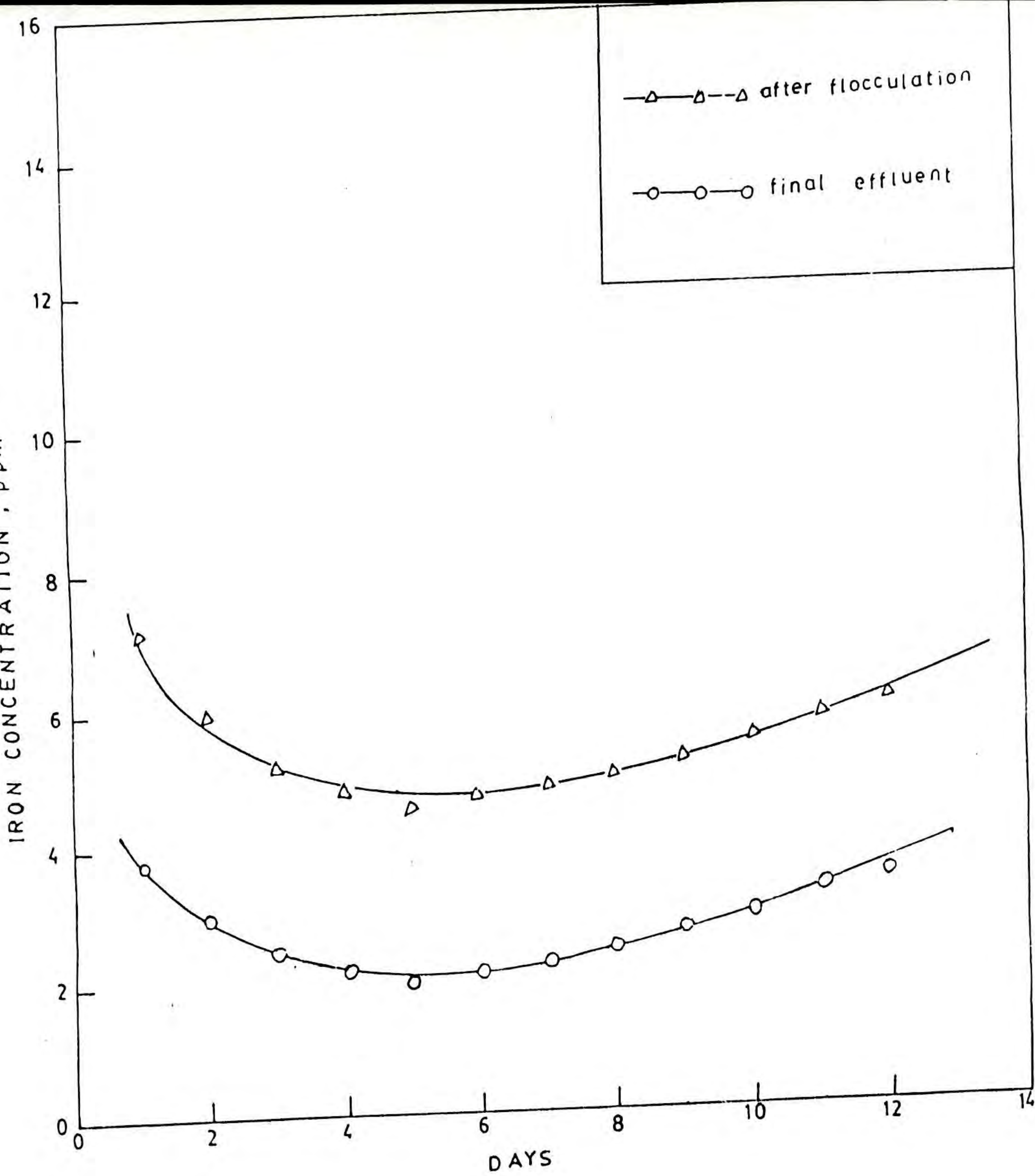



Fig. 4.7 Variation of iron concentration with time of the modified plant before cleaning.

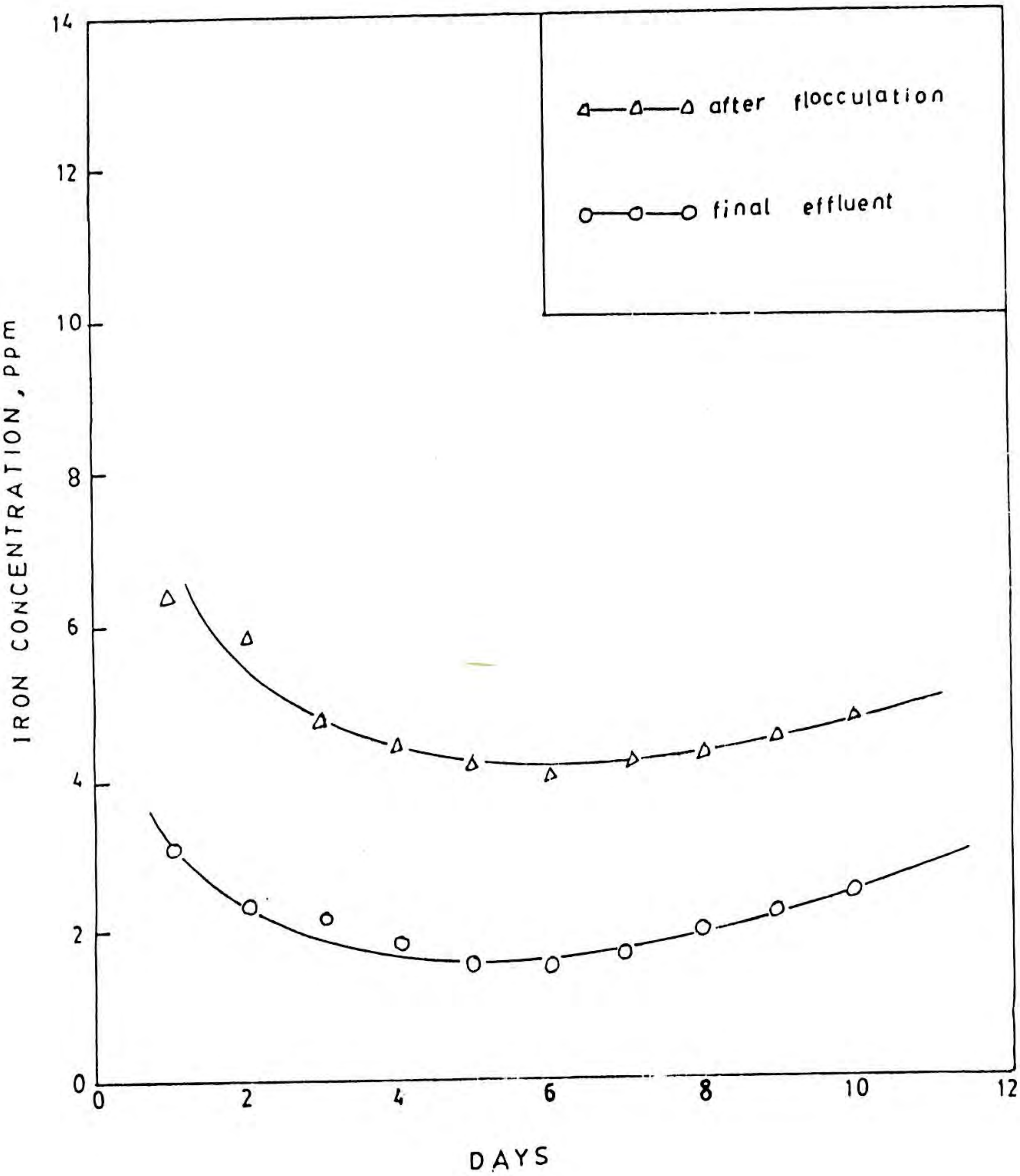



Fig. 4.8 Variation of iron concentration with time of the modified plant after cleaning.

## 4.6 Other water quality parameters

Other water quality parameters like pH, alkalinity and $Co_2$ concentration were also measured in the laboratory.The samples were collected from inlet and outlet. The results have been enumerated in the Table 4.3. It is observed that due to aeration $Co_2$ concentration is reduced from 117 ppm to 31 ppm. The pH increased from 6.4 to 7.2 and alkalinity increased from 207 ppm to 251 ppm.

Table - 4.3 : Other water quality parameters of the modified plant

| Sampling Pt. | pH | Alkalinity ppm | $Co_2$ concentration ppm |
|---|---|---|---|
| inlet | 6.4 | 207 | 117 |
| outlet | 7.2 | 251 | 31 |

## 4.7 Maintenance of IRP

The IRP was cleaned when the treated water becomes too cloudy, has lumps of iron floc or the yield is too low.
The cleaning procedure is as follows :

a) The flocculation drain cap was removed.

b) Using a bucket the coarse media flocculator was flushed several times with tubewell water. The iron floc bearing yellow colored water was allowed to drain out.

c) The sedimentation drain cap was removed

d) The inlet hose pipe was inserted into the back wash pipe. Then tubewell was pumped so that water entered into the sedimentation chamber. The tubewell was pumped for atleast 10 minutes and the deposited iron flocs were allowed to drain out.

e) The drain pipes were replaced using leak proof solution to prevent leaks.

