

**SUBSURFACE AERATION OF GROUND WATER
FOR THE DEVELOPMENT OF
LOW COST IRON REMOVAL DEVICE.**

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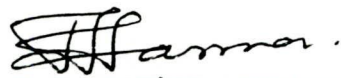
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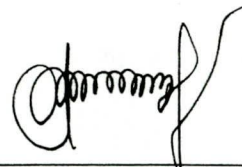
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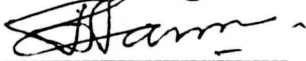
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ABSTRACT

The relative purity and abundance of ground water increase its usage. In some places the iron content in ground water is so high that this metal must be removed before water can be used for drinking or industrial purposes. Iron occurs in two states of oxidation in nature- the ferrous (divalent) and ferric (trivalent) forms.

The subsurface aeration technology developed oxidizes the ferrous ion, which is soluble in water, to the ferric ion, which is insoluble before it comes to the treatment unit for further action and separation. This method achieves a high degree of oxidation in the ground water during its lifting. An airlift pump is employed in the tube well instead of turbine or submersible pumps. Air is forced down into the well under water and an air-water mixture is built up which has a lower density and thus come out of the well. The mixture obviously becomes enriched with oxygen.

The air compressor used in an air lift pump serves at least four purposes- lifting of water; aeration of water; regeneration of encrusted tube well and frequent cleaning of iron sludge from the interstices of the coarse media flocculator in the flocculation chamber. The encrustation of tube well strainer develops higher draw down, causes failure of shallow tube well and hand pump tube well. The regeneration is necessary for the encrusted tube wells for ensuring required discharge resulting energy saving- thus the operating cost. On the other hand regeneration of flocculators increases the efficiency of the coarse media bed.

The unit cost of production of treated water in the subsurface aeration technology has been found to be Tk.1.20/ m^3 while those of DPHE urban water supply is Tk. 1.81/ m^3 , calculated assuming 15% discount factor, in areas where ground water has higher Iron content ($Fe > 5ppm$).

The dose of sodium Hexa-metaphosphate for the regeneration iron encrusted tube well has been calculated and has been found to be suitable for the use in regeneration work supported by air surging from the air compressor.

The process of precipitation of iron in the aquifer has only a slight affect on aquifer permeability. The clogging of aquifer surrounding the well will not occur for a period many times longer than the life span of a typical well.

CHAPTER: I.

INTRODUCTION



1.0.0. General

Water is absolutely essential to both animal and plant life. A supply of water is one of the basic requirements of every human community. A primary requisite for good health is an adequate supply of water that is of satisfactory sanitary quality. It is difficult to imagine any clean and sanitary environment without water. Invariably, the progress of sanitation throughout the world has been closely associated with the availability of water; and the larger the quantity and the better the quality of the water, the more rapid and extensive has been the advance of public health.

While man has always recognized the importance of water for his internal bodily needs, his recognition of its importance to health is a more recent development, dating back only a century or so. Since that time, much has been learned about the role of inadequate and contaminated water supplies in the spread of water borne diseases. Communicable diseases that may be transmitted by water include bacterial, viral and protozoan infections. The bacterial diseases include typhoid, para-typhoid, salmonellosis, shigellosis, Asiatic cholera, bacillary dysentery, legionnaires disease, Pontiac fever (Linden, E., Witherall et al., 1988). Viral disease associated with water includes hepatitis, poliomyelitis, and those cases of gastroenteritis attributable to Norwalk virus and rotavirus (Fred, P., Williams and Elmer W. Akin, 1986). Protozoan such as Giardia and cryptosporidium can produce gastroenteritis and are very resistant to disinfectants (Joan, B. Rose, 1988).

The interaction between water and spread of diseases has been recognized by various public health organizations in developing countries. Approximately 80 percent of all sickness and diseases can be attributed to inadequate water supply or sanitation. Diarrhoeal diseases kill six million children in developing countries every year and affect death of up to 18 million people. World Health Organization (WHO 1977) estimates that about 25,000 people a day die from water-related diseases.

On global basis approximately three out of five persons in developing countries have no access to safe drinking water. In urban areas, 75 percent of the population have some form of water supply on the other hand in the rural areas only 29 per cent have access to safe water.

1.1.0. Water Resources and Problem on Potable Water Usage in Bangladesh

Bangladesh, the 144,000 sq. km delta in the Bay of Bengal, is inhabited by about 110 million people who are mostly illiterate and are among the lowest per capita income generating group of the world. Rivers, ponds, canals, ditches, etc. have been the sources of domestic water for ages. In comparison to existing tube wells extracting ground water, often these surface water sources have been more convenient, easily accessible, socio-economically and culturally preferable, and abundantly available to the majority of the population.

But the practices of indiscriminate defecation and disposal of raw sewage into these surface water bodies have created an environment which is heavily polluted and is of major concern because it has every potentiality to serve as reservoir or carrier of pathogens of water related diseases (Hedayetullah, M, Islam, R., 1985). Only 50 percent of rural and 80 percent of urban population of Bangladesh have reasonable water supply (Rashid, Rahman and Turnquest 1994).

It is important that the water available is attractive and palatable to induce it's use; otherwise the consumers may be inclined to use water of doubtful quality from unprotected stream, well or spring. Water from these sources is dangerously contaminated because of poor sanitary condition. It is found that 10% of the children within 10 years of age are partially disabled either mentally or physically due to attacks of various water borne diseases. It is also estimated by 'WHO' that more than 50% of cases of mortality among infants in the country are due to diarrhoeal diseases (UNICEF and WHO 1977).

1.1.1. Water Sources.

Water is found in nature from two main sources: ground water source and surface water source. Rivers, ponds and ditches are the common sources of surface water in the country. Rivers cover about eight percent of the country even in the dry season.

During the monsoon, another 29 percent of the country are inundated, and most of the rest is water logged from frequent rain. Ponds and rivers are the primary water sources for bathing, washing, cleaning and cooking. About 50 percent of the rural mass preferred the pond water as "good" (DPHE-UNICEF-DANIDA 1985). Surface water sources receive highly polluted discharges from municipalities, industries and commercial centers located around the sources.

The unhygienic sanitary practices of the people, agricultural drainage, and annual floods aggravate the deterioration of the quality of surface water. BOD, COD and dissolved oxygen deficit in many surface water sources indicate the presence of biologically degradable organic waste in water. Turbidity and suspended solids are found to increase in monsoon when the surface water receives additional organic and inorganic loads with the drainage of the surrounding plains.

In surface water, high bacterial count is of great significance from public health point of view. Surface water in ponds, lakes and rivers in Bangladesh often show coliform counts between 500 and 2000 per ml. Many surface waters receiving sewage and human wastes are characterized by extremely high FC counts. The EPCD indicates that most of the main rivers, such as Buriganga, Sitalakhya, Balu, Jamuna, Padma, Halda and Surma which run through the crowded cities of the country have coliform counts above the International Standards. According to the report all samples, mostly collected in monthly intervals, showed coliform counts around the range of 2000 to 5000 colonies per 100 ml.

Ground water has been extracted in Bangladesh by deep, shallow and hand pump tube wells and also by ring wells. A national summary of census (NMIC 1995/96) showed that there was a total of 5,82,335 shallow tube well [STW] and 32,135 Deep Tube wells and 149 other force mode pumps, used for irrigation. An estimated 2.4 million hand tube wells have been installed in rural Bangladesh, of which about 90,000 are publicly owned (Bux and Rahman, 1994). A survey (UNICEF 1989) reveals only 52% of the rural population use tube well water for drinking and few use other domestic purposes.

The ICDDRB published several research papers on cholera and other diarrheal diseases related to water use in Comilla district. Levine and et al (1976) found that tube well water drinkers did not have lower cholera infection rates and attributed this to regular use of contaminated surface sources for all other domestic uses.

Curlin and et al (1976) in a study commissioned by UNICEF compared cholera and shigellosis rates of tube well and surface water drinkers over a period of one year. The shigellosis rates were about 50 percent higher for the surface water drinkers but the cholera rates were four times higher for the tube well water drinkers. In a conclusion they stated that "the small amount of protection afforded by drinking bacteriologically safe water may be overwhelmed by the exposure to polluted surface water through bathing, food preparation and utensil washing".

Khan and et al (1981) have shown that water used for washing or bathing is equally or more important than water used for drinking alone in the occurrence of cholera. In rural areas, in general, during bathing and washing a handful of water is repeatedly taken into the mouth and the nose and are irrigated and rinsed in a way accompanied by vigorous hawking and spitting.

These support that contaminated surface water causes health hazard either by drinking or by use for other domestic purposes. National statistics show that only 50-60 percent rural people use tube well water for drinking purposes and about 10 percent people use tube well water for all purposes (Khan, M.U., Mosley, W.H., Chakravarti, J, 1981). In other words 90 percent of rural people still use surface water for domestic purposes. To ensure the acceptable quality of ground water its treatment is essential.

1.1.2. Iron Problem in Ground Water.

The drive for food self-sufficiency has lead to a tremendous expansion in power driven deep and shallow tube wells extracting ground water for irrigation. As most irrigation takes place in the dry season, this results in a significant decline in ground water levels during this period, particularly in localized areas of high extraction. Due to the decline of ground water level beyond suction limit (7 - 8 meters) of a tube well, an increasing number of hand tube wells used for supplying water for drinking and other domestic purposes become inoperative.

A population of about 11 million in 123 Upazella areas in whole or in part is affected by seasonal water table variation (BADC 1996).

Again the presence of chlorides, iron and hardness in groundwater in excess of acceptable limits restricts the per capita consumption of tube well water in the rural areas (UNICEF 1989). High concentration of iron in almost all areas, chlorides in northern part and salinity in coastal areas of the country is the main reason for this low consumption. The people in the iron problem areas use tube well water without much hesitation (Ahmed, 1981), but water of such quality is not acceptable in the other region of the country.

Iron (Fe), in reduced and ionized forms, is present in ground water. It is estimated that over 70 per cent of tube wells in the country have iron concentration in excess of the 1 mg/l, the maximum desirable level set by the WHO. An investigation made by Ahmed, Hussain, Khan and Badruzzaman (1989) showed that in some places in district of Rajshahi, Jessore, Khulna, Kustia, Rangpur, Kurigram, Pabna, Shirajganj, Tangail, Chittagong and several regions of Dhaka, the concentration of iron varied from 1 to 5 mg/l and in some places it was found as high as 25 mg/l.

In a recent study (Hussain, D., & Huda, M.K., 1997) ground water quality data of about 1000 deep tube well samples from about 124000 sq. km. Area of which 56 out of 64 administrative districts of Bangladesh were analyzed. It is observed that there are iron problems in almost all areas of Bangladesh. Ground water of about 51000 sq. km. (41% of studied area) contains more than 1 ppm of iron. Where as about 28000 sq. km. (22.5% of the studied area) contain iron more than 5.0 PPM. Iron problem is acute in the district of Manikganj, Gopalganj, Narshingdi, Narayanganj, Rajshahi, Bagerhat, Sylhet, Sunamganj, Noakhali, Khulna and Kurigram. About 170 Upazella areas with an affected population of about 15 million fall into this category. By comparison, pond water is iron free and so use of surface water is even more pronounced where the iron content of tube well water exceeds local tolerance levels (Hydrological studies, DPHE-UNICEF-DANIDA 1985).

The allowable limit of iron content can hardly be maintained in water supply in Bangladesh. For this reason, Department of Environment Pollution Control (DEPC 1984), Bangladesh, recommended a desirable limit of 1 mg/l of iron in drinking water.

But in the case of hand pump tube wells in rural areas, the maximum tolerable limit was set at 5 mg/l in the absence of a better source. Because of high consumer tolerance, iron problem areas are defined in Bangladesh as those in which iron content exceeds 5 mg/l. This local standard is being followed in rural water supply in Bangladesh.

1.1.3. Usage of Ground Water in Iron Problem Areas in Bangladesh

At present ground water sources are regarded as the only safe water sources in urban as well as rural areas of Bangladesh because of numerous socio-economical and technical reasons. Ahmed (1981) has observed that the greater the use of tube well water for all domestic purposes the less is the incidence of diarrheal attack. Bacteriological quality carries little importance to the rural people, they prefer water which tastes good and is odorless and which does not change the colour of food or does not stain clothes. The effects of excess iron are bad taste, discoloration of food and clothes, stickiness of hair, roughness of skin and also makes the teeth and nail black (Hussain, D., Huda, M.K., 1997).

In a study (Ahmed, F. & Ahmed, F. 1983) carried out in some iron problem areas of Jessore, Kustia and Khulna districts, the water use pattern of the people was observed and have been presented table 1.1.

Aesthetic (Colour), %	Staining of clothes & utensils, %	Odor, %	Taste, %	Make hair sticky, %	Causes constipation, %.
90.0	68.0	28.0	38.0	42.0	1.0

Table: 1.1. Typical Water use pattern of the people in iron problem area

The findings of the investigation made on the purposes of water usage and on water sources used by households for various domestic purposes in percentage are shown in the table 1.2.

Sources	Drinking	Cooking	Laundry	Washing utensils	Bathing	For cattle	Sanitary & others
Tube well	99.5	8.0	4.0	19.0	4.0	4.0	17.0
Ring well	0.5	1.0	2.0	1.0	2.0	-	1.0
Pond	-	22.0	20.0	19.0	22.0	18.0	20.0
River	-	69.0	74.0	61.0	72.0	82.0	62.0
	100%	100	100	100	100	100	100

Table: 1.2. Water usage in various purposes against water source

In a recent study (Hossain, D., Huda, M.K., 1997), it has been observed (plate 1 & plate 2) that the quality of deep tube well water is suitable drinking water supplies in the country, except about 4400 sq. km (3% of total area) of coastal belts and about 28000 sq. km (19.5% of the total area) of excessive iron problem ($Fe > 5.00$ PPM).

1.2.0. Statement of the Problem

The presence of iron in water is objectionable primarily because the precipitation of iron alters the appearance of the water, turning it to a turbid yellow brown to black. In addition the deposition of these precipitation will cause staining of plumbing fixtures as well as of the laundry. Again iron deposits causes encrustation problem to the tube well strainers, creating higher draw-down resulting lesser yield. Iron deposition can plug screens or perforations, thereby reducing open area and well efficiency. Pore spaces in the aquifer materials or gravel pack immediately adjacent to the intake section can also be clogged, reducing permeability near the well bore (Helweg, O.J., Scott, V.H., Scalmanini, J.C., AWWA). A 400 mm gravel packed municipal well with 300 mm screen in South Dakota originally produced 13 LPs. Twenty years later, encrustation plugged the screen opening and gravel pack to such an extent that well capacity was less than half of its original capacity. Thus cost of yield increases with time. DPHE tube wells and BADC's irrigation tube wells also face the same problem in the country. Again iron slime deposition in the bowl assembly of the turbine pump lessens pump life as a whole and needs frequent cleaning.

Iron imparts a taste to water that is described as metallic or medicinal. The precipitation of iron may lead to difficulty with water treatment processes such as ion exchange, taste, odor and turbidity in tube well water. Due to slow precipitation of oxidized insoluble iron compounds in presence of air discourage the people from using tube well water.

The presence of iron in water supplies causes growth of micro-organisms in the distribution system. These filamentous bacteria, using reduced iron as an energy source, precipitate it, causing pipe incrustations. Accumulation of microbial growths can lead to reduction in the pipe lines capacity and clogging of the meters and valves. Water bearing iron also generally favours the growth of several groups of bacteria including *Crenothrix*, *Leptothrix* etc (Mouchet, P., 1992).

These bacteria require only a small amount of air to grow and since they thrive in dark, they may be found in pneumatic tanks, pipe lines and elevated storage tanks. These bacteria as they decay impart a particularly bad taste and odor to the water making it objectionable to drink or use for sanitary purposes.

In urban areas, however treatment plants have been installed to lower the iron content to an acceptable limit. But these plants are very costly and need sophisticated maintenance. The problem of iron removal as it is faced by municipalities and industrial supplies is easily handled, because they have large costly aeration equipment and can use coagulation methods for precipitation and filtration with the help of trained high salaried man power. These plants have higher investment cost associated with higher maintenance cost. In addition, these need a larger space for installation.

The main problem exists to maintain these plants as well as the source of water. In rural areas attempts have been taken to develop household type iron removal plants attached to hand pump tube wells. Again no attempts have been made to develop community type iron removal plants. Hence an iron removal plant for 'campus water supply' should have to be developed to remove iron from ground water without extra cost of aeration and if possible, without the addition of chemicals for coagulation. Moreover particular attention is to be given to its maintenance so that it can be done with the help of less technical man power and with less sophisticated machinery.

1.3. 0. Rational of the Study

Though a good number of iron removal plants had been constructed since 1874 throughout the world (Mouchet, P., 1992), all of them treat water above ground. Only one attempt was developed in Finland to remove iron through subsurface aeration technology. This method - called Vyredox method developed in Finland and has been in use in Sweden, oxidizes the ferrous ion, which is soluble in water, to the ferric ion, which is insoluble, before the water enters the well. With this attempt iron was being removed from ground water while it was still in the ground, by retaining it in the strata around the aquifer by supplying aerated water into the aquifer (Hallberg, R.O., Martinell, R., 1976).