If the IRP has been properly constructed the only items likely to need repair prior to breakage are the movable parts i.e. the aeration channel, perforated plate and cover slab.

The pump handle fulcrum pins are oiled regularly with any type of oil. This prevents the handle from wearing out so fast and make pumping very easy.

## 4.8. Problems encountered

The iron removal plant experiences various problems. These are listed in the following paragraph.

i) The maximum percent removal of iron was found 91.57% which is more or less equal to the efficiency of the existing plant.

ii) The IRP will have to be cleaned regularly, every 10 to 15 days depending on the usage of water.

iii) Some times the water may be cloudy or contain lumps of iron e.g. immediately after cleaning, when cleaning is needed or when the IRP has been over used.

iv) The plant has no provision of filtration. Because of low settling velocity, the sedimentation chamber removes only a small fraction of precipitated iron. The remaining particles escape the sedimentation chamber and discharge through the delivery pipe, which lead to high concentration of iron in the final effluent.

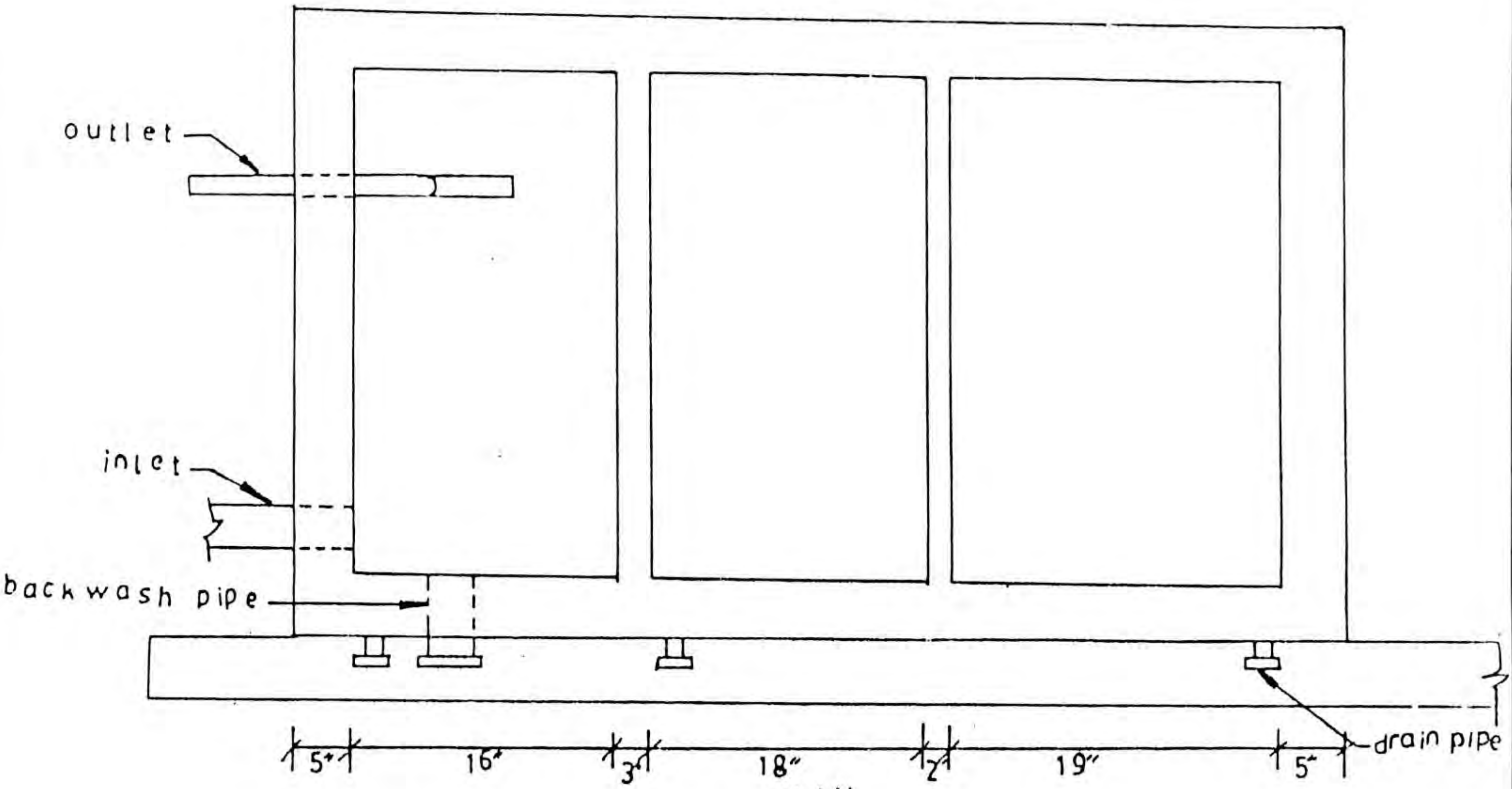
## 4.9 Further modification in the design

In the modified iron removal plant, only flocculation and sedimentation are achieved. There is no filtration chamber. Because of low settling velocity of the particles, some particles escape the sedimentation chamber and discharge through the delivery pipe which eventually increases the iron concentration of final effluent. In order to minimize the iron concentration of final effluent a filtration chamber must be provided. To bring down the iron concentration to the acceptable level, filtration is employed as a final step in the further modified plant. Slow sand filters have generally been found unsatisfactory for large amount of iron precipitates are most critically affected by the permeability of the accumulated solids, whereas rapid sand filters are affected by excessive or insufficient pretreatment, over loading of their limited void volumes and changing in filtration rate or headloss, which may dislodge and carry through the entrapped deposits. Diatomite filtration, which is used in many places as an alternative to sand filtration, is not feasible in small community water supply system. For this reasons a roughing filter was used. To accomplish this a partition was constructed which divided the sedimentation chamber into two compartments. The first compartment was used as sedimentation chamber and the second as filtration chamber. In the filtration chamber brick chips of sizes 1/8" to 5/8" have been used. The detailed drawing of the further modified plant is shown in the Fig. 4.9. The top view of the further modified plant is shown in Plate 4.3 and the side view of the same plant is shown in Plate 4.4.

## 4.10 Working principle of further modified plant

The further modified plant consists of three compartments. After aeration the water drops into the flocculation chamber. The aeration causes soluble iron to precipitate out of solution. The water flows through the coarse media flocculator and the flocs are removed by adhesion.

After flocculation water enters the sedimentation chamber through the perforations at the bottom of the baffle wall. In the sedimentation chamber a fraction of the particles are removed.