In the context of Bangladesh, people is dependent on ground water supplies both urban and rural areas. In some areas of Bangladesh ground water carries a high concentration of iron. Due to aesthetic problem people is not interested in using water that carries iron. Attempts were taken to remove soluble iron from the extracted ground water. Organizations like, DPHE, WASA, Chittagong etc., constructed IRPs in the iron problem areas extracting water from deep aquifer to supply water in urban areas in Bangladesh. The plants built in urban areas are costly in respect of construction as well as maintenance. Again increasing the efficiency of wells and pumps can substantially combat the rising operating costs and conserve precious energy and fuel because the energy demand for pumping may account for 60 to 70 percent of their costs. Improved well and pump efficiency is essential and should be a high priority item. Reduced efficiency and increased energy usage are associated with encrustation problem. Hence well maintenance for removal of encrustation is essential in iron problem areas.

In 1983-85 & 85-86 period 300 iron removal plants were built with hand tube wells extracting water from shallow aquifer as a source of water supply in rural areas throughout Bangladesh by UNICEF under a DPHE-UNICEF-DANIDA research and development programme. But the project was not successful due to constructional failure, inappropriate failure in certain aspects, operational and maintenance problems.

The Improved Iron Removal Plant (IRP) design has been under implementation since 1987-88. Iron removal plants for rural water supply have failed because of poor maintenance and bad workmanship in construction.

Attempts have been made to develop household type iron removal plants in Bangladesh but no attempts have been taken for the development of community type iron removal plants especially in rural areas. To supply water to a campus like Upazella head quarter; Upazella health complex; Palli biddut samity campus, situated in an iron problem area, has been found difficult.

To combat the iron problem in ground water, Sylhet Palli Biddut Samity (PBS) constructed a low cost iron removal plant with simple technology to supply potable water to it's campus in a deep tube well. But it became inoperative and failed within a short time.

The present research work is aimed at to bring the plant under operation by developing & modifying it with an airlift pump as an alternative of a turbine pump to lift as well as to aerate water in the tube well; to study the development and performance of the plant, made for the campus water supply and to study a cost effective well regeneration technique in an iron problem area.

This study leads to a package design of a low cost iron removal device associated with adequate maintenance facilities in rural areas for campus water supply. The package would be of low investment cost, easy to maintain. The operators with less technical know-how can be employed for its operation and maintenance. Moreover there would be easy regeneration technique to regenerate the tube well when it becomes choked up due to encrustation.

1.4.0. Objectives of the Research.

- i. To develop and to investigate the iron removal plant using the subsurface aeration technology through an Airlift pump.
- ii. Development of size of coarse material & dimension of coarse media flocculator for the flocculation of precipitated iron in the iron removal plant. To observe the overall iron removal efficiency of the plant.
- iii. Development of easy cost effective regeneration technique of choked up tube well as well as flocculation chamber in iron problem area for maintaining well yield.

1.5.0. Methodology of Research.

The methodology adopted to satisfy the objectives of the study are

- i. Literature Survey: An elaborate literature survey on the related topics was carried out for the better understanding of the problem.
- ii. Pilot Plant Test: The model iron removal plant was tested to satisfy the objectives of the research.

The plant consists of an air-lift pump and the iron removal unit. This unit has the flocculation chamber and sedimentation chamber.

Sub-surface aeration will be done during lifting water from a deep tube well with the help of the airlift pump. The water discharge is capable to satisfy the demand of a campus like Upazella Heath Complex, Palli Biddut Samity Complex etc. The effectiveness of aeration and the percentage of iron removal at three points in the path of water flow would be studied.

The main part of an iron removal plant is its maintenance. Here in this case maintenance will be as follows:

- a. Maintenance of the Iron Removal Unit.
- b. Maintenance of the tube well itself or in other words regeneration of the tube well when it will be choked up due to encrustation problem.

The easy maintenance procedure has also been studied and tested in the pilot plant.

CHAPTER II.

LITERATURE REVIEW.

2. 0.0. General.

The presence of iron in groundwater produces numerous adverse effects and is now considered to be one of the major problems throughout the world. These problems are severe in the context of Bangladesh, as groundwater is a vital source for the safe drinking and other domestic purposes because of numerous socio-economical and technical reasons of water supply.

2.1.0. Occurrence of Iron.

Since the strata of soil and bedrock vary from place to place, the composition of the ground water will also vary. The composition of ground water depends not only on the geology and hydrology of the area, but also on physical, chemical and biological factors. The presence of iron in groundwater is generally attributed to the solution of rocks and minerals, many oxides, sulfides, carbonates, and silicates containing these metals. Most soils, including gravel, shale and sandstone rock, contain iron. It occurs in the form of various oxides, such as magnetite (Fe_3O_4), hematite (Fe_2O_3), and limonite ($2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$). The sulfide and carbonate minerals are also important sources of iron. These include pyrite (FeS_2) and siderite (FeCO_3). Pyroxenes, amphiboles, and some micas generally contain iron (Clark, J.W., Viessman, W.J., Hammar, M.J., 1977). Ferrous iron (Fe^{++}) is a soluble, invisible form that may exist in well waters or anaerobic reservoir waters. Iron may be present as soluble ferrous bicarbonate in alkaline well or spring waters; as soluble ferrous sulfate in acid drainage waters or waters containing sulfur; as soluble organic iron in colored swamp waters; as suspended insoluble ferric hydroxide formed from iron bearing well waters, after being exposed to air.

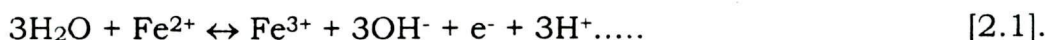
Decomposing organic matter in water removes the dissolved oxygen usually present in water; then the water dissolves mineral oxides, changing them to soluble compounds. Thus ferrous iron may be found in the lower levels of deep reservoirs, flooding soils, or rock containing iron on its compounds.

2.2.0. Chemistry of Iron in Water.

The chemistry of iron salt is complex and mainly depends upon its relative concentration; the pH ; CO₂ and the presence of organic matter. Iron usually occurs in one of the two ionic states and the simple equation,



is the basic to the consideration of iron in solution. In the ferrous state, designated by the symbol Fe⁺⁺, iron is quite soluble. When iron losses an electron [e] and is oxidized to the Fe⁺⁺⁺ or ferric state, it becomes very insoluble. The following equation represents a common type of reaction in ground water:



where, (Fe³⁺ + 3OH⁻): Precipitated as brown Fe(OH)₃; (+ e⁻): Eh and (3H⁺): pH.

The equilibrium in the equation is influenced by the concentration of electrons, Eh as well as by the concentration of hydrogen ions, pH. (Hallberg, R.O., Martinell, R, 1976). Whether iron will be present in the solid state, or in solution and whether it will appear in the ferric or ferrous state depends upon both the pH of the water and the eh, or oxidation-reduction potential of the water. Ground waters are not in direct contact with the atmosphere and may attain a low pH, very low DO, and high ferrous iron content.

Water in contact with air attains a higher pH and DO content and losses it's capacity to retain ferrous iron in solution. When such iron laden water is exposed to the atmosphere, a yellowish or radish brown precipitates of ferric-oxi-hydroxide will normally form and settles out of solution.

Iron (II) (Fe²⁺) is chemically a reduced and soluble form that exists in a reducing environment. These conditions exist in groundwater and anaerobic reservoir water. When it is pumped from underground or an anaerobic hypolimnion, CO₂ and H₂S are released, raising the pH. In addition, water becomes exposed to air creating an oxidizing environment. The reduced iron starts transforming to its stable, oxidized, insoluble form of iron (III) (Fe³⁺).

The rate of oxidation of iron depends upon the type and concentration of the oxidizing agent, pH, alkalinity, organic content, presence of catalysts.

Plate 3 shows the transition between the oxidized and reduced states of iron and manganese (Hallberg, R.O., Martinell, R, 1976). The ordinate shows the Eh in milli-volts and the abscissa refers to the pH of the water. The lower of the two sloping lines shows the balance between ferrous and ferric iron. At every point on the line, the concentration of the two states is equal. For all values of pH and Eh under the line, the concentration of ferrous iron is greater than that of ferric iron. In order to precipitate all the iron, the values of pH and Eh must be raised above those represented by the upper line. The sloping lines vary depending on the presence of other substances in water.

In nature, iron or manganese bacteria of many kinds and forms often provide the high values of pH and Eh. They have the ability to exploit the oxidation of iron and manganese.

They absorb the electrons as sources of energy for their metabolism. Oxidizing manganese provides only about a sixth of the energy that comes from the oxidation of iron. They must oxidize six times as much manganese as iron, in order to obtain the same amount of energy. The greater their preference for manganese, the more they demand organic carbon instead of carbon-di oxide and carbonates (Hallberg, R.O., Martinell, R, 1976). This is shown in plate 4.

2.2.1. Solubility of Iron in Water.

The solution of iron-bearing minerals is often attributed to the action of carbon-di-oxide in ground waters. Most of the carbon-di-oxide is presumably generated by the bacterial decomposition of organic matter leached from the soil.

The solution of the mineral may take place under anaerobic conditions and in the presence of reducing agents such as organic substances; hydrogen sulfide capable of reducing the higher oxides of iron to the ferrous, Fe (II) states. On aeration or by the addition of oxidizing agents, iron is oxidized from the ferrous to the ferric form. Once oxidized, the solubility of iron is severely limited over a wide pH range (4 to 13) by the solubility of ferric hydroxide (Stumn, W., Lee, G.F 1961).

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.

2.2.2. Effect of Alkalinity

In alkaline water devoid of sulfides, phosphates and organic compounds, iron will precipitate from aqueous solution as ferrous hydroxide, ferrous carbonate, ferric hydroxide or mixture thereof depending on the concentration of oxidizing agents and pH. For a given pH the solubility of iron carbonate in natural water is inversely proportional to the bicarbonate ion concentration as, for most waters, the alkalinity.

Stumm and Lee (1961) reported that the reaction rates obtained in solutions of lower alkalinity tend to be of smaller magnitude and more scattered than those obtained in solutions of higher alkalinity.

The lower pH value of groundwater due to the presence of carbon-dioxide and mineral acids and absence of dissolved oxygen creates favorable conditions to hold iron in high concentration in groundwater as ferrous bicarbonate (Bell, G.R., 1965).

Rabinson and Dixon (1968) mentioned that in order to obtain complete oxidation of the ferrous iron, the bicarbonate alkalinity of water should be in excess of 100 mg/l as CaCO_3 .

Generally, if 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.

Ghosh et. Al (1966) observed that within a pH range of 7.49 to 7.78 an increase in alkalinity from 335 to 610 mg/l as CaCO_3 , causes a 10 fold decrease in half-time.

According to Ghosh, O'Connor and Engelbrecht (1966), 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 the solubility equilibrium of ferrous hydroxide become limiting again.

Theoretically iron that precipitates from a supersaturated solution of this type would be either ferrous carbonate or ferrous hydroxide depending on pH. Under practical conditions, the precipitates of basic carbonates, e.g. $[\text{Fe}(\text{OH})_2 \cdot \text{FeCO}_3]$, with some what different solubility characteristics is probable, especially in the pH range of 8 to 11 [Stumm, W., Lee, G.F 1961].

2.2.3. Effect of Temperature

The reaction rate is dependent on temperature. For a given pH value, the rate increases about 10 fold for a 15°C increase in temperature, which is mainly caused by the change in (OH) concentration due to temperature dependence of the ionization constant of water (Stum, W., Lee, G.F., 1961)

2.2.4. Effect of Chloride

Sung and Morgan (1980) observed that chlorides and sulfate ions have a significant retarding influence on the rate constant in the pH range from 6.5 to 7.2. Later Sung and Forbes (1984) 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.

2.2.5. Catalytic Effects

The rate of oxygenation may be increased by the use of catalyst. In the practice of iron removal, contact aerators and contact filters have long been used in an effort to accelerate iron oxidation. The accumulations of deposited iron and bacteria on coke, rocks, and sand grains were presumed to act as the catalysts.

For a given pH value and oxygen concentration the addition of as little as 0.02 mg/L of Cu^{2+} , reduces the oxygenation time by a factor of 5 (Stum, W., Lee, G.F., 1961)

Sung and Morgan (1980) 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. It has also been described that 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 catalytic action of previously precipitated oxides of these minerals on the gravel.

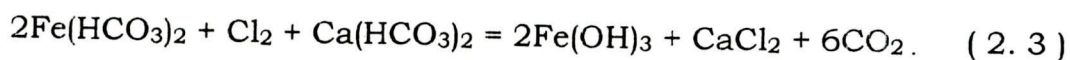
2.2.6. Oxidation and Precipitation of Iron

There are many oxidizing agents, e.g. Chlorine, chlorine-di-oxide, potassium permanganate etc. In case of water having low pH, its value is increased by stripping carbon-di oxide or adding lime.

Chlorine and Chlorine-di-Oxide

These gases are powerful oxidizing agents and can be used to oxidize iron.

Normally only chlorine is found to be used since chlorine-di-oxide is expensive. The reactions with chlorine in the presence of calcium bicarbonate alkalinity are as follows :

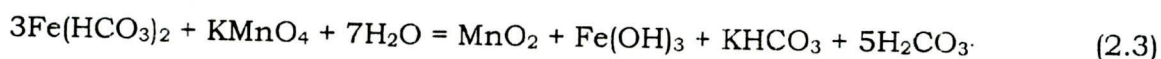


According to Feachem, McGarry and Mara (1977) this reaction will take place over a wide range of pH from 4 to 10 but the optimum pH is 7.

The colder the water, the slower are the reactions which may take as long as 60 minutes retention time to complete (Ahmed, 1987). Oxidation by chlorination alone, without aeration, can also work effectively with colored waters and chelated iron.

Potassium Permanganate

It is also a powerful oxidizing agent and in addition precipitates manganese-di-oxide (MnO_2) on to the granular surfaces of the filter media, which acts as a catalyst to accelerate the reaction to completion. The reactions are as follows:



The precipitates are manganese-di-oxide and ferric hydroxide that precipitates on the surface of the filter media. The other two - potassium bicarbonate, and carbonic acid, which are soluble and remain with the effluent.

2.2.7. Kinetics of Iron Oxidation and Precipitation

Rate of Iron Oxidation

Various investigations on the rate of iron oxidation concluded that the rate of ferrous iron oxidation is of the first order with respect to the iron concentration and the partial pressure of oxygen. In addition, the oxidation rate has been found to be strongly dependent on pH (Ghosh, et. al. 1966).

In such cases pH is increased by stripping CO_2 or adding lime. Alternately the rate of oxygenation may also be increased by the use of catalyst. In practice of iron removal, contact aerators and contact filters have long been used in an effort to accelerate iron oxidation. The accumulations of deposited iron and bacteria on coke, rocks and sand grains were presumed to act as the catalysts.

It has been shown that oxidation of ferrous iron should be expected to occur rapidly in well-oxygenated waters of pH values exceeding 7.2 (Stum, W., Lee, G.F., 1961).

Rate of Iron Precipitation

When ground waters supersaturated with respect to ferrous carbonate, are aerated, the pH increases because of the loss of carbon-di-oxide, thereby the degree of super saturation increases further. 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 (Ahmed, 1987).

pH consideration

Ground waters, although entirely devoid of dissolved oxygen as pumped from the ground, are supersaturated with CO₂. As a result, aeration increases the pH. In waters having low alkalinity and, hence, low buffer capacities, the pH will decrease gradually as the iron hydrolyzes resulting in an increase in the acidity of water. The pH achieved after aeration may be taken as the "equilibrium pH" and considered to be the pH at which the iron is precipitated.

2.3.0. History of the practices of Iron Removal

The first iron removal plant was constructed at Charlottenburg, Germany more than a century ago in 1874. In 1893, the first iron removal plant in the United States was placed in operation at Atlantic Highlands, New Jersey (Mouchet, P., 1992). By 1958, approximately 1340 water treatment plants, roughly 14 percent of the total in the United States, included processes for the removal of iron (AWWA 1971). The great majority served small communities and the total pumpage was only 220 mgd or as average of 370,000 gpd per plant. The earliest plants employed aeration and filtration, sometimes supplemented by the addition of lime, to treat ground waters. The same method of treatment predominates today.

2.3.1. Global Research Works on Iron Removal

Frankel (1979) developed an appropriate technology type of water filter for supplying drinking water to rural communities in south east Asia. The filter consisted of two stages. The first stage was made up of cocoanut fibres and the second stage consisted of burnt rice husk. The coliform removal as well as iron removal was possible with these filters.

The total construction cost of a typical plant was less than US\$ 2.00 per capita for a community of 800 persons.

Equina (1979) has made a study on the Pre-treatment of water containing iron and manganese using a horizontal-flow filter with crushed stone as the filter media. A regression analysis was developed to determine the factors affecting the filter performance. The length of the filter run was found to be the most important factor for the removal of iron from groundwater. At the filtration rate of 0.40 cu.m./sq.m./ h , iron with the average concentration of 1.24 mg / l could be removed by 47 %.

Wong (1984) has shown that processes in which oxidation is followed by removal of suspended solids can effectively remove soluble iron and manganese from water. He has developed three common processes for removing iron and manganese, e.g. 1. aeration-filtration, 2. chlorination-filtration, and 3. potassium permanganate-manganese green sand filtration. These three processes have been described in art. 2.5.1.

Ogedengbe, Olasupo and Adeniji (1984) have shown that powdered palm kernel shells with surface area of 2276 sq.m./gm, have good adsorption capabilities and can remove taste, color, turbidity, acidity and iron from well water, making it palatable. A simple household filter using powdered activated palm kernel shells has been constructed and tested.