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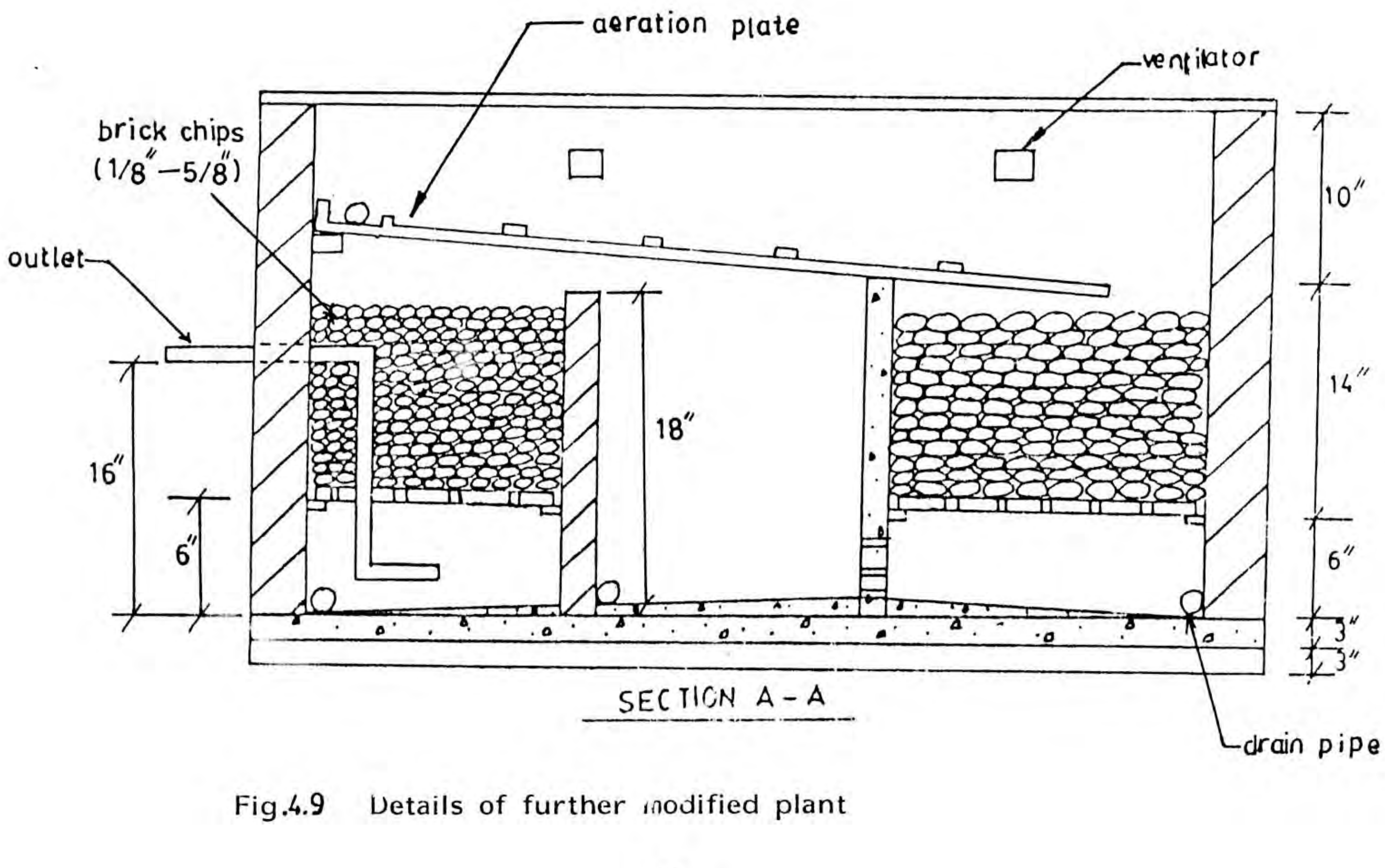



SECTION A - A

Fig.4.9 Details of further modified plant

Plate 4.3 Top view of the further modified plant.

Plate 4.4 Side view of further modified plant

After sedimentation water passes over the partition wall and down through the filter where the rest of the iron flocs are removed.

After passing through the filter the treated water is delivered through the delivery pipe. The flow diagram of the further modified plant is shown in Fig. 4.10.

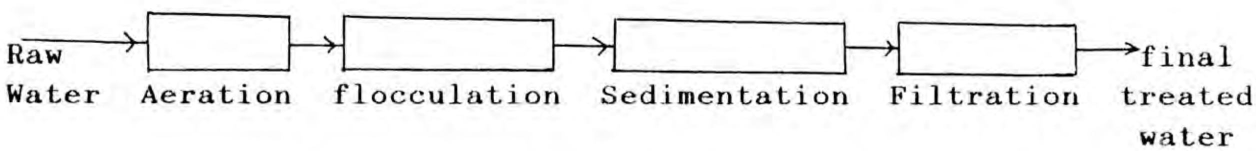



Fig. 4.10 : Flow diagram of further modified plant.

4.11. <u>Method of sample collection</u>

The samples were collected form 4 points these are -

1. Raw water
2. effluent after flocculation chamber
3. effluent after sedimentation chamber
4. Final treated water from IRP.

The samples were collected in a clean plastic Jar with cover. The samples were collected every day and tested in the laboratory. Fig. 4.11 shows the sampling points on the flow diagram.

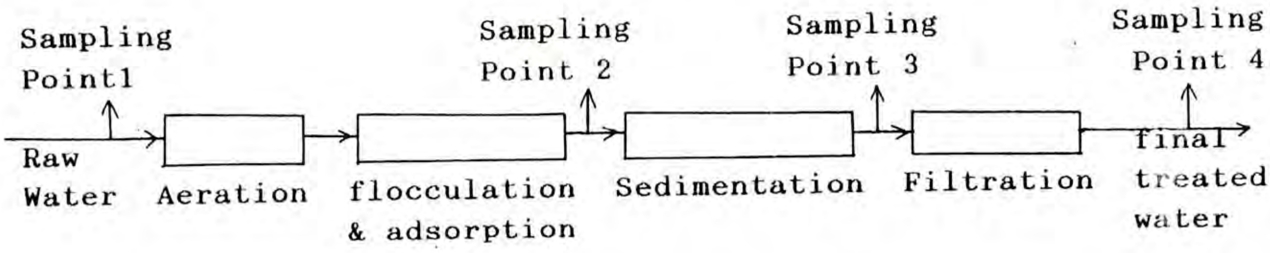



Fig. 4.11 Sampling Points on the flow diagram of further modified plant.

## 4.12 Performance of the further modified plant and its filter run

Table 4.4 shows the iron concentration of samples at various stages. Initially the iron concentration was high. Then it gradually decreased with time. On the 7th day iron concentration decreased from 19 ppm to .1 ppm and percent removal was 99.41%. The iron concentration after flocculation varies from 3.9 to 7.2. Iron concentration after sedimentation varies from 1.6 to 3.2 where the iron concentration of effluent water varies from .1 to 1.2. About 75% of iron were removed in the flocculation and adsorption process and 10% to 12% iron were removed in the sedimentation process and another 10 to 12% were removed in the filtration process.

The filter run was considered as the time when the yield capacity becomes less then 6 l/min. The filter run of the plant was 24 days. The data of Table 4.4 is plotted on a plain graph paper (Fig. 4.12).

After cleaning again water samples were collected at different points. The iron concentration at different points after cleaning has been enumerated in the Table 4.5. The iron concentration after flocculation varies from 3.7 to 6.3. Iron concentration after sedimentation varies from 1.4 to 3.1 where effluent water iron concentration varies from .1 to 1.1. The minimum concentration was found on the 6th day and the percent removal was 99.41%. Then again water quality started to deteriorate. The filter run after cleaning was 22 days.

The data of Table 4.5 is plotted on a plain graph paper(Fig.4.13).

Table 4.4 Performance of the further modified plant before cleaning.

| Days | Initial concentration ppm | Iron concentration after flocculation ppm | Iron concn. after sedimentation. ppm | Iron concentration of final effluent | max. % removal |
|---|---|---|---|---|---|
| 1 | 19 | 7.2 | 3.2 | 1.2 | |
| 2 | 19 | 6.4 | 2.6 | .9 | |
| 3 | 17 | 5.7 | 2.2 | .7 | |
| 4 | 19 | 5.1 | 2.0 | .5 | |
| 5 | 19 | 4.4 | 1.7 | .3 | |
| 6 | 19 | 4.1 | 1.6 | .2 | |
| 7 | 19 | 3.9 | 1.6 | .10 | 99.41 |
| 8 | 19 | 4.2 | 1.7 | .11 | |
| 9 | 19 | 4.6 | 1.8 | .3 | |
| 10 | 18 | 5.3 | 2.1 | .5 | |
| 11 | 19 | 6.1 | 3.0 | 1.0 | |
| 12 | 19 | - | - | 1.1 | |
| 13 | 19 | - | - | 1.1 | |
| 14 | 19 | - | - | 1.2 | |
| 15 | 19 | - | - | 1.25 | |
| 16 | 19 | - | - | 1.3 | |
| 17 | 19 | - | - | 1.5 | |
| 18 | 19 | - | - | 1.7 | |
| 19 | 19 | - | - | 1.8 | |
| 20 | 19 | - | - | 1.9 | |
| 21 | 19 | - | - | 2.1 | |

Table 4.5 Performance of the further modified plant after cleaning.

| Days | Initial concentration ppm | Iron concentration after flocculation ppm | Iron concn. after sedimentation. ppm | Iron concentration of final effluent | max. % removal |
|---|---|---|---|---|---|
| 1 | 19 | 6.3 | 3.1 | 1.1 | |
| 2 | 19 | 5.6 | 2.7 | .9 | |
| 3 | 18 | 4.9 | 2.2 | .5 | |
| 4 | 19 | 4.2 | 1.8 | .3 | |
| 5 | 19 | 3.9 | 1.6 | .1 | |
| 6 | 19 | 3.7 | 1.4 | .1 | 99.41 |
| 7 | 19 | 3.8 | 1.5 | .2 | |
| 8 | 19 | 3.9 | 1.7 | .3 | |
| 9 | 19 | 4.1 | 1.9 | .4 | |
| 10 | 20 | 4.5 | 2.4 | .5 | |
| 11 | 19 | 5.4 | 3.4 | .8 | |
| 12 | 19 | – | – | .9 | |
| 13 | 19 | – | – | 1.1 | |
| 14 | 19 | – | – | 1.2 | |
| 15 | 19 | – | – | 1.25 | |
| 16 | 19 | – | – | 1.3 | |
| 17 | 19 | – | – | 1.4 | |
| 18 | 19 | – | – | 1.6 | |
| 19 | 19 | – | – | 1.8 | |
| 20 | 19 | – | – | 1.9 | |
| 21 | 19 | – | – | 2.0 | |
| 22 | 19 | – | – | 2.1 | |