Zirschky and Carlson (1984) have shown that overland flow, an effective wastewater treatment process, can also be used for potable water treatment. Many ground water's contain excessive amounts of ferrous iron that result in a water of poor aesthetic quality. The natural aeration that occurs during overland flow oxidizes ferrous iron to the more insoluble ferric form. The resulting precipitate then settles on the slope. An existing overland-flow treatment system in Salo, Finland, achieves 97% iron and manganese removal.

Bajracharya (1984) made a study on the possibility of iron removal by a simple low cost filtration technique, using coarse sand of effective size 3 mm and proposed a simple filtering unit that can be constructed in conjunction with hand pumps in iron prone areas.

An attempt was also made to determine the possibility of back washing under low heads. The efficiency with different loading of concentration was also investigated.

Czekalla, Mevius and Hanert (1985) have shown that microorganisms in rapid sand filters can remove iron and manganese. For reduced North German groundwater containing iron and manganese. The filters of 21 treatment plants mainly handling ground water in North Germany, were examined by analyzing the back washing material and the microbial settlement on the surface of the filter sand, using scanning electron microscopy particularly with the aid of in situ time on growth experiments. The formation of the oxides was observed. Following the formation of oxides, it was seen that metal iron oxidation only took place in direct contact with biological structures. The highest oxidation rates were achieved using a process called EPS (Extra cellular Polymeric Slime substances) iron oxidation.

2.4.0. Review of some Development of Iron Removal Plants (IRP)

A good number of IRPs had been constructed since 1874 throughout the world (Mouchet, P., 1992). All of them treat water above ground.

2.4.1. In situ Purification of Groundwater

Only one attempt was developed in Finland to remove iron through subsurface aeration technology. This method- called Vyredox method developed in Finland and has been in use in Sweden, oxidizes the ferrous ion, which is soluble in water, to the ferric ion, which is insoluble, before the water enters the well. With this attempt iron was being removed from ground water while it was still in the ground, by retaining it in the strata around the aquifer by supplying aerated water into the aquifer (Hallberg, R.O., Martinell, R., 1976).

The aim of vyredox method is to achieve a high degree of oxidation in the strata around the well. The Eh and pH are kept so high that the iron and manganese are precipitated and retained in the strata (Plate 6).

The water that enters the well is thus free from iron and manganese. Iron is precipitated first in the zone furthest from the well. The method consists of one or more wells for supplying water (plate 5). Each well has a pipe fitted with a screen. A number of injection wells, aeration wells, are situated in the form of a ring around each supply wells. Conduits connect each well to a nearby building. The water that would be forced into the injection well must first be degassed and enriched with oxygen.

This is done with the help of an aerator- the oxygenator- housed in the building. How the method works is described in Appendix I-D.

When wells are operated, the results achieved as summarised (Hallberg, R.O., Martinell, R., 1976) are as follows:

- The zone around the supply well becomes artificially enriched with oxygen. With the aid of the bacteria, the dissolved oxygen oxidises the iron & manganese. The precipitated metallic hydroxides are retained in the ground.
- The groundwater is filtered through the zone on its way towards the supply well

2.4.2. The Iron Removal Plant Developed in India

According to Dixit and Pathak (1971) an Iron Removal Plant for domestic purposes was made in India by C-PHERI (Central Public Health Engineering Research Institute). After the initial laboratory experiments it was tested on a field scale at Howrah for nearly three months. Water containing 1 to 6 mg/l of Iron and 142 to 427 mg/l of free CO₂ was improved to zero and 37 to 57 mg/l respectively. The astringent taste and odor from water were also removed.

Design and Principle of the Plant

The general layout of the unit is shown in plate 08. It has a capacity of 40 GPH and diameter of 37 cm. The raw water is sprayed over the top-chamber of the four-chambered iron removal plant. The top two chambers contain assorted coke of 2.0-2.5 cm size, 30cm depth. The third chamber contains 30 cm of coarse sand, supported over a 5cm layer of 1.0-2.0 cm gravel. The water spread over the first chamber rains to the second chamber and then to the third and so on. Water while trickling through the coke bed gets sufficiently aerated and CO₂ is released. Process of dripping through the second chamber provides further aeration to the already aerated water to reduce the dissolved CO₂ still more.

Performance of the Plant

The field tests were carried out on tube wells located at Onkarmal Jettia Road and College Ghat Road, Howrah, West Bengal. Sampling of raw and treated water was done at the start and every 60 minutes thereafter. Iron content was measured. The analysis of raw water and treated water of the tube wells is given in Table 2.1.

Period of sampling	Tube well at Onkarmal Jettia road		Tube well at College Ghat Road	
	Raw water	Treated water	Raw water	Treated water
	21.2.70 to 3.3.70	240 min after the start of the plant	12.3.70 to 16.4.70	210 min after the start of the plant
Total Iron (mg/l)	1.76-11.0	Nil	2.35-4.96	Nil
pH	6.4-6.7	7.15-7.35	6.5-6.7	7.2-7.4
Free CO ₂ (mg/l)	165-472	37-57	144-274	30-50

Table:2.1 Analysis of Raw water and Treated Water of Tube wells.

2.4.3. Iron Removal Plant (Community type) Developed in Bangladesh

According to Ahmed (1981) iron removal at the household level was attempted in some places in the country with four earthen pitchers placed one above the other, placed on tripod stand. Raw water from the top pitcher dripped through a bottom hole and passes through two pitchers filled with burnt wood charcoal and sand. The treated water was collected in the bottom pitcher. Although it was a low cost system, it took about one and half an hour to get one pitcher of treated water and thus unsuitable for all domestic uses.

UNICEF water section, Dhaka, constructed an experimental plant at Manikganj utilizing force pump to lift water to a height of eight feet from the ground for spraying the water on a filter bed, placed in G.I. sheet enclosure. Efficient removal of iron was achieved, but the maintenance of the force pump, cleaning of filter bed was not easy. The construction cost of such plant was about Tk. 3000.00.

In other places, a G.I. barrel of 200 L capacity, partially filled with filter materials, was placed below the discharge mouth of the hand pump by raising it to about five feet higher elevated position from the ground. Treated water was collected through a tap fixed at the bottom portion of the barrel. As the pump was fixed at a higher level, normal operation and maintenance facilities were greatly hampered.

The operation and maintenance difficulties of the previous plants in rural areas led to the necessity to develop simple iron removal plants with easy operation and maintenance facilities that would be acceptable to rural people. The community type iron removal plants have been developed and studied in the country in recent years. These IRPs have been installed along with hand pumps. One such study is reviewed here.

2.4.3.1. Iron Removal Plant Developed by BUET, Dhaka

This is an outcome of a joint research project of UNICEF-WHO-DPHE-BUET (Ahmed, F., Ahmed, M.F., 1983). The plant shown in Plate 09 consists of four unit aeration channel, sedimentation, adsorption and filtration chambers. The aeration channel is made of 4" PVC pipe partially filled with brick and is slotted at the top. Water discharged through the mouth of the tube well passes over the khoa and gets sufficiently aerated and drips in the aeration chamber. In the sedimentation chamber, water falls on the charcoal bed at the top, which provides further aeration. Some portion of the precipitated iron flocs settles at the bottom of the sedimentation chamber.

The water then enters into the adsorption chamber at the bottom through small holes and flows upward. Small precipitated iron flocs adhere to the surface of khoa in the adsorption chamber and assist further removal of iron. It then flows over a weir and enters into the filter bed, where most of the remaining precipitated iron strains by filter materials and iron free water is discharged through 1.5" dia PVC pipe.

Evaluation and discussion

The difference between the two plants installed in Jessore district was only the type of filter materials and is shown in the subsequent table. The plant No.1 contained 4" thick coarse sand and fine gravel layer within brick chips in the filter bed. The raw and treated water samples were tested for iron content. The test results have been presented in the tables 2.2 and 2.3.

Plant no. with Filter material	Raw water	Treated water		Yield gal/min Tube well	IRP		Av. Increase in water collection (gpcd)	Length of run, days.
		Cont. pumpi ng	Intermitt ent pumping		Initi al	Final		
I Khoa	7.6	2.0	1.4	5	3.5	2.5	1.56	30
II Sand, gravel & khoa	7.9	0.6	0.4	5	2.5	1.5	2.50	20

Table: 2.2. Field analysis of water samples and performance of iron removal plant
(after Ahmed, F., Ahmed, M.F., 1983)

Water type	Iron, ppm	Dissolved CO ₂ , ppm	Total alkalinity, ppm	Mn, ppm	Total hardness	Chloride, ppm	pH
Raw	8.00	130	418	0	444	100	6.8
Treated	0.40	60	428	0	410	100	7.3

Table: 2.3. Laboratory analysis of water samples in plant II. (after Ahmed, F., Ahmed, M.F., 1983).

Free CO₂ concentration of the raw water was very high (130mg/l) and may be responsible for slow dissolution of iron from iron bearing strata. After aeration free CO₂ in the treated water was reduced and pH increased to 7.3. This is together with high total alkalinity (418 mg/l) was responsible for a rapid precipitation of soluble iron in the plants. The result indicates that intermittent operation yields water with less iron content than continuous operation. In intermittent operation precipitated iron flocs gets more time to settle. If complete removal is not desired, sand bed may be omitted for more discharge.

The estimated cost of construction of the plant was Tk. 700.00 (1990) that was about 15% of the cost of the tube well. Time to time cleaning of the filter bed by opening the bottom holes, washing and rearranging of filter materials is required which is very simple and can be done by one man in five minutes (Ahmed, F., Ahmed, M.F., 1983).

2.5.0. Unit Processes of Iron Removal

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 and the other may be called organic iron or chelated iron which is colored with humic acids that chelate the iron. Organic iron may be present in colored well as well as surface waters. The method used to remove the iron depends on the type of iron and is entirely different from one another. While adopting certain methods of iron removal, one must examine the type of iron present in water.

Removal of Organic Iron

The iron content of highly colored waters containing humic substances from muskeg, rotting vegetation, etc. can often exceed 10 mg/l (Walker, R., 1978). The process of removal is almost diametrically opposed to the processes used for inorganic iron.

Simple aeration is not effective and since color is usually pH sensitive, raising the pH only intensifies the color and fixes the iron.

According to Walker (1978) usually these waters are low in pH from 4.0 to 6.5 and are also low in alkalinity. In order to remove iron, it is necessary to remove the color. In one experiment it was found that reducing the color by flocculation to about 50% of its original value reduced the iron content by the same amount. One of the methods of treating highly colored waters high in iron is to add chlorine (often requires 5 or more mg/l) from a gas chlorinator. The chlorine seems to break down organic chelating agent and destabilizes the colloidal color with the result that the iron together with the organic color forms a floc, which can be removed by tube settlers and filtration.

Removal of Inorganic Iron.

The removal of inorganic iron is an oxidation process for precipitation followed by settling and filtration. Alternatively, many water treatment plants oxidize and filter out iron all on one filter. Usually well waters containing iron are saturated with carbon dioxide (CO_2), the quantity of which can be determined from its pH value. If aeration is done, the free CO_2 will be liberated and pH will be slightly elevated.

The majority of iron removal plants employ aeration, flocculation, sedimentation and filtration processes. To aid oxidation, oxidizing agents such as chlorine, chlorine di oxide, potassium permanganate etc. are added following aeration. Lime is added for rapid oxidation, where pH is too low.

2.5.1. Aeration

Aeration is the treatment process whereby water is brought into intimate contact with air for the purpose of

- i. increasing dissolved O_2 content,
- ii. reducing dissolved CO_2 content and
- iii. removing various organic compounds responsible for taste and odor.

Aeration is a physical phenomenon in which gas molecules are exchanged between a liquid and gas at a gas liquid interface. The solubility or addition of a gas depends on :

- its partial pressure in the atmosphere in contact with water,
- the water temperature,
- the concentration of impurities.

The rate of precipitation or removal of a gas is controlled by:

- the degree of super saturation,
- the water temperature,
- the interfacial area of a gas contact and water exposure.

The aims of aerators is supported by the most common gas transfer equation and is represented as (Stumn, W., Lee, G.F., 1960),

$$C_t = C_o + (C_s - C_o) [1 - \exp \{ - K_g (A/C) t \}], \dots \quad [2.5]$$

where, C_t & C_o = concentration of gas at time $T = t$ and $t = 0$, respectively
 C_s = the saturation concentration at a given temperature,
 A/C = the area of interface per unit volume of liquid.
 $(C_s - C_t)$ = concentration difference for absorption
 $(C_t - C_s)$ = concentration difference for desorption
 K_g = proportionality factor, a function of A/C . gas transfer coefficient.

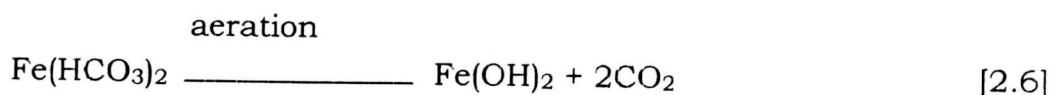
For the adsorption of oxygen in centimeter per hour, it's value has been reported to be, $K_g = 32.3 \times 1.018^{(T - 20)}$. This value can be both higher and lower in different circumstances.

The above equation indicates that the oxygen transfer can be optimized by:

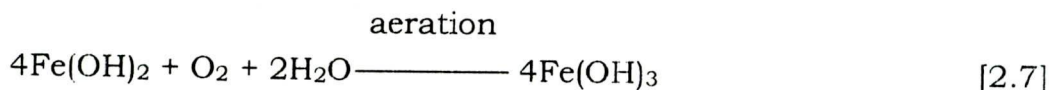
- generating the largest practicable area, A , of interface between a given volume of water, C , and air.
- inducing a long exposure time, t .
- preventing the buildup of thick interfacial films to keep transfer coefficient, K_g , high.
- Ventilating the aerator and it's components well enough to maintain highest possible concentration difference, $(C_s - C_t)$ for absorption, and $(C_t - C_s)$ for desorption.

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 subsequent sedimentation and filtration.

In iron removal process, aeration is required to precipitate the ferrous bicarbonate to ferric hydroxide in accordance with the following equations:



further aeration :



In order that the reaction will go to completion and precipitate the ferric hydroxide, it is necessary that the pH be approximately 7 or higher (Walker, R., 1978). If possible, the pH should be raised to 7.5 to 8.0, but even so the reaction may take 15 minutes retention before it is complete and in some cases as much as one hour retention has been necessary (Walker, R., 1978).

The length of retention time depends on the degree of aeration and the dissolved oxygen content of the aerated water as it enters the retention zone. Aeration can be optimized by increasing contact time and interfacial area. There are various types of aerators:

i. Gravity Aerators

- a. Cascades
- b. Inclined aprons
- c. Vertical stacks
- d. Stacks of perforated pans or troughs
- e. Multiple tray aerators
- f. Packed column system

ii. Spray Aerators,

- a. Orifices or nozzles in stationary pipes
- b. Orifices or nozzles in movable pipes

iii. Mechanical Aerators:

- a. Submerged / Surface paddles
- b. Propeller blades
- c. Turbine blades

iv. Air Diffusers.

2.5.1.1. Gravity Aerators

The various types of gravity aerators are shown in plate 10.

Cascades

Cascades consist of a flight of three or four concrete or metal steps over which the water tumbles in a thin sheet. Water is allowed to fall down a series of concrete steps as a thin sheet; turbulence & hydraulic jump formation assist aeration. The head required depends on the height of the structure, which is typically 1 to 3m. These are less effective than other aeration device (McGhee, T.J, 1991). Some types have low weirs at the periphery of the metal steps.

It is of little or no use in reducing algae odors but may reduce CO₂ from 20% to 45 %. Head required will be 1 to 3 m. It is also stated that a single cascade with a 400 mm supply can aerate 9000 m³ of water a day with 50% - 60% carbon-di-oxide removal (Walker, R., 1978).

Inclined aprons

Water flows supercritically down a steeply inclined apron or channel. Turbulence can be increased by fitting studs or plates and a zigzag movement. 25% - 50% of carbon di oxide may be removed here (Walker, R., 1978). (Walker, R., 1978).

Tray Aerators

These consist of a series of trays formed of wooden slats, perforated plats, or screens which are spread about 500mm apart. The individual trays sometimes contain a 200 to 300mm deep layer of coke, slag, stone, or ceramic balls 50 to 150mm in size. The water is applied at the top of the structure through either sprays or a perforated pan. Application rates are 40 to 200 lpm per square meter of total tray area depending on application. Air flow through the trays is provided by open louvers on the sides, normally with natural draft.

According to Walker (1978) a tray area of 0.015 and 0.045 m² per cubic meter of water passing through each hour should be provided. The Indian ministry of health recommends 5-12 mm dia holes at 25 - 75 mm centres. Tray aerators are often built in stacks of four to six trays giving a total height of 1.2m to 3m. It gives 30% - 60% removal of CO₂ (Walker, R., 1978).

Aeration with contact bed

There are various ways in which aeration and contact beds can be combined in a system resembling a series of trays or cascades. This could precede sedimentation and slow sand filtration in a small treatment plant.

2.5.1.2. Spray Aerators

Water is discharged under pressure through nozzles, causing spray formation and air entrainment. Small nozzles, less than about 25mm dia tend to clog.

According to Walker (1978) when water is already under a pressure head of 7 m or more, as when discharged from bore holes, it can be sprayed into basins through nozzles of special design. The basin should be large enough to catch wind blown spray. Spray nozzles provide a large air-water surface area but exposure time is short, 2 sec or less. They require considerable head and so much space that housing is difficult. They are usually operated at heads of 70 to 140 kPa. The amount of water discharged per nozzle depends on nozzle design and head used. A nozzle of good design having a 25 mm orifice will discharge 0.3 m³ / min to a height of 2 m at a pressure of 70 kPa (10 psi). Up to 75% of carbon dioxide can be removed in a spray aerator.

2.5.1.3. Mechanical Aerators

There are many kinds of mechanical aerators. The followings are of special interest:

- Submerged paddles: Circulate the water in aeration chambers and renew its air-water interface.
- Propeller blades: Whirling at the bottom of a central downdraft tube in an aeration chamber and aspirating air into the water.
- Turbine blades: capping a central updraft tube in an aeration chamber and spraying droplets over its water surface.

2.5.1.4. Diffused-air aerators

Most air diffusers or injection aerators bubble compressed air in to water through orifices or nozzles in air piping, diffuser plates or tubes, or spargers. Generally these consist of concrete tanks with depth ranging from 3 to 5 m, width ranging from 3 to 10 m, and length adequate to provide a desired detention time of 5 to 10 min.

The air is applied by means of diffusers, which may be placed in the tank bottom or mounted on the tank walls (Plate 11). In either case the air produces a spiral flow of water within the tank which increases the contact time between the bubbles and the liquid. Air flow ranges from 0.04 to 1.5 m³ per m³ of water depending on the application. This type of aerator has the advantage of long contact time and also provide some mixing and flocculation.

2.5.2. Flocculation

The most important task of a water treatment process is the separation of colloidal suspended particles from water, which are roughly concentrated in the sub micron size range. In the treatment process several terms are being used. The word *stirring*, describes the disturbing of the flow pattern of a fluid in a mechanically orderly way for the purpose of effecting a dynamic redistribution of particles by the induced turbulence. *Mixing* is a brief operation seeking a quick response. *Agitation* of particles is referred to as floc growth; break up of floc, as floc shear. A combination of mixing and stirring or agitation that produces aggregation is called flocculation.

The destabilized particles or precipitates formed by aeration are of very small size and not heavy enough to settle down due to gravity. A study (Forbes, E., Sung, W., 1984) showed that when ferrous iron solution with initial concentration on the order of 2-5 mg/l is oxygenated, the precipitate is roughly concentrated in sub micron range. Such particles would have a stokesian settling velocity on the order of 10 cm/day under quiescent conditions. This translates to a surface overflow rate (SOR) of 102 LPD/m², a factor of 400 lower than that of a typical sedimentation basin. So to enhance the settling characteristics they proposed for flocculation before settling.

If chemical is mixed, the destabilized particles and chemical precipitates resulting from coagulation may settle very slowly. In the process of flocculation, the slow mixing process, these particles are brought into contact in order to promote their agglomeration. The rate of agglomeration or flocculation depends on the number of particles present, the relative volume, which they occupy, and the probability of collisions among the particles.

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.

This is expressed as (Weber 1972),

$$G = \sqrt{[P / \mu C]} \text{ sec}^{-1}$$

where, G is the 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, μ , the absolute viscosity.

Micropulsation generated during mixing not only contributes to floc formation but causes floc damage as well. Extended mixing also multiplies the recurrence of floc formation and damage, leads to the screening of active centres, decreases the flocculation rate and reduces of floc. CAMP has developed the flocculation criteria for optimum floc formation by combining the average velocity gradient with the mean or displacement time. This is expressed as dimensionless CAMP number, Gt_d (Fair, Geyser and Okun 1971)

$$Gt_d = \sqrt{[P / C\mu]} \times C/Q = \sqrt{[P C / \mu]} \times 1/Q.$$

A specific range of values is maintained for a particular condition. The design and performance of a flocculator can be related to the term Gt_d .

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 forms particles of larger 'diameter' - but percentage of big flocs is usually low. Flocs grow when particles are colliding with each other and the chemistry of the system enables particles to stick together.

Various models on flocculation have been developed, one may be reviewed here (Fig 2.1).

Smoluchowski's model for flocculation:

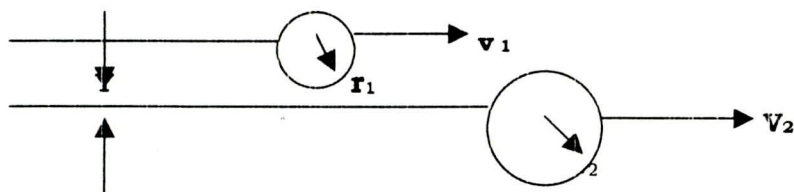


Fig 2.1 : Smoluchowsky model of flocculation

If $y < (r_1 + r_2)$ and $V_1 > V_2$ the two particles will collide. The velocity gradient G can be written as

$$G = [V_1 - V_2] / y$$

This velocity gradient must be induced by any means slowly.

The Smoluchowsky model leads to the result that the total number of collisions per unit volume in unit time is given by,

$$N = 2/3 n^2 G d^3$$

where, n is the number of particles per unit volume
 d is the particle diameter and
 G is the velocity gradient.

So the rate of flocculation is proportional to the velocity gradient; the volume of the sphere of influence of the particles and the square of the numerical concentration of the particles.

A high velocity gradient promotes rapid flocculation, but will shear large, delicate flocs. Tapered flocculation uses a high G at the beginning, and a lower value subsequently to prevent erosion or rapture of large flocs. A mathematical relation describing the kinetics of flocculation has been derived. This relation indicates that the rate of entrapment of suspended matter in the floc is dependent upon the volume of floc, not the number or size of the floc particles.

Usually the sources of power for flocculation devices are gravitational, pneumatic or mechanical. A simple solution to the flocculation process is the one involving coarse media bed in which water is allowed to flow through a packed bed of coarse media.

The hydraulic flocculator e.g. gravel bed flocculator which consist of a bed of gravel proves to be simple, reliable and inexpensive.

The packed bed of gravel provides ideal conditions for the formation of compact settleable flocs because of continuous recontacts provided by sinuous flow of water through the interstices formed by gravel. Besides, gravel bed flocculator has the ability to store agglomerated flocs within the interstices or to settle flocs below the gravel. These agglomerated flocs will further help in adsorbing finer particles as they come into contact with the settled flocs. Moreover in an up flow system as the flow emerges from the coarse media, due to sudden drop in velocity, agglomerated flocs will settle on the top of coarse media bed forming a layer of sludge which is also effective in the removal of finer particles. This type of flocculator occupy small area and no external source of power is required. Moreover the whole bed of coarse media is effective for flocculation purposes (Ahmed, 1995). Some researchers used satisfactorily locally available brick chips as coarse media due to the unavailability of gravel in the areas.

In the flocculation chamber, velocity gradients are purposely intensified by enforced changes in the direction of flow. A baffled channel or a chamber filled with brick khoa or stones differs from an unobstructed open channel and, for that matter, from a pipeline in that shear gradients or turbulence are not merely functions of frictional resistance to flow. For such channels or for flow through flocculating chamber of capacity C, in which a loss of head h is incurred when the rate of flow is Q, the useful power input $P = Q \rho g h$, where ρg is the weight density of water. Accordingly the permissible channel loading at a given value of $G t_d$ is

$$Q/C = \sqrt{[Q \rho g h / \mu C] / (G t_d)} \dots\dots (2.)$$

Here g is the gravity constant and μ the dynamic viscosity of the fluid.

The practical design factors include the detention times of 20 to 30 minutes and the values of G between 25 and 65 s^{-1} . In practice, the loss of head increases in addition to normal channel friction due to change of velocities over-and-under or around-the-end of the coarse media flocculators.

In arriving at this estimate the assumption is made that necessary velocities must be redeveloped at each change in direction of flow.

2.5.2.1. Design of coarse media flocculator

The requirements for the flocculation process in coarse media beds can be defined in terms of the expression for the average velocity gradient of fluid motion. Annular brick chips may be used as coarse media in the flocculator. The size of the khoa or gravel can be determined with the derived equations. Although this type of flocculators are now in use in many small community water systems in Thailand, India, Bangladesh and Latin American countries, the design parameters and the factors affecting the design of coarse flocculators have been developed and tested in the laboratory recently by Ahmed (1995).

Ahmed (1995) developed expressions for G and G_{td} on the basis of hydraulic parameters. (The development of the expressions is shown in appendix IV).

$$G = \sqrt{k} \cdot (Q/a) \cdot \{(1-f)/f^2\} \cdot \{6/(\psi d)\}.$$

And $G_{td} = \sqrt{k} \cdot \{(1-f)/f\} \cdot (S/d) \cdot L$ from which

Considering k (Kozeny) = 5; S (Shape factor) = $(6/\psi)$; f (porosity) = 0.4

$$G = 8.38 \cdot (Q/a) \cdot (s/d).$$

$$G_{td} = 3.354 \cdot (S/d) \cdot L$$

Ahmed (1995) has shown that since G is directly proportional to Q and td is inversely proportional to Q , the CAMP number is independent of Q . For a constant rate of flow Q the displacement time td is a function of volume of gravel bed V . Therefore for a constant rate of flow Q , and a specific size and shape of gravel, the cross sectional area of gravel bed, and the length of bed L are the variable parameters, for controlling of mean velocity gradient G and CAMP number G_{td} . Again a given volume of gravel V , the cross-sectional area a can be varied by varying the length of the flow path, L , making it up and down flow. Varied G can be obtained along the direction of the flow by varying or gradually reducing the cross sectional area a .

Ahmed (1995) proposed a design guidelines that in a coarse media flocculator, the mean velocity gradient G and CAMP number G_{td} are mainly a function of face velocity, Q/a and length of flocculator L respectively. Both the terms are inversely proportional to the size of the coarse media, d although G is directly proportional to Q .

CAMP number is independent of Q .

For a constant rate of flow Q , and given volume of gravel V , varied mean velocity gradient G , can be obtained either by increasing or decreasing length of the flow path, L , or gradually enlarging or reducing the cross sectional area a . Similarly varied CAMP number, G_{td} , can be obtained by increasing and reducing the length of flow path, L .

Some test indicate that floc can be made 10 times more compact by extended agitation ($Gt = 200,000$) than by limited agitation ($Gt = 10,000$), without impairing its settling characteristics. Increases in flocculation time and intensity should reduce the work required of filters by reducing the volume of flocs to be removed.

Since G is directly proportional to Q and t_d is inversely proportional to Q , CAMP number is independent of Q . For a constant rate of flow Q , the displacement time, t_d , is a function of volume of gravel bed, V . Therefore, for a constant rate of flow, Q , and a specific size and shape of gravel, the cross sectional area of gravel bed, a , and the length of bed L , are the variable parameters, for the controlling of mean velocity gradient G , and CAMP number, G_{td} .

2.5.3. Sedimentation

Sedimentation is the process of separation of suspended heavier particles from water by gravity settling. The purpose of sedimentation is to remove the suspended particles from aqueous solutions when it stands still or flows slowly through a basin. The basic theory of sedimentation assumes the presence of discrete particles. Due to the low velocity of flow, 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.

Ideal Sedimentation Basin

Most sedimentation processes are designed to remove small particles, which settle slowly, and is based on theoretically on the concept of the ideal settling basin. Particles in water are not spherical. The effect of irregular shape is not pronounced at low settling velocities, and most sedimentation devices are designed to remove small particles, which settle slowly. Larger particles, which settle at higher velocities, will be removed whether or not they follow Stokes or Newton's laws.

In an ideal sedimentation basin (fig. 2.2). A particle entering the basin will have a horizontal velocity equal to the velocity of the fluid, $V = Q/A = (Q/w.h)$ and a vertical velocity, v_s , equal to its terminal settling velocity defined by Stoke's or Newton's law. If a particle is to be removed, its settling velocity and horizontal velocity must be such that their resultant, V , will carry it to the bottom of the basin before the outlet zone is reached.

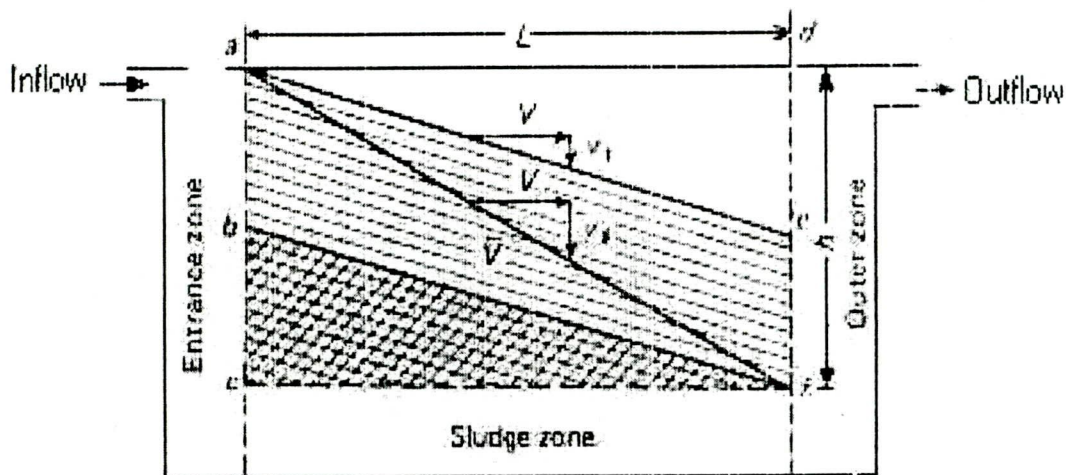


Fig. 2.2: Ideal settling basin

If a particle entering at the top of the basin is so removed, all the particles with the same settling velocity will be removed. Considering the slope of the velocity vector in fig 2.12, one may write:

$$v_s/V = h/L$$

$$\text{Or, } v_s = (Vh/L) = (h/L) \times (Q/w.h) = Q/wL \quad [2.9].$$

This equation defines Surface Overflow Rate (SOR) which is numerically equal to the flow divided by the plan area of the basin, but which physically represents the settling velocity of the slowest settling particle which is 100 % removed. Those particles which settle at velocities equal to or greater than the SOR will be entirely removed, while those which settle at lower velocities will be removed in direct proportion to the ratio of their settling velocity to v_s , assuming that they are uniformly distributed upon entering the basin.

The basin will remove all the particles having settling velocity V_s or larger, which is independent of depth of the basin, dependent only on flow (Q) and the area of the basin in plan (A). From this concept, sedimentation basin should be constructed as shallow as possible to optimize the removal efficiency. Tube settlers or basin with false bottom are alternatives to shallow basins for higher efficiency in removing suspended solids. The basin shown in Fig 2.12 will also remove the particles with settling velocity $V_s < V$ if the particles enter the tank at height h or lower, so that $h/h_o = V_s / V$.

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 of water purification in which water is allowed to pass through a bed – a filter media - usually a sand and gravel. The filter media are very efficient in retaining finer and colloidal particles of clay and silt. It also aids in removing colour, odor, turbidity, iron and manganese.

Three types of filters are in use:

- Slow sand filtration, SSF.
- Rapid sand filtration, RSF.
- Roughing filtration, RF.

According to Huisman, Sundarsan, Netto and Lanoix (1981) a short comparison between the types can be made and is shown in table 2.4.

Rate of filtration	SSF	RSF	RF
	2-7 m ³ /m ² /day	120-360 m ³ /m ² /day.	0.5-4 m/hour
Medium thickness	0.15-0.34mm	0.4-1.2mm	1st:10-15mm 2nd:7-10mm 3rd:4-7mm.

Table 2.4. A comparison between the filtration process.

2.6.0. Iron Removal Technology.

All the conventional treatment processes available on a world scale fall into seven main categories (Mouchet, R., 1992). These are

- Aeration followed by sand filtration or dual media filtration, which is often complemented by a contact tank, settling or flotation and the addition of chemicals,
- Chemical oxidation(without pre-aeration) followed by filtration,
- Filtration with a special medium that acts ion or electron exchanger e.g. manganese-green sands, Zeolite of volcanic origin (tecto silicates) or sand that is artificially coated with manganese di oxide to simulate a "Natural green sand effect",
- Manganese oxide or diatomite.
- Conventional treatment combined with lime softening,
- Sodium silicate, Phosphates or Polyphosphates as sequestering agents, and
- In-situ treatment – in which oxygenated water is introduced into the aquifer by means of feed wells, this is based on the combined effect of simultaneously occurring physical, chemical and biological phenomenon.

Among the techniques there are three general techniques used for the control of iron in public water supplies. The primary method involves precipitation followed by filtration. The second method involves ion exchange, and the third method involves stabilization of iron in suspension using dispersing agents to prevent the deposition of iron. More specifically, the treatment processes employed in the control of iron deposition include:

i. Precipitation and filtration

- a. Aeration - filtration method
- b. Chlorination - filtration method
- c. Potassium permanganate-manganese green sand filtration method

ii. Ion exchange

- a. Water softening method
- b. The manganese - zeolite process

iii. Stabilization with polyphosphates.

2.6.1. Precipitation and Filtration.

Aeration-filtration Method

Aeration-filtration equipment typically includes an aerator, retention tank and filters. Oxygen from the atmosphere reacts with iron in raw water to produce relatively insoluble salts of ferric oxide. The rate of reaction depends on pH. It is more rapid at higher pHs. Retention time of several hours may be necessary after aeration depending on raw water characteristics. Sometimes sedimentation tanks with sludge collection and removal facilities are used instead of a simple retention tank if iron concentration is high. Pressure filters preferably with dual media of anthracite and sand are used to remove iron. The major disadvantage of this method is that the initial cost is so high (Wong.,1984).