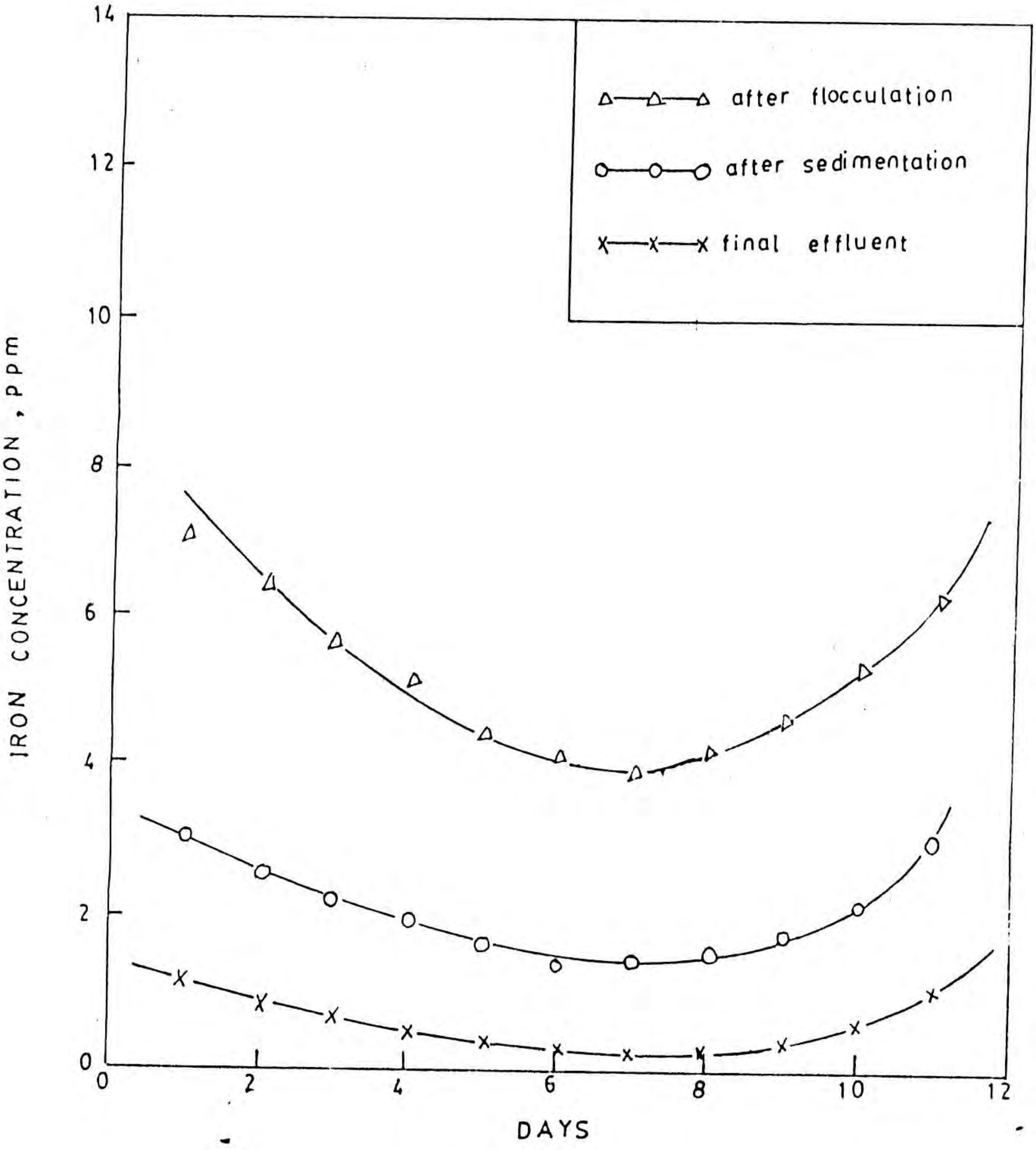



Fig. 4.12 Variation of iron concentration with time of further modified plant before cleaning.

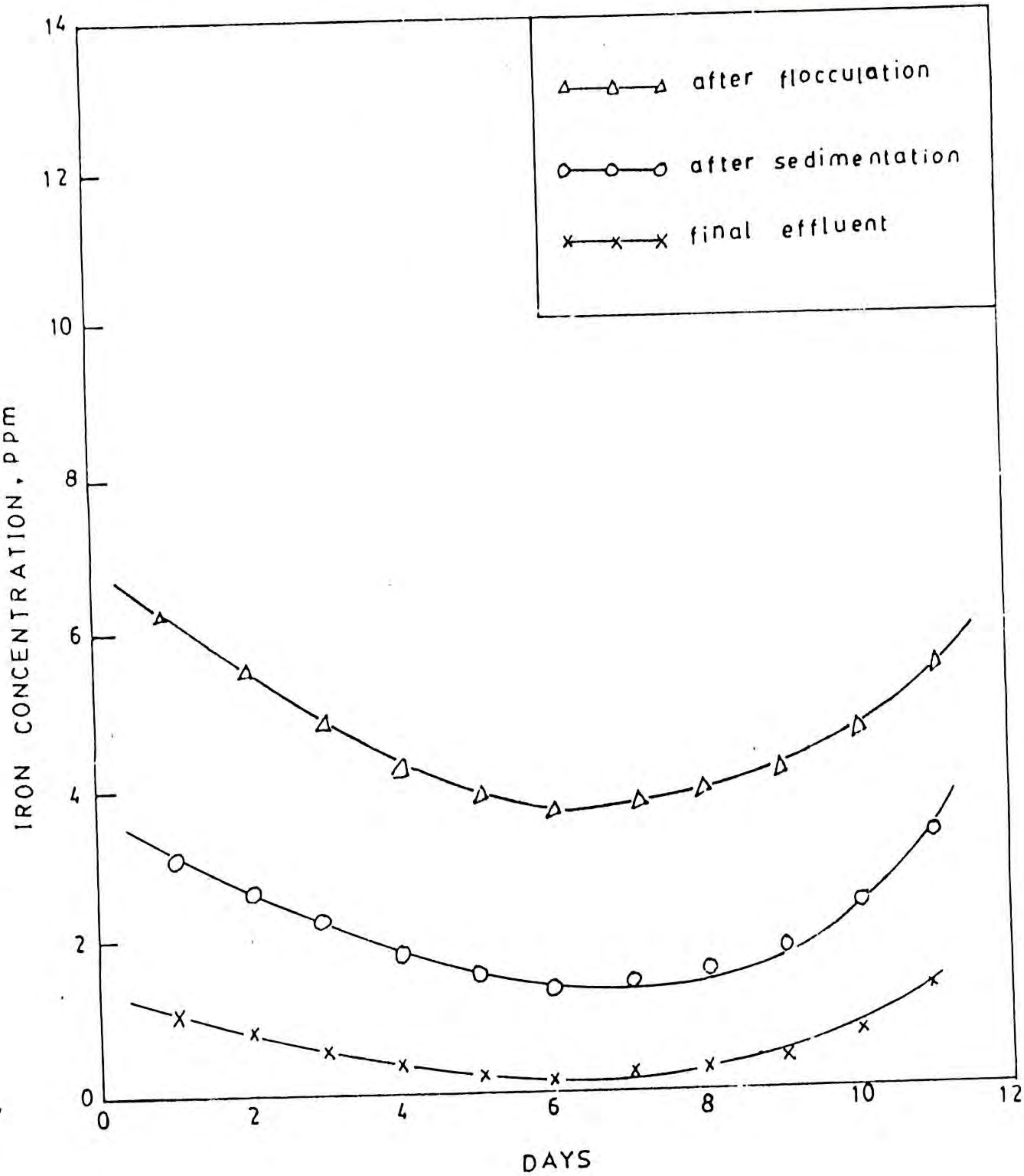



Fig. 4.13 Variation of iron concentration with time of further modified plant after cleaning.

Plate 4.5 Operation of further modified plant.