Chlorination-Filtration Method

It consists of a chemical feed system and filters. Sometimes a small retention tank and a pH adjustment system to feed soda ash, caustic soda (NaOH), or lime $[\text{Ca}(\text{OH})_2]$ are required. Either gaseous chlorine or hypochlorite can be used as the oxidizing agent. The filters used in this process are similar to those used in aeration - filtration process (Wong.,1984).

Potassium Permanganate - Manganese Green sand Filtration Method

The equipment for this process is similar to that for chlorination-filtration process but differs in the primary oxidizing agent and the filter media (Wong.,1984). A 1-4% solution of KMnO_4 is continuously fed into the raw water line, prior to filtration, to reduce the amount of soluble iron going to the filter. Manganese treated green sand is a mineral capable of exchanging electrons and thereby oxidizes iron to its insoluble and filterable states. The green sand has the ability to oxidize and to filter. Its oxidative capacity is limited and the bed must be regenerated with KMnO_4 after back washing. This process has an advantage in that the green sand can act as a buffer. If the feed of KMnO_4 does not oxidize all the soluble iron, the green sand will oxidize and filter it.

If the KMnO_4 feed is in excess of the demand, the excess KMnO_4 (pink color) is used up in regeneration of the green sand. Major disadvantages of this process are high operational costs associated with chemical requirements and filter bed deterioration if the pH falls below 7.1 (Wong, 1984). In some cases, chlorine is used in conjunction with KMnO_4 to reduce chemical costs.

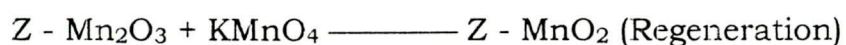
2.6.2. Ion Exchange Method

Water Softening Method

Lime-soda softening can remove iron. If split treatment is employed, KMnO_4 can oxidize iron in water by passing the first stage excess lime treatment. Lime treatment has been used to remove organically bound iron from surface water. The process scheme aeration - coagulation - lime treatment - sedimentation - filtration can treat surface waters containing color, turbidity, and organically bound-iron.

Manganese Zeolite Process

Manganese zeolite is made by coating natural green sand (glauconite) zeolite with oxides. Manganese dioxide removes soluble iron until it becomes degenerated. The filter is regenerated using KMnO_4 .



Manganese zeolite filters are generally pressure types. Disadvantages of the regenerative - batch process are the possibility of soluble manganese leakage when the bed is nearly degenerated, and the waste of excess KMnO_4 needed to regenerate the green sand.

2.6.3. Stabilization Methods

The alternative to iron removal is stabilization or dispersion. According to Clark, Viessman and Hammer (1977) sodium hexa meta phosphates at dosages of 5 mg per mg of Fe plus Mn have been used for this purpose. While this treatment will stabilize iron in suspension, it reportedly is not suitable where iron concentration of 1 mg/l is exceeded. Moreover, when the water is heated, the polyphosphate will revert to orthophosphate and lose its dispersing properties.

The application of 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.

2.7.0. Preventive Treatment of Iron

Preventive measures may sometimes be used with reasonable success. Sodium hexa-metaphosphate has been found to be effective in sequestering iron in some supplies. When applied in proper dosage, before oxidation of the iron occurs, metaphosphate tends to hold iron in solution. Metaphosphate does not prevent oxidation of iron but stops agglomeration of the individual tiny particles of iron oxides. Thus the sequestered oxides pass through the distribution system without creating accumulation which periodically cause badly discolored water.

Success of this treatment is very difficult to predict, since it depends on the concentrations of iron, the level of chlorine residual established for disinfection, and the time of passage through the distribution system. The latter is established by the extent of the distribution system, pipe sizes in the network, and location and volume of storage reservoirs. Reduced iron in water promote the growth of autotrophic bacteria in distribution mains. Heavy chlorination or addition of copper sulfate in the isolated sections of water mains followed by flushing has been effective in some cases. The only permanent solution to iron problem is removal by proper treatment of water.

2.8.0. Acceptable Limit of Iron in Ground water

The recommended maximum allowable limit of 0.3 mg/l iron for drinking water or potable water can hardly be attained in Bangladesh, since iron free water is rarely available from ground water extracted either by hand pumps from the shallow aquifer or by turbine pumps from the deep aquifer. To maintain the limit of iron, some sort of treatment is essential.

The Department of Water Pollution Control (Bangladesh) has recommended the desirable limit of 1 mg/l in drinking water, but in the case of hand pump tube well in rural areas, the maximum tolerable limit may be up to 5 mg/l in the absence of better sources. This local standards is also being followed by the DPHE in the tube well sinking programme. The term 1 mg/l or 5 mg /l is meaningless to the rural people who are the main users, since the presence of iron in water does not involve any health risk. It was observed (Ahmed, F., Ahmed, M.F., 1983) that rural people use hand pump tube well 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 tube well water is maintained within 2 mg/l, it can be expected that such water will be acceptable to all most all consumers.

2.9.0. Conventional Iron removal techniques and their drawbacks

According to various surveys carried out in USA, only 50 to 60 percent of the plants examined produces water that met standards for iron and manganese levels. In France, as observed by Mauchet (1992), almost a third of the existing plant did not yield consistently satisfactory results.

When analysing the causes of the poor functioning of particular plants, the followings were observed.

Causes	Observations in % of cases.	Remarks
Iron complexation	75%	The complexing agents are silica and humic substances.
Oxidation pH is too low	35%	
Negation effect of chlorination	25%	Inhibiting biological phenomenon that would otherwise enhance treatment.
Problems related to flocculation of oxidised iron or manganese.	20%	
Effective size of sand too large	20%	
Lack of analytical data or representative samples at the time of design.	20%	
Deterioration of raw water quality over time	15%	
Interference by nitrification.	15%.	
Oxidation time too short	10%	
Reagent dosage locations not optimum	10%	

Table: 2.5. Drawbacks in conventional IRP, abroad (Mauchet 1992).

In Bangladesh a survey (WHO/ DPHE/ UNICEF 1990) was conducted to find out the causes of non usage of the IRPs developed to install with hand pump tube wells. This is summarized in the table 2.6.

District	Number of IRP		Causes of non-usage and number of IRPs.					
	Installed	Abandoned	Breakage & spare parts non availability	Lack of interest	Access of insects	Beak down of TW	Necessities not felt by the users	Damaged during flood
Pabna Total (%)	54	6 (100.0)	1 (16.7)	1 (16.7)	0 (0.0)	1 (16.7)	3 (50.0)	0 (0.0)
Sirajgarj Total (%)	114	22 (100.0)	10 (45.0)	4 (18.2)	2 (9.1)	1 (4.5)	4 (18.2)	1 (4.5)
Sylhet Total (%)	1	1 (100.0)	0 (0.0)	1 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Grand Total (%)	169	29 (100.0)	11 (37.9)	6 (20.7)	2 (7.0)	2 (7.0)	7 (24.1)	1 (3.5)

Table: 2.6. Survey of the IRPs not in use in B'desh (after WHO/ DPHE/ UNICEF report, 1990).

It is seen that the maintenance problem is the main for the non usage of the IRPs. However the report showed that iron removal was satisfactory by the IRPs. With an average cleaning interval of 12 days (min 5 days), the iron concentration had been reduced to 1.5ppm(av) from 15ppm(av). With the same interval of cleaning it was also observed that the higher the concentration in raw water the higher the concentration in treated water but not exceeding 2.5 ppm.

2.10.0. Rehabilitation of the encrusted Tube Wells.

Tube well is the main source of the ground water abstraction and is a valuable asset. A new well, properly drilled, cased and developed, will give years of satisfactory service with little maintenance and care. The productivity of a well depends upon a number of factors such as aquifer condition, well design, appropriate construction, proper development of the well etc. Many wells yield decreasing quantities of water and thus fail.

The causes of well failure or well troubles are as follows (Barnes, I., Clarke, F.E. 1969):

- depletion of ground water supply.
- well failure due to faulty well construction.
- the most prevalent cause of well failure results from corrosion and encrustation of well screens or strainers.

Corrosion may result from direct chemical action of ground water or from electrolytic action caused by presence of two different metals in the well. Encrustation is caused by precipitation on or near well screens of materials carried in solution of ground water. The sudden pressure drop associated with water entering a well under heavy pumping can release CO₂ and cause precipitation of calcium carbonate.

Another cause of encrustation is due to change of soluble ferrous iron to insoluble ferric hydroxide. Slime forming organisms can also block screens by forming Jelly like bacterial slime (Mogg, J.L., 1972). The most common form of chemical or bacteriological clogging of strainers in Bangladesh is iron or manganese hydroxide encrustation.

Tube well rehabilitation or regeneration refers to the treatment of a production well by mechanical, chemical or other means to recover as much as possible of the lost production capacity (Koenig, L., 1960). Well rehabilitation methods and application to various types of aquifers are shown in Appendix I-E.

Increasing the efficiency of the tube wells can substantially combat the rising operating cost, because energy demands for pumping may account for 60 to 70 percent of the costs. In iron problem areas, well maintenance has to be given importance to handle the encrustation problem to maintain well efficiency. Encrustation can plug impellers; bowls or even pump head thus operating efficiency is decreased. This requires the pump to be pulled out for reconditioning. Several concepts and definitions are widely used to describe the efficiency of wells. Well efficiency is a measure of the effectiveness of a well in extracting water from the aquifer. The performance of a well can not be determined by applying traditional efficiency ratio of output work to input energy, because no input energy is consumed by a well in causing water to flow.

Helweg, Scott and Scalmanini, suggested the followings to measure the well efficiency.

1. A ratio of actual specific capacity (SC) at the design rate to theoretical specific capacity, based on aquifer characteristics and well geometry both after 24 hours of continuous pumping. Measuring SC_{theo} may be inaccurate, So SC_{max} , the specific capacity when the well was new, can be substituted.

$$e_u = S_{act}/S_{theo} = S_{act}/S_{max}.$$

2. A ratio of theoretical drawdown at the design rate of drawdown when the well was new to actual drawdown required to produce that rate, both measured at the same time after pumping has began. This is the same as a ratio of actual to theoretical specific capacities, but measured after any duration of pumping,

$$e_u = S_{theo}/S_{act} = S_{max}/S_{act}.$$

The Correlation between the water quality and encrustation is complex. The principal indicators are total carbonate hardness, total iron content, total manganese content and pH.

Encrustation in the well cause decreased specific capacity accompanied by a larger draw down in the well, The draw down and discharge of a pump is interrelated. When the draw down increases the discharge becomes less and for the required quality of water more running hours of the pump is required. The energy consumption is increased proportionately, which is reflected in the monthly consumption bill. It has been observed that with 50% reduction of specific capacity in a well the running hours become doubled. Hence it is essential that the screens are to be cleaned to maintain the well's productivity.

Encrustation of the mineral type is normally attributed to a reduction in head (or pressure) resulting from pumping a well. Lowering of the pressure below normal tends to upset the solubility equilibrium with ground water. The result is formation and precipitation of insoluble mineral from salts normally held in solution. Local evidence of encrustation may be obtained by inquiring as to the effects of ground waters on surface installations such as tanks, taps, pipe connections. Also the effects are observed on pump columns rods and casings.

The insoluble minerals precipitate, regardless of the metal or material of the well screen, and encrustation may buildup on plastic, fiberglass concrete, fibrillate, etc.

Generally more than 90% of mineral encrustation problems are caused either by calcium carbonate or by iron oxides. Bacterial plugging is commonly caused by organisms known as iron bacteria.

2.10.1. Techniques to remove tube well incrustations.

The techniques followed to handle encrustation problems are very much similar to those being followed for well development process. These may be categorized as

1. Mechanical Treatment and
- II. Chemical Treatment.

2.10.1.1. Mechanical Treatment

This includes over pumping, surging, use of compressed air, hydraulic jetting and use of explosives. The mechanical agitation breaks up the clogging materials or precipitates and improves their exposure to the chemicals. Agitation time and intensity depends on location and type of clogging. After a reaction period that can vary from hours to a day, the solution is agitated again and finally the waste is pumped out. The methods are briefly described below:

Over pumping

It involves pumping a well in a series of steps to one exceeding the design capacity of the well. To be most effective, the intake area of the pump may be extended to near the center of the screened section. At each step the well is pumped until the clear water comes out, after which power is shut-off and waters in the pump column surges back into the well. The step is repeated. This irregular and non-continuous pumping agitate the clogging material in the screen opening, carried into well and is pumped out. The coarser fraction entering the well is removed by a bailer from the bottom of the well.

Surging with surge blocks

It can be accomplished by the up and down motion of a surge block inside the well. Solid, vented and spring loaded surge block is generally employed. The cylindrical block is 2 to 5 cm smaller than the well screen diameter and fitted with belting rubber or leather that will not damage the screen. As the block is moved up and down in the screen, a surging action is imparted to the water. The down stroke caused backwash to break any bridging due to encrustation while the upstroke pulls dislodged materials into the well. Surging should begin with a slow stroke at the bottom of the screen. This should be repeated with increasingly faster strokes. Surging is completed when accumulations of materials at the bottom of the well become negligible.

Surging with air

An air compressor is connected to an air pipe fitted inside a discharge pipe in to the well as shown in fig . Both pipes should be capable of being shifted vertically up & down by clamps. Initially, the pipes extend to near the bottom of the screened section. For efficient operation, the water depth in the discharge pipe should exceed two thirds the length of the pipe.

To begin development the air pipe is closed and the air pressure is allowed to buildup to 0.7 to 1.0X10⁶ pa, it is then released suddenly into well by means of a quick opening valve. The inrush of air creates a powerful surge within the well first increasing then decreasing the pressure as water is forced up the discharge pipe. The process loosens the incrustations surrounding the screen opening. The materials are then brought out of the well by continuous air injection, making it an airlift pump.

Back washing with air

In this method the top of the well is fitted with an airtight cover. Air compressor, air pipe and discharge pipes are installed in the similar way to the air surge method. A separate short air pipe and a threeway valve as shown in the figure are also installed. Compressed air is released through long air pipe forcing air and water out of the well through the discharge pipe.

After the water clears, the air supply is shut-off and the water is allowed to return to its static level. The three-way valve is then turned to admit air into top of the well through the short air pipe. This back washes the water from the well through the discharge pipe and at the same time agitates the clogged strainer opening. Air is forced into the well until it begins escaping from the discharge pipe, after which three-way valve is turned and the air supply is directed down the long air pipe to pump the well. Back washing is repeated until the well is fully cleared.

Hydraulic Jetting

Jetting with high velocity stream of water is an effective development technique in wells containing screens with large percentage opening. The jet nozzle, mounted horizontally, is attached to a string of pipe which is connected through a swivel and hose to a high pressure, high capacity pump. The jet head is slowly rotated and pulled to successively higher level. The deposited materials are dispersed by the turbulent flow.

2.10.1.2. Chemical Treatments

For most methods adding one of the polyphosphates to water in the well will aid the regeneration process. These compounds act as deflocculants and dispersants of clogging agents thereby enabling them to be more readily removed by the methods of mechanical treatments. Block of carbon-di-oxide (dry ice) are sometimes added to a well after acidizing and surging with compressed air to complete well regeneration.

The accumulation of gaseous carbon-di- oxide released by sublimation build up a pressure within the well; upon release this cause a burst of sludged water from the well.

2.10.2. Regeneration or Rehabilitation Programme of Deep tube wells under DPHE, Bangladesh

In the year 1982 the department of Public Health Engineering attempted well regeneration work [DPHE production wells] in the country. The regeneration result was promising, but later on successful regeneration of wells were not possible without a proper monitoring programme (Rahman. M., 1993). Various methods were followed in the regeneration work. The treatement methods both chemical and mechanical as adopted by DPHE are here by discussed in brief.

An investigation of the DPHE wells (excluding the tube wells at Dhaka, Chittagong & Narayanganj city) indicates that about 45% tube wells show a gradual decrease of capacity & efficiency due to clogging. Also 10% to 20% start yielding sand after a certain operation period. Performance and condition of the well can be known by regular monitoring of the well.

Regeneration of production well is technically feasible and is extremely attractive from an economic point of view. A standard dose of chemicals to be used or the method to be applied to regenerate wells is a complicated job (Rahman.M., 1993). Most form of clogging of wells can be removed effectively by treating the well effectively with chemicals in combination with mechanical agitation. The success of regeneration depends on the type and rate of clogging. So regeneration shall be taken at the primary stage of clogging. Better achievement may be expected of the regeneration can be taken up at the decrease of 25% of its specific capacity (Rahman. M., 1993).

2.10.2.1. Chemical Treatment

Chemical treatment has proved to be very effective in well regeneration. Chemicals are usually dissolved or diluted in a container and subsequently injected into the well by a small dia of hose pipe. The number of application and chemical dose are determined by screen length of the well and assessed problem. DPHE used several types of chemicals (DPHE., 1993) and the treatement has been proved to be very effective.

Sodium hypochlorite

It is a strong oxidizing agent. The oxidizing action kills any bacterial growth, which may have developed in the gravel pack and in the adjacent part of the aquifer.

Sodium hypochlorite was commonly applied and the recommended dose was about 30 to 40 liters per meter of screen (150mm dia). Consequently the required quantities varied from 600-1200 kg based on the length of the screen 20-30 M. (DPHE., 1993).