Plate 4.6 Raw water flowsover the aeration plate

## 4.13 Yield Capacity of further modified plant

The yield capacity of the further modified plant and the tube well was measured. To determine the yield capacity of the tube well, it was pumped at uniform rate. The discharge through the spout per minute (14.55 l/min) represents the yield capacity of the tubewell. To determine the yield capacity of the further modified plant, tube-well was pumped at uniform rate. The water level in the filtration chamber started to rise. Water discharged through the delivery pipe due to this head. Tube-well was pumped at such a rate that the head remains constant (3.2 inch). The discharge through the delivery pipe per minute was measured. This discharge per minute (10.20 l/min) represents the yield capacity of the further modified plant. Therefore the percent yield loss is 29.89% with respect to the tubewell yield. The yield capacity was measured on alternate days. Table 4.6 shows the yield capacity at different time. The data of Table 4.6 are plotted on a plain graph paper (Fig. 4.14). The plotted curve is a straight line. Which means there are perfect correlation between the yield capacity and days. Calculation of Appendix F shows that the equation of the straight line is,

$$y = - .2142x + 10.6.$$

where, $y$ = yield capacity, in l/min

and $x$ = days after operation of IRP

Table 4.6 : Yield capacity of the further modified plant.

| Days | Yield capacity l/min |
|---|---|
| 2 | 10.20 |
| 4 | 9.75 |
| 6 | 9.35 |
| 8 | 8.90 |
| 10 | 8.50 |

To determine the yield capacity of the further modified plant under falling head tubewell was pumped at uniform rate. The water level in the filtration chamber started to rise. Tubewell was pumped at such a rate that the head remains constant (3.2 inch). Then tubewell pumping was stopped and the discharge through the delivery pipe per minute under falling head was measured. This discharge per minute represents the yield capacity of the further modified plant under falling head. The yield capacity under falling head was measured for 11 minutes. Table 4.7 shows the variation of yield capacity under falling head with time. The data of Table 4.7 is plotted on a plain graph paper (Fig. 4.15). A total of 74.25 l water was discharged during the period of 11 minutes. So the average yield capacity under falling head was found 6.75 l/min.

Table : 4.7 Variation of yield capacity under falling head with time.

| Time,min | Yield capacity l/min |
|---|---|
| 1 | 10.45 |
| 2 | 10.20 |
| 3 | 10.00 |
| 4 | 9.40 |
| 5 | 8.60 |
| 6 | 7.50 |
| 7 | 6.50 |
| 8 | 5.20 |
| 9 | 3.80 |
| 10 | 2.20 |
| 11 | 0.40 |

## 4.14 Water quality parameters.

The other water quality parameters like pH, oxygen concentration and $Co_2$ concentration were also measured in the laboratory. The samples were collected from inlet after aeration and outlet. The results has been enumerated in the Table 4.8. It is observed that due to aeration $Co_2$ concentration was reduced from 121 ppm to 27 ppm. But pH increased from 6.3 to 7.1 and oxygen concentration increased from .1 ppm to 3.9 ppm.

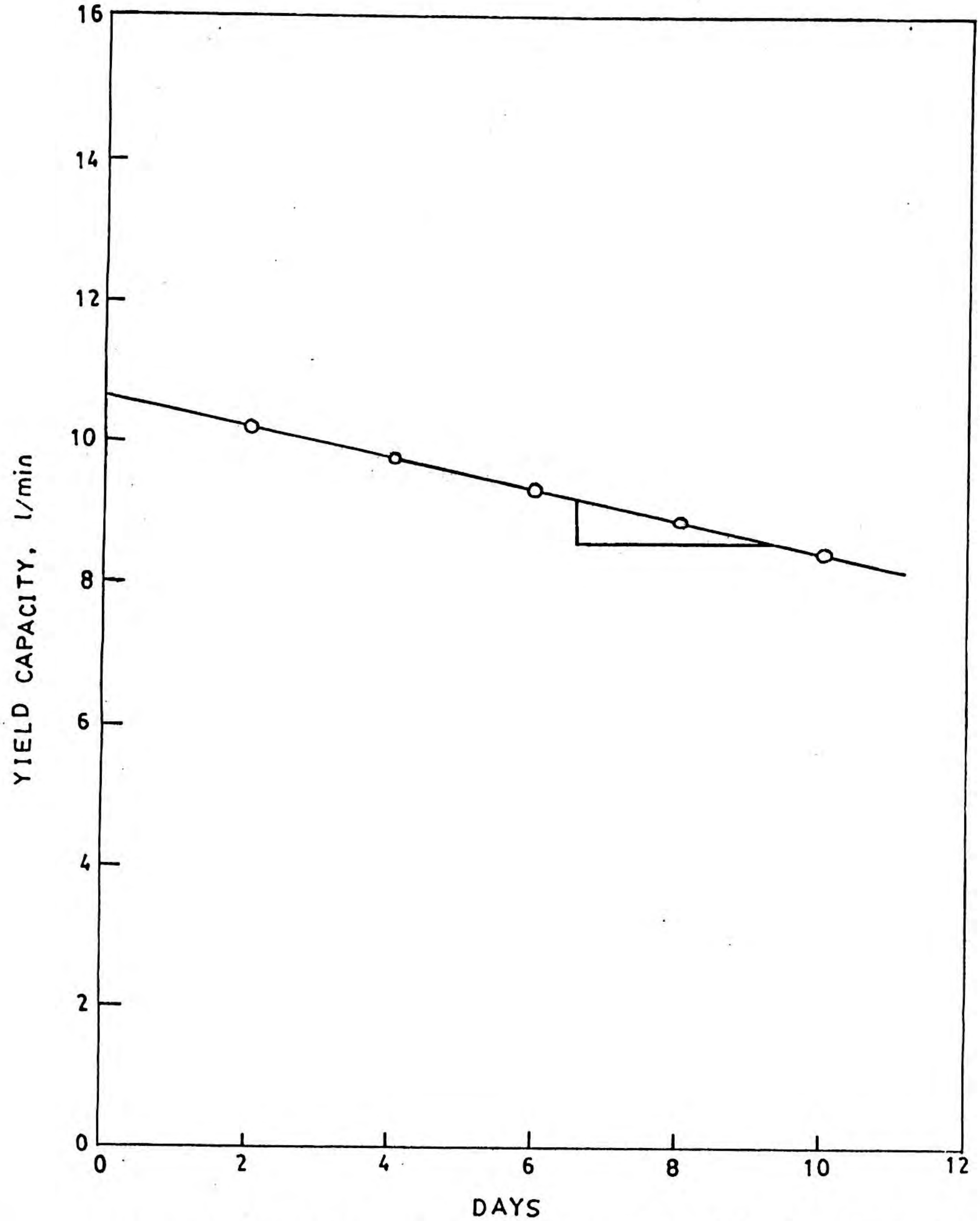



Fig. 4.14 Variation of yield capacity with time of further modified plant.

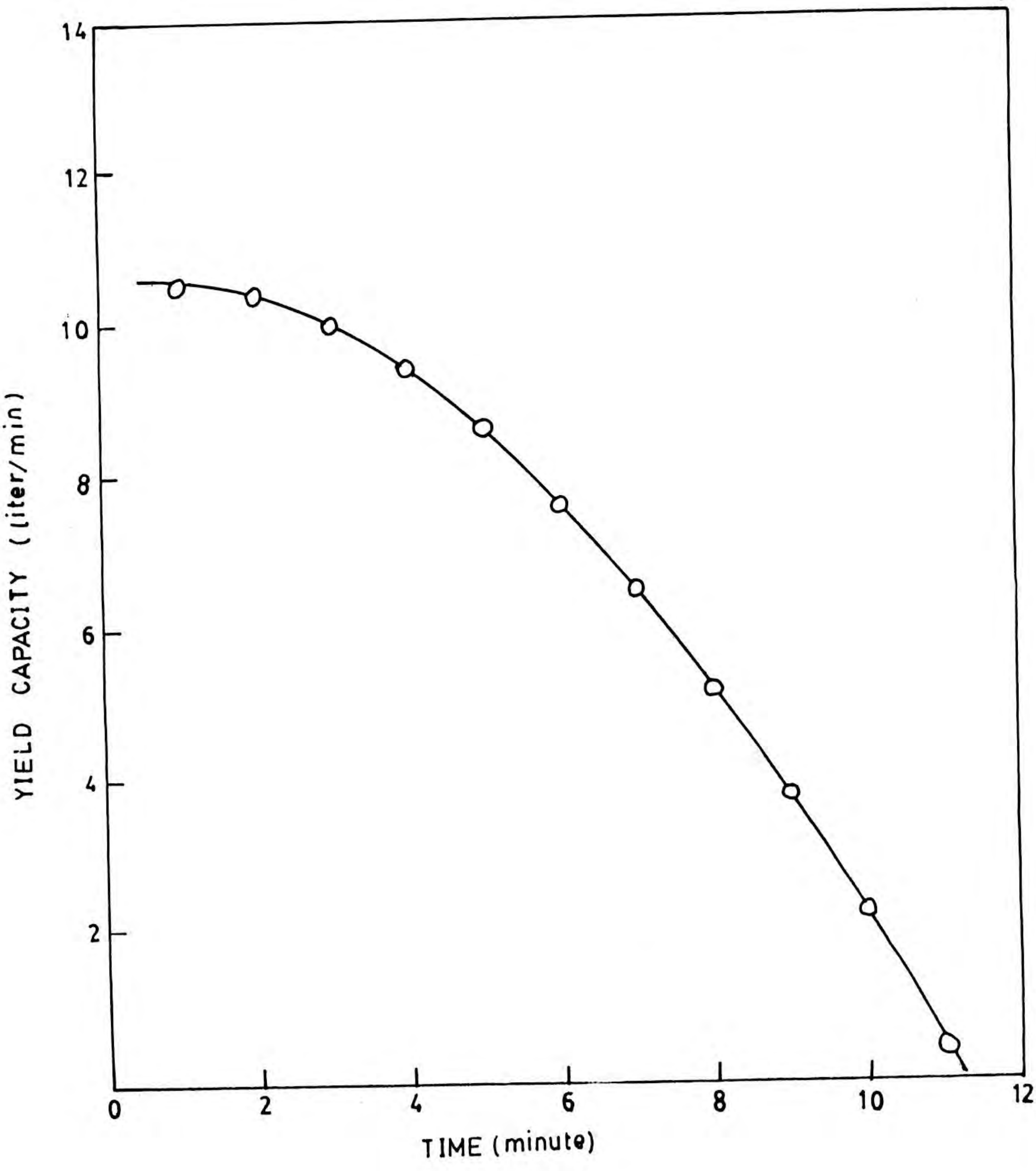



FIG.4.15. Variation of yield capacity with time of further modified plant under falling head.

Table 4.8 : Other water quality parameters of further modified plant (tested in the laboratory).

| Sampling points | pH | $O_2$ concentration ppm | $Co_2$ concn. ppm. |
|---|---|---|---|
| inlet | 6.3 | .1 | 121 |
| after aeration | - | 3.9 | - |
| Out let | 7.1 | | 27 |

4.15 <u>Field Survey</u>

A survey was carried out among the households who live near the further modified plant and regularly use water from IRP. The results of the survey have been listed in the Tables 4.8 and 4.9. A total of 41 people were interviewed out of which 27 people use water for all purposes and 8 people use water only for drinking purpose (Table 4.9). The survey shows that 100% peoples are satisfied with the effluent water quality, 65.85% people are satisfied with yield and about 80.48% people are interested to clean the IRP regularly (Table 4.10).

Table - 4.9 Use of water for different purpose (Field Survey)

| No. of beneficiaries interviewed | No.of people use water for | | |
|---|---|---|---|
| | All purpose | Only drinking | Drinking & |
| 41 | 27 (65.85%) | 8 (19.51%) | 6 (14.63%) |

Table 4.10 Beneficiaries opinion toward the further modified plant (field survey).

| No.of beneficiaries interviewed | Satisfied with yield | | Satisfied with effluent water quality | | interested to clean the IRP | |
|---|---|---|---|---|---|---|
| | Yes | No | Yes | No | Yes | No |
| 41 | 27 (65.85%) | 14 (34.15%) | 41 (100%) | 0 | 33 (80.48) | 8 (19.52%) |

4.16 <u>Estimated cost of the further modified plant.</u>

The further modified plant was built at Kalampur near Dhamrai. The major materials were purchased form the local market but some items which were not available in the local market, were purchased from Dhaka. The cost of different materials purchased for one iron removal plant are listed in Table 4.11.

Table 4.11 : Estimated cost of further modified plant

| Item | Amount | Rate | Cost |
|---|---|---|---|
| Brick | 600 Nos. | Tk. 2200 /1000 | Tk. 1220 |
| Cement | 4 bags | Tk. 210/bag | Tk. 840 |
| Sand | 25 cft | Tk. 400/100 cft | Tk. 100 |
| Khoa making | 12 cft | Tk. 6/cft | Tk. 72 |
| Pudlo | 1 kg | Tk. 45/kg | Tk. 45 |
| Wire mesh | 40 sq.ft. | Tk. 5/sq.ft. | Tk. 200 |
| 3/4" pvc pipe (back wash pipe) | 4 ft | Tk. 2/ft | Tk. 8 |
| 3/2" pvc pipe (drain pipe) | 3 ft. | Tk. 8/ft | Tk. 24 |
| pvc cap | 3 Nos. | Tk. 5/cap | Tk. 15 |
| 3/4"gate bulb | 1 No. | Tk. 80 | Tk. 80 |
| Net | 1 sq. ft. | Tk. 8/sq. ft. | Tk. 8 |
| 1/4" rubber tube | 5 ft. | Tk. 3/ft | Tk. 15 |
| 3" Hose pipe | 3 ft. | Tk. 35/ft | Tk. 105 |
| 5/2" clip | 1 Nos. | Tk. 25 | Tk. 25 |
| Polythin | 30 sq.ft. | Tk. 1/3 sq. ft. | Tk. 10 |
| Mason | 3 x 1 | Tk. 100 | Tk. 300 |
| Labour charge | 3 x 1 | Tk. 60 | Tk. 180 |
| Material transportation cost. | | - | Tk. 400 |
| Total cost | | | Tk.3,767 |

The Overall cost of the further modified plant was found to be Tk. 3767. Since most of the materials were purchased from the local market, the over all cost was higher. If IRP is constructed on large scale; bulk amount of materials is to be purchased and the total cost would be much less.

@

# CHAPTER 5

# COMPARISON AND DISCUSSION

## 5.1 Comparison between the existing plant and further modified plant

The Performance of the existing plant and the further modified plant is compared in tabular form in Table 5.1.

As the level of iron concentration, socio-economy, tradition, technology, hygiene education, alternative source of water etc. vary from area to area, the results of the survey can not be directly compared.

Table 5.1 Comparison between the existing plant and further modified plant.

| Performance | Existing plant | Further modified plant |
|---|---|---|
| Avg iron concentration | 15.2 ppm | 19 ppm |
| Maximum Iron removal efficiency | 90.66% | 99.41% |
| Yield capacity | 13.15 l/min | 10.20 l/min |
| % yield loss | 24.20% | 29.89% |
| Filter run | 12 days | 24 days |
| Avg no.of users | 77 | 75 |
| Beneficiaries acceptance (Satisfied with yield Capacity) | 35.48% | 65.85% |
| Beneficiaries use water for all purpose | 28.3% | 65.85% |
| Beneficiaries perticipate in cleaning | 19.35% | 80.48% |
| Internal dimension | 88" x 33" x 38" | 58" x 33" x 36" |
| Estimated cost | Tk.3918 | Tk.3767 |

Table 5.1 shows that although the yield capacity of the existing plant is greater then that of the further modified plant, the beneficiaries are more satisfied with the yield capacity of the further modified plant. This is due to the differences of the socio-economy,tradition, alternative source of water between the two areas.

## 5.2 Discussion :

High iron content in ground water indirectly affects the health of a vast majority of the rural population in many developing countries where installation of pipe water supply or sophisticated treatment plant is not feasible or practicable for various socio-economic reasons. In developed countries industrial processes and water supply systems are greatly affected for the presence of iron in water and both conventional and sophisticated iron removal techniques are in use. However little effort has been made to develop appropriate technology for small communities in developing countries.

Relevant literature on chemistry of iron content water, theories and practice of iron removal techniques and water use pattern in iron problem areas have been reviewed in chapters 1 and 2. Some field data have been obtained through the WHO officials and previous field experiences have been utilised for the development of the modified plant.

The improved iron removal plants installation began in 1987-88 in

Sirajgonj and Pabna district. As mentioned earlier the main objective of this study is to investigate the iron removal efficiency of the existing improved iron removal plants, to investigate the operational and maintenance difficulties of the existing plants and to develop a modified iron removal plant.

In the existing plants aeration is done by means of a perforated rectangular channel, which is very narrow and produced thick film of water. Since the detention time is short and renewal of air exposed interfacial area is not effective, efficient aeration is not done. In the existing plant the dissolved oxygen concentration after aeration increased from .1 ppm to 2.1 ppm. In the further modified plant, a wide aeration plate which produces thin film of water was used. There are undulation on the aeration plate and renewal of interfacial area is effective. The dissolved oxygen concentration increased from .1 to 3.9 ppm in the further modified plant. So the aeration plate of the further modified plant is more effective in aerating water than perforated aeration channel of the existing plant.

Although the existing plant consists of a large sedimentation basin, iron precipitates, which are very small in size can not be settled during its detention time which is ultimately deposited on the coarse media in the following chamber, causing a rapid clogging of pores. As the pores of the filter material are clogged very rapidly, the plants are required to be cleaned very frequently (12 days interval). So a flocculation chamber was used in the modified plant prior to sedimentation.

The survey conducted by WHO in Sirajgonj shows that the iron removal efficiency of the existing plant is 90.66% where as the iron removal efficiency of the further modified plant was found 99.41%. So further modified plant is obviously more effective in removing iron from ground water.