Sodium hexa-mataphospate (Calgon)

It is a strong dispersing agent. Calgon, a trade name for sodium hexa-mataphosphate is most commonly used chemical. Calgon has to be used in combination with bleaching powder of Sodium hypochlorite due to the fact that calgon is a nutrient for iron bacteria. Recommended dose was 1-2 kg per meter of screen. (DPHE., 1993).

Hydrochloric Acid

Hydrochloric Acid has been applied in few cases only. No reliable conclusion was drawn. However 400 liters were injected in 30M long screen.

2.10.2.2. Mechanical Treatment

The mechanical agitation breaks up the clogging materials of precipitates and improves their exposure to the chemicals. Agitation time and intensity depends on location and type of clogging. After a reaction period, which can vary from hours to a day, the solution is agitated again and finally pump the waste.

Generally two treatments are necessary but in exceptional cases four treatment have been applied. A powerful flow and turbulence has to be induced in and around the gravel pack in order to dislodge the precipitates. Usually four mechanical methods have been applied by DPHE(DPHE., 1993).

Rawhiding

In the method, (plate 13) the pump of the well is connected with a 2M³ capacity water reservoir. A surging action consists of alternately pumping a column of water at a significant column distance above the pumping water level and letting the water to fall back into the well.

This process is called Rawhiding or back wash. A clogging is a self accelerating process, frequent application of a light and simple regeneration technique like rawhiding is expected to work as preventive. Preventive rawhiding can not replace the complete regeneration system, but it is expected that it will delay the clogging process considerably and hence the operation of preventive rawhiding has been recommended to be done in once every six weeks. Production test for one hour is to be done before starting the rawhiding. It will be more effective if the well is injected by a small dose of bleaching powder solution, approximately 10-15 kg, on the eve of rawhiding.

This operation is done by closing & opening the sluice valve/ gate valve of the delivery line. Roof tank will be filled up with water by pumping and water will flow back into the well by gravity. After two hours of rawhiding the waste water is to be pumped out. The process may be repeated(DPHE., 1993).

Water Jetting

A submersible pump is connected with a jetting tool (plate 14). The tool contains few nozzles by means of which the water mixed with chemicals is jetted into the screen area of the well. The whole device is moved slowly up and down in the well for about one day (DPHE., 1993)

Pressurizing with air

It is the method of Surging with air-compressor (agitation by compressed air). The well is closed by means of a steal cover (plate 15). Then the well is pressurized, pushing the water level down and forcing the chemicals to penetrate into the aquifer. After this the pressure is suddenly released, causing the strong flow back into the well. The cycle is repeated three to four times an hour for a period of about 48 hours or more. Then the pump is lowered and operated to bail out the chemicals and wastes(DPHE., 1993).

Section wise cleaning

During section wise cleaning a short piece of screen, which is more or less separated from the rest of the screen by means of packers, is subjected to a vigorous surging and pumping action (plate 16). The cycle starts with pressurizing the 100 mm dia pipe, to which the cleaning device is attached, up to 2-5 bar, depending on the condition of the screen.

The water level inside the 100 mm dia pipe is pressed down, and the water is pushed through the short piece of screen between the packers, into the shrouded zone. Then the pressure is suddenly released by means of a ball valve, resulting in a very strong flow entering through the same piece of screen. This cycle is repeated for two or three times in one particular section of the screen. Subsequently the main valve is opened and the wastes can be removed by airlift pumping(DPHE., 1993).

2.11.0. Selection of Appropriate Technology

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

- i. Water quality.
- ii. Water Use pattern and socio-economic conditions.
- iii. Condition of the water resource.

In the absence of organic matter, for alkaline ground water supersaturated with carbon-di-oxide, aeration for gas transfer is the simplest way of oxygen addition and carbon-di-oxide removal. Field data indicates that there was an increase in pH value above 7.0 even without any effective aeration of water. In these cases, 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 (Clark, Viessman, W.J., Hammar, M.J., 1977).

A good number of conventional iron removal plants for community water supply have been constructed since 1874 throughout the world (Mouchet, P, 1992). In Bangladesh attempts were taken to remove soluble iron from the extracted ground water. Organizations like DPHE; WASA, etc., constructed iron removal plants in the iron problem areas to supply water in urban areas in Bangladesh. These are costly in respect of construction as well as maintenance and were constructed to supply large volume of water for industrial as well as domestic usage. A few attempts have been taken by UNICEF; DPHE for the development of community type iron removal plants (IRP) with hand pump tube wells. Recently this has been observed that in some areas, during dry season of the year the hand pump become inoperative due to drop of water level beyond suction limit of a hand pump.

Again there is every possibility of encrustation of the strainers of the hand pump tube well in iron problem area. This eventually causes higher pumping water level [PWL] resulting less discharge or even failure of the tube well. No study has been done on this point also. Thus due to maintenance and operational problems, these attempts were not successful.

Again there have not been found any development of IRPs using low cost technology with deep tube wells in iron problem area. Usually these tube wells have higher static water level as well as higher water discharge associated with higher drawn down.

Most of the conventional methods treat water above ground surface. Only one attempt was developed in Finland to remove iron through subsurface aeration technology. This method - called Vyredox method was developed in Finland and has been in use in Sweden. This oxidizes the ferrous ion in the aquifer, which is soluble in water, to the ferric ion, which is insoluble, before the water enters the well. With this attempt iron was being removed from ground water while it was still in the ground, by retaining it in the strata around the well by supplying aerated water into the aquifer (Hallberg, R.O., Martinell, R., 1976).

2.11.1. Choice of an airlift pump for sub-surface aeration

Generally a turbine pump is employed to extract water from a deep tube well with higher static water level. Airlift pump may also be installed for the same reason.

Airlift pump utilizes compressed air for raising water. The density of a mixture of air in water is much lower than that of pure water, if such a mixture is balanced against water column, the former will rise much higher than the latter. When the atmospheric free air mixes with the ground water with the help of an air compressor, this adds oxygen and thus aerate water. Considering it only a pump, it has less efficiency but with the consideration of other factors it would be an appropriate technology. Aeration is done with either of the methods described in art. 2.5.1. Diffused air aerators also aerates water but above ground surface. All of these require either extra head or another pump to be employed to pump water over the aeration structures. Again the structures involve large investment cost and require large land area.

An air-lift pump would be the best choice to provide sufficient aeration of ground water with less investment cost and without additional aeration structures as well as land area requirement. Again the same air compressor of an airlift pump can easily be used for removing the incrustation developed on the strainer wall. In an iron treatment plant, maintenance is the main problem. The flocculation chamber and other chambers can easily be maintained with the help of the compressor of the airlift pump with simple modification.

Some experts in the field of ground water technology put opinion not to add oxygen inside tube well in the iron problem areas on the plea that it would encourage incrustation problem in tube well strainer as well as in voids of the aquifer around. But Vyredox method of in-situ purification of ground water has been in use with success and the method applies aerated water into the aquifer to remove iron. However it is anticipated that the iron deposition in and around the tube well, might easily be handled with the airlift pump. The working principle is reviewed in appendix: I-B.

The following purposes are anticipated to be achieved with the air lift pump:

- i. To lift water from the tube well to the ground surface and to discharge up to the inlet of the flocculation chamber of an iron removal unit or a water reservoir.
- ii. To aerate water during lifting providing sufficient contact time and larger interfacial area between air and water.
- iii. To regenerate the tube well by removing the iron deposits from the strainer opening in case when the tube well strainer becomes clogged due to incrustation.
- iv. To agitate & disperse the coarse media flocculators in the flocculation chamber for the purpose of cleaning the iron deposits inside the interstices of the flocculators.
- v. To reduce maintenance cost & down time.
- vi. To provide easy operation and maintenance technology. Unskilled operators can be able to operate and maintain it with little effort. Local workshops will be able to repair it.
- vii. One of the main advantage of the pump is that it has no moving parts below water level and therefore can not be damaged by iron depositions etc., as may happen in bowl assembly of the turbine pumps.

- viii. In vyredox method more than one main bore and several other injection bores around each main bore are required. But in this case only one main bore will serve the purpose.

2.11.2. Technology for flocculation and sedimentation

The oxidized and precipitated iron particles after aeration process are so small in size that it is very difficult to separate them through sedimentation. These small particles are allowed to grow or flocculate to sizes to settle at satisfactory velocities through the process of flocculation. Use of chemical coagulants; mechanical mixing devices are not feasible and practicable in community water supply system. A simple solution to the flocculation process may be the one involving coarse media flocculators like brick khoa or gravels of proper size with horizontal flow.

The sedimentation process in iron removal provides for the settling and removal of heavier and larger flocculated particles of the effluent from the flocculator. The water received after sedimentation may be used or may be processed through filtration. The removal efficiency in the sedimentation basin determines the requirement of subsequent process and loadings thereof. Rectangular horizontal flow sedimentation basin without mechanical sludge removal devices are advantageous for communities in developing countries because of their simplicity and ability to adopt to various raw water conditions. Hence a plain sedimentation basin without further filtration unit may be appropriate in this case.

CHAPTER III

DEVELOPMENT AND CONSTRUCTION OF THE SUB-SURFACE AERATED IRON REMOVAL PLANT

3.0.0. General

A few attempts have been taken by UNICEF, DPHE for the development of community type iron removal plants (IRP) with hand pump tube wells. But due to maintenance and operational problems, these attempts were not successful as anticipated. Again there have not been found any development of community type IRPs with deep tube wells in iron problem area. Usually these tube wells have higher static water level as well as higher water discharge associated with higher drawn down.

Most of the conventional methods treat water above ground surface. Only one attempt was developed in Finland to remove iron through subsurface aeration technology. With this attempt iron was being removed from ground water while it was still in the ground, by retaining it in the strata around the well by supplying aerated water into the aquifer (Hallberg, R.O., Martinell, R., 1976).

Since iron problem is a practical field problem and simulation of field condition is difficult in the laboratory, it was proposed that an investigation would be carried out with subsurface aeration technology directly in the field in an iron problem area. In the Sylhet Paurasava area most of the deep tube wells yield water with higher iron content. Such a tube well is situated at Palli Biddut Samity (PBS) campus with 12ppm iron content. An iron treatment plant was also constructed to remove iron content. Due to lack of proper design and technical information, the whole plant became out of order within a short period of operation. The whole campus suffered from water supply. It was proposed that the tube well would be brought under operation. Subsequently the field investigation would be carried out in that particular well and plant with required modification on experimental basis to develop a package plant of low cost iron removal device using subsurface aeration technology associated with adequate maintenance facilities. The Deep tube well was drilled to provide potable water to it's campus. In co-operation with PBS, it would be possible to monitor it's performance and to collect related data on the plant.

3.1.0. Design Considerations

The conventional treatment processes on a world scale fall into eight main categories and have been reviewed in chapter-II. These processes have several drawbacks. The statistics on the causes of the poor functioning of the plants are important as they highlight the parameters those must be considered while designing a new plant.

The description of the Deep Tube well – the Source of water and the water quality test results obtained by testing water samples collected from the test well are being presented in appendix-I. The present plant is primarily a community type iron removal plant. Some form of chemical treatment of the ground water is indispensable in any such plants when iron complexing phenomenon occurs. In Bangladesh about 400 IRPs of small capacity have been installed along with hand pump tube well, extracting water from shallow aquifer throughout the country but no evidence in any study has been found for complexed iron. The chemical oxidation for the treatment was avoided because of non-existence of complexed iron. It's higher application cost and complexity in use also can not be ignored.

It has been observed in several studies that without adopting the filtration process, the iron content came down within acceptable limit. Moreover the filtration rates are restricted to a maximum of 10 - 15 m/h. It is desired to get a continuous flow of effluent water with acceptable limit of iron concentration before the filtration process, the step was avoided.

Thus the removal of soluble iron from the available ground water prior to supply it to overhead tanks for ultimate consumption, the process adopted in the plant was **aeration - flocculation - sedimentation**, followed by adequate and simple maintenance facilities.

The plant consists of an airlift pump, a flocculation chamber and a simple sedimentation tank. The process of flocculation & sedimentation have been accomplished in a brick-built treatment unit allowing horizontal flow - called the iron removal unit (IRU). The unit consists of flocculation and sedimentation chambers including a separating chamber along with inlet and outlet boxes of suitable dimensions. There is another underground water reservoir, constructed to collect the treated water from the IRU and from where it is being pumped to overhead tanks on respective buildings in the campus.

3.1.1. Aeration

To aerate raw water an intimate contact between water and air should be achieved and it can be obtained in a number of ways and those have been reviewed in chapter II. The aerators have the aim to create extensive, new, and self-renewing interfaces between air and water, to restrict interfacial films from building up in thickness, to optimize the time of gas transfer, and to accomplish these aims with minimal expenditure of energy. All the aerators are costly and require larger area & additional detention time.

The deep tube well of the pilot plant was commissioned as the source of potable water for the campus. The diameter of the housing pipe was designed to accommodate pump bowl of a turbine pump. The airlift pump can be used with success either in a 150 mm dia. deep tube well or even in 38mm dia hand pump tube well. The same pump may be capable to aerate the ground water properly during lifting. Since aeration is a function of contact time and interfacial area, both can be increased with the help of an airlift pump. The optimum aeration may be accomplished by the compressed air, supplied by the airlift pump during extraction of water from the aquifer. If turbine pump is installed, another device or structure should be there for the aeration of the extracted ground water. Hence an airlift pump has been recommended to avoid the aeration structure. Thus an air lift pump is installed in the deep tube well instead of a turbine pump to lift as well as to aerate water though provision had been kept for the installation of a turbine pump.

3.1.1.1. The design of the air lift pump

Efforts have been made to review literature on the detailed design criteria of an airlift pump. After compiling the information received, it has become clear that, for an airlift pump there are some criteria to be taken into consideration for designing it with desired capacity for a particular site. These are based on the rate at which the water is to be pumped and the height to which it is to be lifted. The design of airlift pumps is largely empirical. But no information was found on the aeration performance by the airlift pump during the time ground water would be lifted from a tube well.

Some factors have been found important in designing an airlift pump with a desired capacity of water discharge to be extracted from a tube well are:

- An air compressor capable of discharging adequate amount of air flow under a certain pressure required to lift desired amount of water.
- The percent submergence of the airline and the column pipes under water and relative sizes of the air and column pipes. The length of the column pipe and that of the airline pipe depend on the pumping water level of the particular tube well against a definite discharge. As the data were not known, the design was made arbitrarily.

Hence on the basis of the criteria, the main components of the airlift pump are:

- i. One air compressor capable of producing suitable amount of air flow with adequate pressure.
- ii. Column pipes of suitable diameter to lift water from the well with an arrangement at the top to divert the direction of flow.
- iii. Airlines of suitable diameter to direct required amount of air under water at certain depth and with certain pressure.

Selection of the Air compressor for the airlift pump.

A suitable compressor is generally selected using two parameters-compressor's capacity to supply desired amount of air and the compressor's ability to develop desired pressure to the supplied air.

It is also considered that for the regeneration of the tube well, the same air compressor would be used. Hence the compressor should have sufficient capacity to discharge anticipated amount of air at the tube well bottom. Before air can discharge from the lower end of the air pipe under water inside a well, the compressed air must push all the water out of the air pipe. To do this, the air pressure must obviously be greater than the water pressure before start to pump.

The power required to transfer the air to the bottom of the air pipe depends upon the pressure at the compressor, which in turn is a function of the depth of the submergence of the piping and the head loss through the air piping and valves. Thus,

$$P = wh, \quad [3.1]$$

Where, P = pressure, kg/cm^2

W = unit weight of water, $1 \times 10^{-3} \text{ kg/cc}$.

h = Water column height, centimeter.

Starting pressure, P_s kg / cm²

$$P_s = [(A + D) / 10] \text{ kgf/cm}^2 \text{ (Considering fig:3.1),} \quad [3.2]$$

Where, $(A + D)$ = height of water column in meter, which is to be overcome by compressed air pressure on starting airlift.

Working pressure, P_w , Kg/cm²,

$$P_w = [A / 10] \text{ kgf/cm}^2 \text{ (Considering fig:3.1),} \quad [3.3]$$

Where, A = the water column height in meter, which is to be balanced by air column at airlift operation.

The figure 10 in the denominator of the formula is equal to height in meters, of water column equal to 1 kgf/cm².

The required pressure of the Compressor

The tube well length is 97.425 m from the ground level. But water would be lifted up to the discharge head. Hence total fixture length becomes 98.00 m. Taking 5.00 m as the lowest Static Water Level [SWL] and if air is injected at a point 2.0 m above the dead bottom of the tube well, the hydrostatic pressure at the point becomes,

$$\text{Height, } (A + D), = (98.00 - 5.00 - 2.0) = 91.00 \text{ m.}$$

$$\text{Hence from eq. 3.2, } P_s = [(A + D) / 10] \text{ kgf/cm}^2 = [91.00] / 10.$$

$$\text{Or, } P_s = 9.1 \text{ kg / cm}^2.$$

The selection was finally adopted by considering probable head losses in airflow using empirical formulae (McGhee, T.J., 1991). The head loss in the airline pipe may be approximated from

$$H = 9.82 \times 10^{-8} (f L T Q^2 / P D^5), \quad [3.4]$$

Where, H = head loss, mm of water

L = pipe length, m

D = diameter, m

T = temperature, K

P = pressure, atm

Q = airflow, m³/min

f = friction factor of steel pipe = $0.029 (D^{0.027} / Q^{0.148})$

The top of airline will be above 0.5 m from the discharge head and will extend up to 2.0 m above the tube well bottom. Hence the length of the airline L_1 is $98.00 + 0.5 - 2.0 = 96.5$ m.