The yield of IRP is an important consideration. It has been found that immediately after operation the yield was high. Then it gradually decreases with time. This may be due to the fact that as the particles clog the interstices in the filter material there would be some increase in head losses. The yield of the existing plant was 13.15 l/min where that of the further modified plant was 10.20l/min. So the yield of further modified plant is 22.43% less then that of the existing plant. This is due to the greater head loss in the further modified plant. The average yield capacity of the further modified plant under falling head was found 6.75 l/min. It is 52.35% of the yield capacity of the further modified plant under constant head.

The filter run of the existing and the further modified plant was taken as the time after operation, when the yield capacity of the plants become less then 6 l/min. In fact there are no standard method to determine the filter run of iron removal plants. So to compare the performance of the two plants, this method of computing filter run was used.

One of the main objectives to develop the modified plant was to increase the filter run. The filter run of the existing plants was found 12 days where the filter run of the further modified plant was 24 days. Therefore the further modified plant is to be cleaned less frequently.

On aeration the water becomes cloudy with finer suspended flocs of iron and the flocs accumulate on the bed of settling chamber and on the brick chips. After the cleaning of the plant, removal of iron from treated water for a day or so has been noted to be low, as indicted by the cloudy water. This is because, the particles are removed in the coarse media flocculator by adsorption. But immediately after cleaning the adsorption is not very effective as the pores in the interstices of the coarse media are open.

Gas transfer equations indicate that oxygen transfer can be optimized by generating the largest practicable air/water interface, including a long exposure time and preventing the build up of thick interfacial films. It was observed that allowing iron content water to flow over stone chips and undulations on a slightly inclined slope is a simple technique for aeration particularly where there is a limitation of available head and space. Coke is sometimes used in perforated trays, but use of stone chips has not been reported on an inclined plane. This technique provides a larger area of air/water interface due to additional surface area of stone chip longer exposure time due to obstacles on the flow path, finer dispersion and continuous renewal of interface during the flow of water around stone chips. Laboratory results show that the aeration plate used in the further modified plant results in an increase of 3.8 mg/l of dissolved oxygen. Further oxygen transfer also takes place in the subsequent treatment processes.

It was observed that use of stone chips in aeration process also assists in the flocculation of some of the precipitated iron particles. These flocculated iron particles settle or adsorb on the surface of stone chips, resulting in some iron removal in the aeration process directly. This depends on the rate of flow of water, size and quantity of stone chips.

Field survey among the households near the existing plant and the modified plant has shown that 65.85% households at the modified plant are satisfied with yield where only 35.48% households at the existing plant are satisfied with yield. So the modified plant is more acceptable among the beneficiaries as far as yield is concerned.

Only 28.3% households use water for all purpose in the existing plant where 65.85% households use water for all purpose in the modified plant. So the modified plant is more acceptable among the house holds.

Field data indicates that the average soluble iron content of ground water is around 19 ppm. Carbon dioxide concentration is also high (117 ppm) and alkalinity is 207 ppm in the raw water. Theoretically this types of water can easily be oxidized and precipitated and the pH value can be raised above 7.0 without using any chemicals through simple aeration. Less than 2 mg/l of dissolved oxygen is required to oxidize all soluble iron.

Field investigation of the existing plants at Sirajgonj shows that some of the IRPs contain frogs, fishes and different water born insects. This is due to the ignorance of the beneficiaries about its ill effects. The further modified plant is free from water born insects. Field investigation also shows that the peoples attitude toward the IRPs is quite satisfactory. They are satisfied with the effluent iron concentration although some of them complained about its low yield.

Though all the interviewed beneficiaries admitted that IRP treated water is better, its use had not been encouraging. The users do not hesitate to take the fresh water with invisible dissolved iron from hand pump spout.

The estimated cost of the existing plant was found Tk. 3918 where as the cost of the further modified plant was Tk. 3767. The cost of the existing plant was fixed on the basis of the present market price. So the further modified plant is slightly (Tk. 151) cheaper than the existing plant.

# CHAPTER 6

# CONCLUSION AND RECOMMENDATIONS

## 6.1 Conclusion

The following conclusions are drawn on the basis of results obtained from field investigation.

(i) The iron removal efficiency of the finally modified plant (99.41%) is higher than the iron removal efficiency of the existing plant (90.66%).

(ii) The filter run of the existing plant (12 days) is less than that of the further modified plant (24 days). So finally modified plant is to be cleaned less frequently.

(iii) The yield capacity of the existing plant (13.15 l/min) is higher than the yield capacity of the finally modified plant (10.20 l/min).

(iv) The aeration plate of the finally modified plant is more effective in aerating water than the perforated aeration channel of the existing plant.

(v) The coarse media flocculator is very effective in removing iron from ground water. About 75% iron are removed in flocculation and adsorption process.

(vi) The finally modified plant is more acceptable among the beneficiaries than the existing plant.

## 6.2 Recommendations

1. The flow rate in the delivery pipe of the improved IRP needs to be raised to approach that of the flow from hand pump spout. The design of the filter media should be such that the head loss in the IRP is minimum.

2. The design of partition wall, filter media and delivery pipe should be such that with the pumping the tubewell, water comes out without any delay.

3. For successful implementation of the IRPs in all the iron problem areas, Sample of IRPs so far built in different regions should be studied to develop a sound methodology for wider coverage.

4. The IRP design should offer sufficient flexibility in getting raw water direct from hand pump spout as well, iron free water for bathing and washing clothes and utensils and potable water after treatment.

5. The demonstration IRP plants should be built in areas of high iron content. NGO's and private agencies may be involved in their promotion and introduction.

6. It is recommended that an attempt should be made to determine the optimum size of the coarse media used in the flocculation and filtration chamber which would produce maximum iron removal efficiency. The optimum size and number of the stone chips used on the aeration plate of the further modified plant should also be determined.

7. The precast members, i.e. the aeration plate, cover slab should be light so that it can be easily removed during cleaning of IRP.

8. To keep the water cool the plant should be located as to avoid direct sunshine.

# APPENDIX

Appendix - A

Table 1 : Water Sources used by the household (percent) for various domestic purposes in iron problem areas(22).

| Purpose of uses | tubewell | Ring well | Pond | River |
|---|---|---|---|---|
| Drinking | 99.5 | .5 | - | - |
| Cooking | 8 | 1 | 22 | 69 |
| Washing cloths | 4 | 2 | 20 | 76 |
| Washing utensils | 19 | 1 | 22 | 80 |
| For cattle | 4 | - | 18 | 10 |
| Sanitary purposes | 17 | 1 | 20 | 68 |

Table-2 Reasons (%) for usage of tubewell water in iron problem areas (22).

| Aesthetic colour | Strain of cloths and utensils | Odour | Taste | Causes constipation |
|---|---|---|---|---|
| 90 | 68 | 28 | 38 | 1 |

## Appendix -B

Table 1 : Hand pump with iron removal unit cost estimates (23).

| Population | Design flow $m^3/d$ | Capital cost | | Operation & maint. cost | |
|---|---|---|---|---|---|
| | | Total cost Rs/day | Total Cost $Rs/m^3$ | Total Cost Rs/day | Total cost $Rs/m^3$ |
| 250 | 10 | 17000 | 1700 | 61.60 | 6.16 |
| 500 | 20 | 197000 | 9850 | 81.60 | 4.10 |
| 1000 | 40 | 220000 | 5500 | 112.00 | 2.30 |

Table-2 : Continuous iron removal system for community water supply cost estimation for iron removal unit (23).

| Design flow $m^3/h$ | Capital cost | | Operation & maintenance cost | |
|---|---|---|---|---|
| | Total cost Rs/day | Total cost $Rs/m^3$ | Total cost Rs/day | Total cost $Rs/m^3$ |
| 5 | 95000 | 792 | 235.60 | 2.35 |
| 10 | 133000 | 554 | 397.00 | 1.65 |
| 20 | 215000 | 448 | 608.00 | 1.26 |