The equivalent length of gate valve in the air line

$$L_2 = 55.4 CD^{1.2} \quad [3.5]$$

where, L = equivalent length in M
 D = pipe dia in m
 C = a factor given in the table 3.1.

$$\therefore L_2 = 55.4 \times 0.25 \times (0.01905)^{1.2} = 0.119 \text{ M}$$

$$\text{Total length } L = L_1 + L_2 = (96.5 + 0.119) = 96.619 \text{ m}$$

And the friction factor of steel pipe carrying air may be taken to be:

$$f = 0.029 [D^{0.027} / Q^{0.148}]. \quad [3.6]$$

$$f = 0.029 [0.01905^{0.027} / 1.0^{0.148}], \text{ (assuming an air flow rate of } 1.0 \text{ m}^3/\text{min).}$$

$$\therefore f = 0.026.$$

Again, the absolute temperature at the compressor, T in $^{\circ}\text{K}$,

$$T_2 = T_1 (P_2/P_1)^{0.283} \quad [3.7]$$

Where, T_1 = (ambient temp + 273),
 P_1 = pressure, atm
 P_2 = (atm. pressure + gage pressure), the pressure rise.

$$\text{Now, } T_2 = (\text{ambient temp} + 273) \times (P_2/P_1)^{0.283}$$

At 34°C ambient temperature,

$$\therefore T = (34^{\circ}\text{C} + 273) \times (10.0/1)^{0.283} = 589.03^{\circ}\text{K} \text{ (assuming, } P = 10 \text{ kg/cm}^2\text{)}$$

Now, Putting the values of L , f , T , from above in eq. 3.4.

$$H = 9.82 \times 10^{-8} [(0.026)(96.619)(589.03)(1.0)^2] / [(10.0)(0.01905)^5]$$

$$H = 5791.75 \text{ mm of water or, } 0.579 \text{ kg/cm}^2$$

$$\therefore \text{Total pressure required: } 9.1 \text{ kg/cm}^2 + 0.579 \text{ kg/cm}^2 = 9.68 \text{ kg/cm}^2$$

It may be considered that a compressor of 10 kg/cm^2 capacity pressure would fulfil the purpose. Compressor power requirements may be estimated from the airflow, discharge & inlet pressures, and air temperature by using the eq: 3.7, which are based on an assumption of adiabatic conditions (McGhee, T. J., 1991)

$$P = [(wRT_1)/(8.41 e)] \times [(P_2 / P_1)^{0.283} - 1] \quad [3.7]$$

Where, P = power required in kW.
 w = air mass flow in kg/s
 R = gas constant (8.314)
 T_1 = inlet temp in $^{\circ}\text{K}$
 P_1 = inlet pressure in atm.
 P_2 = outlet pressure in atm.
 e = efficiency of the machine (Usually 70% - 80%).

$$P_{kw} = [(0.01918 \times 8.314 \times 307) / (8.41 \times .75)] \times [(9.678 / .95)^{0.283} - 1].$$

$$P_{kw} = 7.35.$$

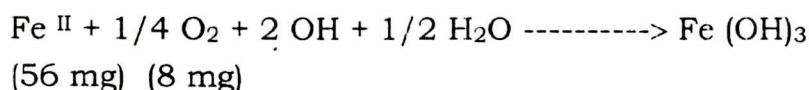
Hence, the motor with 1% belt slippage and 99% efficiency becomes
 $7.35 / (0.99 \times 0.99)$
 $= 7.42 \text{ kW} \Rightarrow 7.5 \text{ kW}$ motor may be coupled with the compressor.

Amount of Air required to be injected to ground water by the air lift pump.

The amount of air discharged by the compressor has the importance on two major grounds - to ensure the desired discharge of water by the airlift pump and to aerate properly thereby ensuring proper oxidation of the water during the time of lifting.

Best operation of an airlift pump requires good regulation of the amount of air being injected. Too much of air causes excessive friction in the pipe lines and waste of air on the other hand too little air results in reduced yield & intermittent discharge (kill, D., 1973).

Again it is assumed that only 01 mg DO is required to oxidize 07 mg of iron, which can be calculated from the following relationship.



In other words, 7mg/L of iron is being oxidized by 1 mg/L of oxygen. Hence oxygen requirement to oxidize water containing 12 mg/L of iron will be $(1 \times 12) / 7 = 1.714 \text{ mg/L}$.

For the water discharge at the rate of 7.0 Liter per second, O_2 requirement will be $7.0 \times 1.714 = 11.998 \text{ mg/sec}$

Or, $11.998 \text{ mg/sec} \times (1\text{g}/1000\text{mg}) \times (1\text{kg}/1000\text{g})$
 $= 11.998 \times 10^{-6} \text{ kg/sec}$ oxygen is required.

Again air contains 23.2 % oxygen by weight and at standard temperature and pressure, has a density of 1.2 kg/m³, hence the amount of air required is given by (McGhee, T. J., 1991)

$$Q_{\text{air}} = [\text{O}_2 \text{ demand}] / [0.232 (1.2)] \quad [3.8]$$

Assuming the efficiency of transfer of oxygen from air to be 10%, the air flow required is

$$\begin{aligned} Q_{\text{air}} &= [11.998 \times 10^{-6} \text{ kg/sec}] / [0.232 (1.2 \text{ kg/m}^3) \times 0.1] \\ &= 4.31 \times 10^{-3} \text{ m}^3/\text{sec}. \end{aligned}$$

$$\text{Or, } 4.31 \times 10^{-3} \text{ m}^3/\text{sec} \times (60 \text{ sec}/1 \text{ min}) \times (1000 \text{ L}/\text{m}^3) = 25.86 \text{ L/min.}$$

Hence, for aeration of the ground water, free air is to be injected at a rate higher than 26 liter/min.

In addition to the oxygen transfer, the amount of air is important in an airlift pump for its capability of water discharge and is based on well known formulae $P_1V_1 = P_2V_2$. [P= pressure; V= volume]. Once the desired pressure is chosen, the volume of water discharge is directly proportional to the volume of air being injected into the water column inside tube well.

Hence an air compressor with 10kg/cm² pressure and with highest airflow capacity is selected on the basis of availability in the local market.

Selection of the Pump Fixtures

The general piping assembly used for airlift pumping from a well consists of a vertical discharge pipe - called the column pipe and a smaller diameter air pipe. Both the column pipe and the air pipe must be submerged in water in the well with sufficient percentage of their lengths extending below the pumping water level. Submergence is the proportion of the length of the airline that extends below the water level. It is the length of air line that is submerged below the pumping level divided by the distance from the level of water discharge to the lower end of the air line and multiplied by 100 to give the result as a percentage. Referring to fig. 3.1, Percent submergence = $[A/(L+A) \times 100]$.

Both the column pipe and the airline must be submerged in water in the well with 40% or more of their lengths extending below the pumping water level. The airlift pump works best with a submergence of 60 percent or more (Kill, D., 1973).

Again the velocity in the column pipe depends upon the volume of air and water being discharged and the area of the annular space between the airline and the column pipe.

Kill, D.(1973) presented a table that gives the sizes of airlines for various sizes of column pipes. The table recommends that for a discharge of 9 to 16LPS, the sizes of airline and that of column pipe should be 3.75cms and 12.5cms respectively. On the other hand in a turbine pump having 14 to 20LPS capacity has column pipes of 10cms dia. These M.S. column pipes are suspended from the discharge head. The coupling sockets are there to provide drive shafts centrally fitted inside.

Kill, D., (1973) also observed that when the water yield is unusually low, the difference between the size of column and air pipes may have to be less in order to reduce the area of the annular space and thus increase the discharge velocity enough to prevent excessive air slippage in the column pipe

Now there are mainly two ways of airlift arrangements as follows

- i. The air pipe passes inside the column pipes.
- ii. The air pipe is carried down outside and parallel with the column pipe and turned in near the bottom end of the pipe.

However among the arrangements the inside airline is preferred, as its depth can be adjusted by trial and error method, if some adjustments are to be made.

In the present case, the column pipes of 10cm dia. used in turbine pumps, may be selected for installation into tube well housing pipe since this arrangement can easily be converted to turbine pump with simple modification. Moreover with this arrangement, pumping water level can then be measured with steel or electronic tapes. To allow sufficient submergence of the airline pipe, 30M column pipe-same as housing pipe length, may be installed.

The column pipe's sockets can accommodate the line or drive shafts passing through these. The sockets have rubber bushing inside those the drive shafts of a turbine pump rotate. In this case G.I pipes of 1.9cm dia to serve as the airline pipe are installed through the rubber bushings of the column pipe sockets.

A higher diameter airline could be used as had been suggested in the table shown by Kill, D. (1973) but the rubber bushings of the column pipe socket will not permit it.

A flexible rubber hose pipe of same diameter may also be chosen to connect the outlets of the air compressor and the G.I. airline pipe. The bottom end of the airline may be kept arbitrarily at least ten feet above from that of the column pipe.

Selection of Discharge head.

The same discharge head as normally is being used in 100mm X 75 mm turbine pumps is selected. It was meant for the following purposes:

- the M.S. column pipes and air line pipes are suspended into the tube well housing from it.
- to divert the direction of flow to about 90° when the flow reaches into it.
- delivery pipe up to the inlet of the flocculation chamber is attached to it.
- to cover tube well opening at the pump house floor.
- to provide a port to lower the probe and wire line to measure the water level inside the tube well.

Selection of Delivery pipes.

M.S. pipe of suitable diameter compatible with the discharge head may be fitted with the outlet of the discharge head up to inlet of the iron removal unit.

Thus the designed airlift pump would consist of

- i. an air compressor with 10kg/cm² pressure and with highest airflow capacity as may be available in the market.
- ii. one set of turbine pump fixtures without pump bowl and line shafts, such as,
 - a. 100mm dia. pump column pipes of 3048 cm length (same as housing pipe),
 - b. discharge head and
 - c. delivery pipe (7.6cm dia ms pipe with suitable length from discharge head up to inlet chamber of the iron removal unit.
- iii. air line pipes (1.9cm dia; 2743 cm length G.I. pipes).

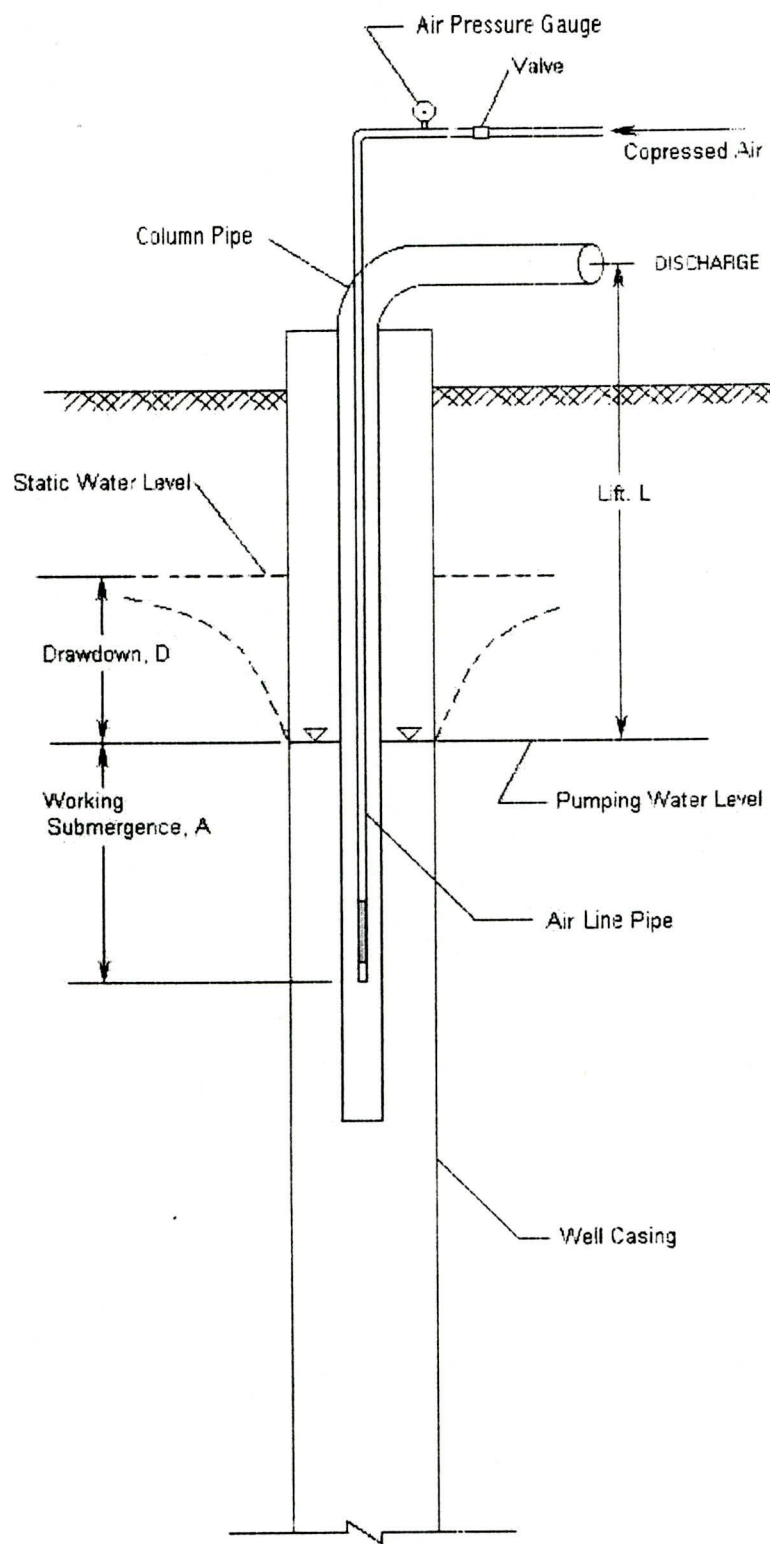


Fig 3.1 : Principle of operation of an airlift pump

3.1.2. Flocculation

The most important task of a water treatment process is the separation of colloidal suspended particles from water, which are roughly concentrated in the sub-micron size range. A combination of mixing and stirring or agitation that produces aggregation of colloidal suspended particles is called flocculation. The destabilized particles or precipitates formed by aeration are of very small size and are not heavy enough to settle down due to gravity.

A study by Forbes (1984) showed that when ferrous iron solution with initial concentration on the order of 2-5 mg/l is oxygenated, the precipitate is roughly concentrated in sub micron size range. Such particles would have a stokesian settling velocity on the order of 10cm / day under quiescent conditions. This translates to a surface overflow rate (SOR) of 102 LPD/m², a factor of 400 lower than that of a typical sedimentation basin. So to enhance the settling characteristics it is proposed for flocculation before settling.

Choice of a flocculator

Usually the sources of power for flocculation devices are gravitational, pneumatic or mechanical. In the present case, the mechanical flocculators (reviewed in chapter II.) were not used as they require extra power. Baffle flocculators require large number of baffles, which are costly to construct. Rotating paddles or impellers need electricity that also adds extra cost.

A simple solution to the flocculation process is the one involving coarse media bed in which water is allowed to flow through a packed bed of coarse media. The hydraulic flocculator e.g. gravel bed flocculator which consist of a bed of gravel proves to be simple, reliable and inexpensive. The packed bed of gravel provides ideal conditions for the formation of compact settleable flocs because of continuous recontacts provided by sinuous flow of water through the interstices formed by gravel. Besides, gravel bed flocculator has the ability to store agglomerated flocs within the interstices or to settle flocs below the gravel due to drop in velocity or even during continuous flow through the floccularors. These agglomerated flocs will further help in adsorbing finer particles as they come into contact with the settled flocs. This type of flocculator occupy small area and no external source of power is required.

Moreover the whole bed of coarse media is effective for flocculation purposes (Ahmed, 1995). Some researchers used satisfactorily locally available brick chips as coarse media. Hence brick chips flocculators may be used in the plant before sedimentation.

3.1.2.1. Design of coarse media flocculator

Design parameters.

In the process of flocculation the sub micron size precipitates are brought into contact in order to promote their agglomeration. The rate of agglomeration or flocculation depends on the number of particles present, the relative volume, which they occupy, and the probability of collisions among the particles. Collision may result from variable velocity of suspended particles and from micro pulsation 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., G .

Extended mixing also multiplies the recurrence of floc formation and damage, leads to the screening of active centres, decreases the flocculation rate and reduces floc. CAMP has developed the flocculation criteria for optimum floc formation by combining the average velocity gradient with the mean or displacement time. This is expressed as dimensionless CAMP number, Gt_d (Fair, Geyer and Okun 1971). A specific range of values is maintained for a particular condition.

The design and performance of a flocculator is related to the term Gt_d and G . Ahmed (1995) proposed a design guidelines that in a coarse media flocculator, the mean velocity gradient G and CAMP number Gt_d are mainly a function of face velocity, (Q/a) and length of flocculator, L respectively. Both the terms are inversely proportional to the size of the coarse media; d although G is directly proportional to Q . CAMP number is independent of Q .