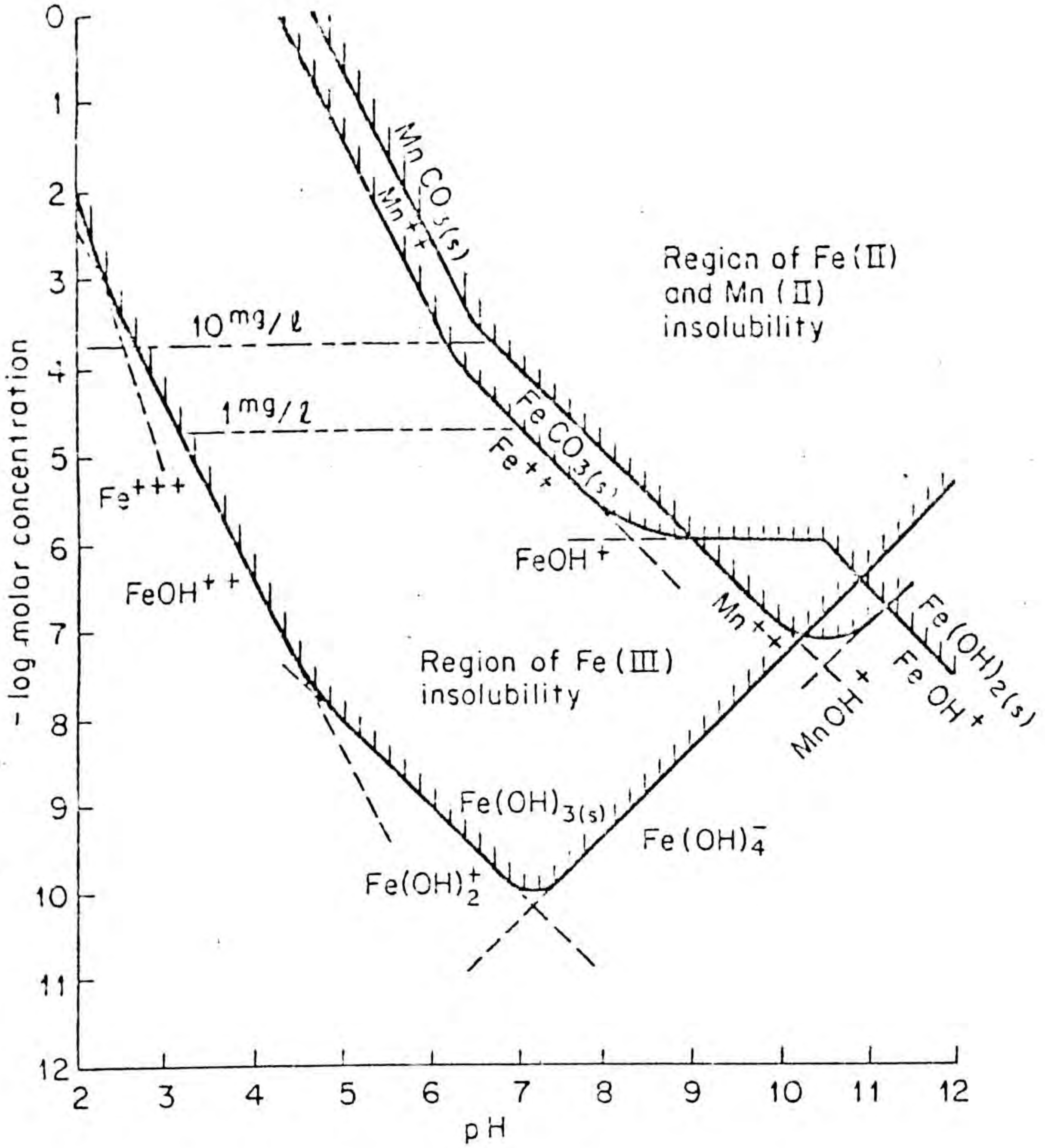
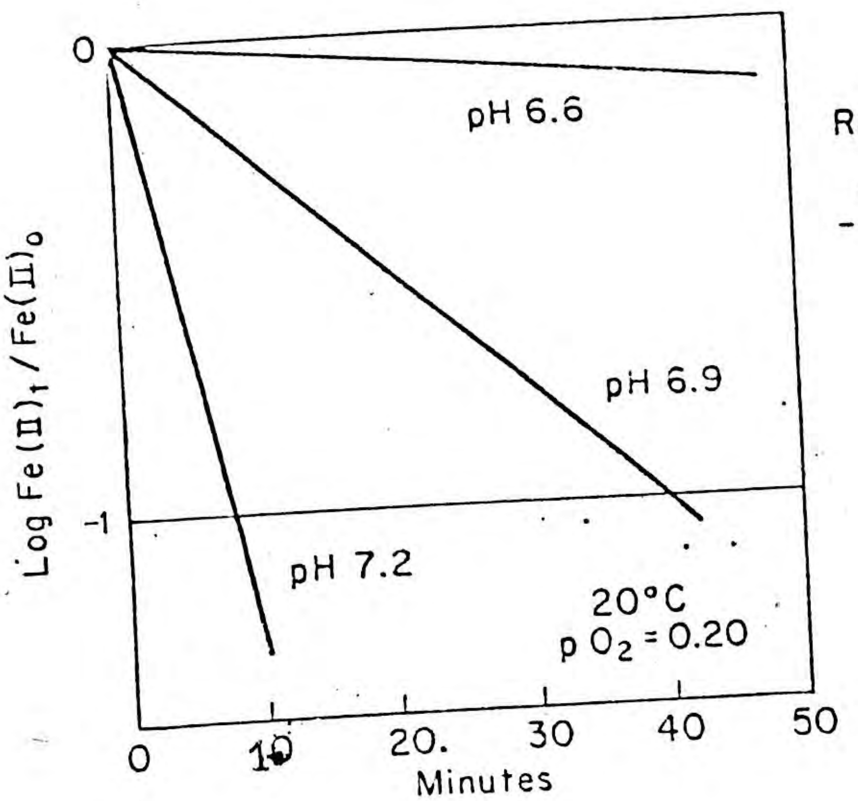



FIG. Solubility of Fe(II), Mn(II) and Fe(III) in Carbonate Bearing water. (17)




Rate law for Fe(II) oxygenation:

$$-\frac{d[Fe(II)]}{dt} = k[Fe(II)][O_2][OH^-]^2$$

FIG. Oxygenation of Fe (II) (17)

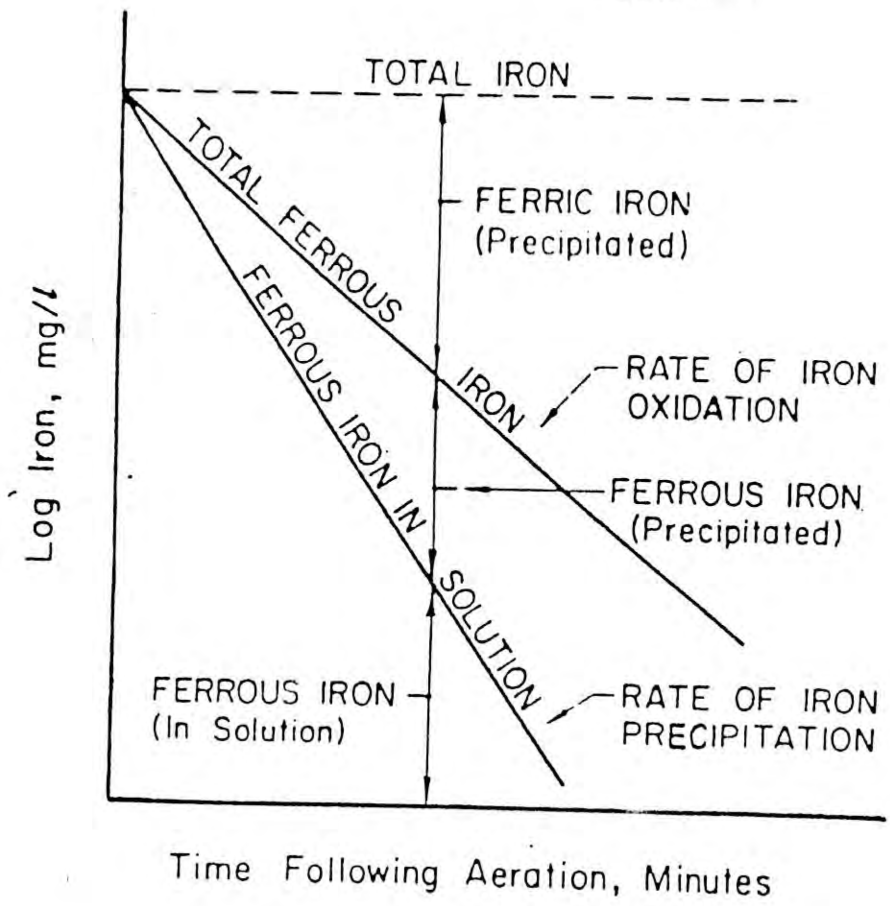



FIGURE RATE OF IRON OXIDATION AND RATE OF IRON PRECIPITATION (31)

# Appendix - F

Calculation of the equation of the straight line of Fig. 4.14.

The equation of the straight line is, $y = mx + c$

From graph, $c = 10.6$

Taking any two points on the graph,

$$\text{slope of the line, } m = \frac{y_2 - y_1}{x_2 - x_1}$$

$$= \frac{8.6 - 9.2}{9.4 - 6.6}$$

$$= -.2142$$

There fore the equation of the straight line is,

$$y = -.2142x + 10.6$$

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