The requirements for the flocculation process in coarse media beds can be defined in terms of the expression for the average velocity gradient of fluid motion. Ahmed (1995) derived expressions for ' G ' and Gt_d in coarse media bed.

$$G = 8.38 * (Q/a)*(S/d) \quad [3.9]$$

$$G t_d = 3.354 * (s/d)*L \quad [3.10].$$

The detail of the expressions are shown in annexure II-F.

Annular brick chips may be used as coarse media in the flocculator. The size of the khoa or gravel can be determined with the derived equations. Ahmed (1995) recommended the ranges of values of some parameters. A face velocity, Q/a , between 0.1 to 0.3 cm/sec for average 0.75 to 0.85 cm. dia, size of coarse media flocculators (gravels) d , may be chosen. Again for a range of CAMP number, Gtd , between 3000 to 6000, lower mean average velocity gradient, G , between $10^{-\text{sec}}$ to $20^{-\text{sec}}$ gives better iron removal performance under laboratory condition.

Design of the flocculator

Though the deep tube well, the source of water, has the capacity of 14 LPS, it is assumed that the pump would have 7 LPS discharge capacity. For horizontal flow let us assume a clear cross-section of 300 cm X 244 cm (10' B X 8' H) for handling the water flow into the iron removal unit. A height of 244cm can allow a man to clean and maintain it easily, The effective height of the flocculation chamber may be taken 215 cm.

Now with 40% porosity of the coarse media flocculator in the flocculation chamber, the face velocity, (Q/a) becomes $(7 \times 1000)/(300 \times 215 \times 0.4) = 0.271 \text{ cm/sec}$.

Due to clogging the face velocity increases, assuming a 10% increase of the velocity, the designed face velocity becomes $0.271 \times 1.1 = 0.298 \text{ cm/sec}$, which fall within the recommended range of 0.1 to 0.3 cm/sec.

According to Charman (1937) the shape factor, S for brick chips is 7.7. Putting the value in eq. 3.9 of average velocity gradient G , developed by Ahmed (1995),

$$G = 8.38 \times (Q/a) \times (S/d).$$

$$\text{Or, } G = 8.38 \times 0.298 \times (7.7/d),$$

$$\text{Or, } G = 19.2287/d \quad [3.11].$$

Brick khoa size, d can be found out against the recommended ranges of G values from eq. 3.11.

$$\text{Thus } d = 1.90 \text{ cm for } G = 10^{-\text{sec}}$$

$$\text{And } d = 0.96 \text{ cm for } G = 20^{-\text{sec}}$$

Hence the range of coarse media can be taken between 1.9 cm and 0.96 cm.

Taking an average value of d and putting the value in eq.3.10. to find out the length of the flocculation chamber within the recommended value range of Gt_d .

$$Gt_d = 3.354 \times (s/d) \times L.$$

$$\text{Or, } Gt_d = 3.354 \times (7.7/1.43) \times L$$

$$\text{Or, } Gt_d = 18.06 \times L \quad [3.12].$$

Calculating the values of L for different Gt_d , in eq. 3.12.

$$L = 166.00\text{cm for } Gt_d = 3000$$

$$L = 332.00\text{cm for } Gt_d = 6000$$

$$L = 249.00\text{cm for } Gt_d = 4500.$$

Hence $L = 249\text{cm}$ may be taken considering an average Gt_d value of 4500.

3.1.3. Sedimentation.

Two major classifications of sedimentation basin are:

- i. Horizontal flow unit.
- ii. Up flow unit.

Since up flow unit requires extra head for the collection of water, so horizontal flow unit may be recommended for plain sedimentation. The sedimentation chamber would receive water from flocculation chamber in which large flocs are formed. These flocs will settle down due to gravity in the sedimentation tank.

The partition walls of the flocculation chamber will retain coarse media flocculators inside it. The walls have sufficient numbers of holes to allow water to flow through it. But if the effluent water from the flocculation chamber enters the adjacent sedimentation chamber through these holes horizontally, there would be disturbance in the sedimentation action. Hence the flow from the flocculation chamber is desired to enter from the upper end of the sedimentation chamber. Therefore, an intermediary compartment between the flocculation and sedimentation chamber is recommended to make a continuous sheet of water flow over the common separating lined wall cum weir between the intermediary compartment and the sedimentation chamber.

3.1.3.1. Design of Sedimentation Chamber

Overflow rate or settling velocity,

$$V_s = Q / (B \times L) \text{ in cm}^3/\text{cm}^2/\text{min} \quad [3.13]$$

Where, Q = Flow rate (cm^3/min)
 B = width of sedimentation chamber, cm.
 L = Length of sedimentation basin, cm.

It has been shown (Ahmed 1995) that a range of overflow rates (SOR) in between 1.25 and 1.50 $\text{cm}^3/\text{cm}^2/\text{min}$ may be selected for the design of a sedimentation basin.

Taking $V_s = 1.50 \text{ cm}^3/\text{cm}^2/\text{min}$, in eq. 3.13.

$$\text{Or, } 1.5 = Q / (B \times L), \quad \text{Here water flow } Q = 7.0 \text{ liters / sec} \\ = 420000 \text{ cm}^3/\text{min}$$

$$\text{So, } 1.5 = 420000 / (B \times L)$$

$$\text{Or, } (B \times L) = 280000 \text{ cm}^2.$$

It is desired that 12ppm iron content should come down to at least 1ppm which is required for piped water flow. Hence 92% iron removal is essential. Assuming 5% removal is accomplished in the outlet chamber after the sedimentation chamber, 87% of iron content must be removed up to sedimentation chamber. In flocculation chamber with plan area of $249 \times 300 = 74,700 \text{ cm}^2$, settling of iron floc will occur. Again iron flocs will settle in the compartment in between the flocculation and sedimentation chamber, the proposed surface area of which is $(300 \times 60) \text{ cm}^2 = 18,000 \text{ cm}^2$. Considering these,

$$[B \times L] = [(280000 \times 0.87) - (74,700 + 18,000)] = 150900 \text{ cm}^2.$$

Keeping $B = 300\text{cm}$ to adjust the flocculation chamber, the length to be maintained, $L = [150900/300] = 503 \text{ cms}$.

Hence the size of the sedimentation chamber may be taken = $[300 \text{ cm} \times 503\text{cm}]$.

3.2.0. Development of the Iron Removal Unit of the Subsurface Aerated Water

The iron removal unit would be based on the design shown in art. 3.1.2 to 3.1.3. The unit would use the horizontal flow of aerated water under gravity and consists of the flocculation chamber with coarse media flocculator and a plain sedimentation chamber. The sedimentation chamber would be rectangular type, the flow would be directed along the longer axis. The chamber offers certain economics in construction by using common wall design.

There would be two compartments at the two ends of the run, meant for inlet and outlet of water flow and an intermediary compartment in between the two chambers meant for stilling the water flow from the flocculation chamber and changing the flow path towards the sedimentation basin. The water will flow horizontally to the flocculation chamber from the inlet compartment that receives aerated water from the delivery pipe of the airlift pump. The partition walls of the flocculation chamber will be brick built to retain coarse media flocculators inside it having sufficient numbers of holes to allow water to flow through it.

To have smooth inner surface area of the holes and ease in construction and subsequent maintenance, 13 mm dia. PVC pipes may be installed at equal distances from each other throughout the entire area of the wall of the inlet side and likewise at the outlet side of the flocculation chamber.

The intermediary compartment between the flocculation and sedimentation chamber is recommended to be constructed to make a continuous sheet of water flow over the common separating wall cum weir between the intermediary compartment and the sedimentation chamber. Here at this point an arrangement would be made to trap the iron flocs due to settling effect and to bail out the deposited sludge from the chamber by a sludge pump.

The slope of the floor would be towards the sludge sump constructed at the base of the weir. So that two suction pipes from a single sludge pump can bail out the sludge, deposited in the hopper type trap made crosswise at the base of the two sides of the weir. Water flows and passes the sedimentation chamber to the outlet compartment and from there to underground reservoir through M.S. pipes.

The designed plan of the iron removal unit is shown in fig, 3.2 and that of the section on A-A of the plan is shown in fig, 3.3. The section on A-A shows the IRU in detail. The aerated water from the delivery pipe of the airlift pump would fall in the left end chamber from the top and passes to the flocculation chamber through a number of 1.27cm dia holes, built through the wall. This wall is unlike the second partition wall of the chamber in that it may consist of holes in its full area i.e. 244X 300cm area. On the other hand the holes in the second wall would not be allowed to install in areas beyond at least 210cm height from the floor because the flow from these holes would not get stabilised prior to enter into sedimentation chamber over the weir.

The RCC weir crest is 213cm high from the floor although it has a total height $(213 + 20 + 30) = 263\text{cm}$ from the floor of the sludge sump. The RCC weir is 13cm thick up to a depth of 213cm but 25cm at the pedestal in sludge sump floor. The RCC floor of the unit is 25cm in thickness at the start but becomes 20cm at the end of the flocculation chamber maintaining a slope towards the sump at the FFL.

The RCC floor thickness is 20cm throughout its length but maintains a 50:1 slope towards the sludge sump. The important aspect of the floor levels is that at the sides of the sump end the floor of the flocculation chamber is at a level of 13cm above than that of the sedimentation chamber. To maintain a water height of 213cm equivalent to the height of the weir, the height of the end wall of the sedimentation chamber has been designed to be $[(213+13) - (1/50) \times (504-90)] \approx 218\text{cm}$. The water would remain stagnant in the flocculation chamber as well as the sedimentation chamber up to the weir height or end wall height and start flowing over the weir crest or end wall when only the pump is in operation. The water spills over the end wall of the sedimentation chamber to the reservoir via the outlet chamber. As the elevation of the underground reservoir is lower than the IRU the out let chamber would remain only half-full.

The flocculation chamber may be packed up with coarse media flocculator in full depth. When void volume decreases with time due to sludge trap, the inlet chamber may over flows thus higher head loss occur.

The RCC baffle wall has been designed at a distance of 61cm prior to the end wall of the sedimentation chamber has a depth of 91cm from the anticipated water surface and has been designed to divert the flow towards the floor for more floc to settle.

3.3.0. Construction of the iron removal Plant

A deep tube well was commissioned as the source of potable water for the campus. The designed capacity of the tube well is 14 LPS. The diameter of the housing pipe is 355 mm which is sufficient to accommodate pump bowl of a turbine pump. It is assumed that the airlift pump will pump 7 LPS discharge. The full iron removal plant thus consists of

- i. An air lift pump.
- ii. A flocculation chamber with coarse media flocculator.
- iii. A simple plain sedimentation tank.

3.3.1. The construction of the air lift pump

The design of airlift pumps is largely empirical. The materials and fixtures have been chosen on the basis of availability in the local market and ease in installation. The components of the designed air lift pump are:

- i. One air compressor.
- ii. One set of pump fixtures such as,
 - Pump column pipes,
 - Air line pipes,
 - Discharge head and
 - Delivery pipes.

The components of the developed airlift pump are shown in the fig: 3.4.

3.3.1.1. Procurement of the Air compressor

A suitable compressor may be selected using two parameters: compressor capacity and compressor pressure. Hence the procured air compressor with 10kg per cm² pressure and with 1600 LPM or 56.5cfm displacement capacity on the basis of availability in the local market, may be suitable for the plant.

Thus the *VESPA* air-compressor with auto stop device, manufactured by Ming Tyan Iron Works Co., Ltd. Taiwan, was installed. The specification of the compressor is as follows:

Model	Motor, kW	Bore x stroke mm	Cylinder, Nos.	Working pressure kg/cm ²	Max. Pressure, kg/cm ²	Compre ssor speed, RPM.	Displac ement, cfm.
MT- 410P	7.5	95x75	4	8	10	750	1600 LPM or 56.5 cfm

TABLE 3.1 Specification of VESPA air-compressor

Air is a compressible fluid. At ambient temperature and pressure its volume would be the displacement volume.

3.3.1.2. Installation of the Pump Fixtures

Among the arrangements, installation of airline inside the column pipe is preferred, as its depth can be adjusted by trial and error method, if some adjustments of placement are desired.

In a KSB or any equivalent turbine pump having 14 to 20LPS capacity has column pipes of 100mm dia. These M.S. column pipes are suspended from the discharge head. The coupling sockets are there to provide drive shafts centrally fitted inside. To allow sufficient submergence of the airline pipe, 30.48 M column pipes have been designed. The length of column pipe installed was 3048cm as has been shown in fig., 3.4.

Installation of the airlines

The column pipe's sockets with water lubricated rubber bushings can accommodate the line or drive shafts to run impellers inside a pump bowl, passing through these. The sockets have rubber bushing inside those the drive shafts of a turbine pump rotate.

In this case G.I pipes of 1.9cms dia., to serve as the air line pipe are installed through these rubber bushings of the column pipe sockets. This prevents sagging and axial movement of the airline pipe. A higher diameter airline could be used but 1.9 cms diameter was chosen on the basis of ease in installation inside column pipe socket.

The total length of the airline pipe was 4542 cm. Later on it was reinstalled with such a length that the lower open end was at a depth of 300cm less than the column pipe's end which was 3048 cm (fig. 3.4).

A flexible rubber hose pipe of same diameter is also chosen to connect the outlets of the air compressor and the G.I. airline pipe.

Installation of the Discharge head and Delivery pipe

The same discharge head as is being used in 100 mm X 75 mm turbine pumps was installed. A 75mm dia. M.S. pipe was fitted as the delivery pipe with the outlet of the discharge head up to inlet of the iron removal unit.

3.3.2. Flocculation Chamber

The designed dimension of the flocculation chamber for a water flow of 7 LPS was calculated to be 300cm X 249cm. The actual dimension of the flocculation chamber is 302cm X 234cm and is shown in fig:3.6. It is deviated from the designed dimension due to lack of prior proper design as well as bad workmanship of the contractor. The separating brick walls made were provided with holes for water flow towards sedimentation basin. Thirteen millimeter dia PVC pipes of lengths similar to the wall thickness (127mm) were installed at equal distance apart for the purpose.

3.3.2.1. Coarse media flocculator

Annular brick chips were used as coarse media in the flocculator. The flocculation chamber was made packed up with brick khoa. The size of the coarse media was chosen arbitrarily 4.5 cm to 5.0cm for the first run and that of second run was 3.0cm to 4.00cm, though the designed size range was 1.9cms to 0.96cms.

3.3.3. Sedimentation chamber

The plain sedimentation unit was designed for horizontal flow for the collection of flocculated water. The sedimentation chamber receives water from flocculation chamber in which large flocs are formed. These flocs settle down due to gravity in the sedimentation basin.

3.3.3.1. Construction of the Sedimentation Chamber

The size of the sedimentation chamber was designed as 300 cm x 504cm. But during construction it was made 302cm X 438cm. A depth of 213cm was desired but have been constructed and maintained by the weir of height 209cm. But to adjust with the depth of the adjacent chamber for flocculation, the roof height of the unit from the floor is 244cm.

3.4.0. Development of the Iron Removal Unit of the Aerated Water

The unit uses the horizontal flow of aerated water under gravity and consists of the flocculation chamber with coarse media flocculator and a plain sedimentation basin.

There would be two compartments at the two ends of the run, meant for inlet and outlet of water flow and an intermediary compartment in between the two chambers meant for stealing of flow & changing of flow path towards sedimentation chamber. The unit have been constructed as per description given in art. 3.2.4 with deviation in dimension. The unit actually constructed is shown in fig. 3.6 and 3.7. The partition walls of the flocculation chamber has a few number of 1/2" dia holes made by installing 1/2" dia PVC pipes through the walls to allow water to flow.

There is a sludge pump coupled with 1hp. Single phase horizontal motor, having two 1" dia. G.I. suction pipes, at two sides of the weir in the sludge sump by which the deposited sludge is being bailed out from the IRU. The outlet compartment has two nos. 150mm dia m.s. pipes connecting the underground reservoir.

3.4.1. The deviations between the designed and the actually constructed iron removal unit.

The deviations observed are presented in the following table:

Component	Designed dimension	Constructed dimension
1. Width of all chambers	300cm	302cm
2. Length of chambers		
a. inlet	50cm	51cm
b. flocculation	249cm	234cm
c. intermediary	60cm	56cm
d. sedimentation	504cm	438cm
e. outlet	50cm	49cm
3. Height		
a. weir crest	213cm	204cm
b. end wall of sedimentation chamber	218cm	213cm
c. baffle wall	91cm	107cm

Table 3.2 : The deviations between the designed and the actually constructed iron removal unit

3.5.0. Working Principle of the Iron Removal Plant

The plant consists of many components. The main components of the plant are: i. The Airlift pump. and ii. The Iron removal Unit.

The air compressor is the source of air that flows through the airline and escapes inside the column pipe. To get sufficient submergence both the pipes have been installed at a safe depth within the housing pipe. Air-water mixture rises up to the surface and flows to the inlet of the Iron Removal Unit.

From the inlet compartment, the aerated water flows through the wall holes of the flocculation chamber and passes through the coarse media flocculators and subsequently passes over a weir, the common partition of the intermediary compartment and the sedimentation chamber. The water then overflows to the plain sedimentation chamber and from there to the outlet compartment of the plant. Treated water then goes to the underground reservoir through 2 nos. 150 mm dia M.S. pipes, fitted with the wall of the outlet compartment.

3.6.0. The estimate and costing of the iron removal unit(IRU)

The costing of the iron removal unit consisting of flocculation and sedimentation chambers etc. was Tk.1,87,605.00, the detail is shown in appendix: III.

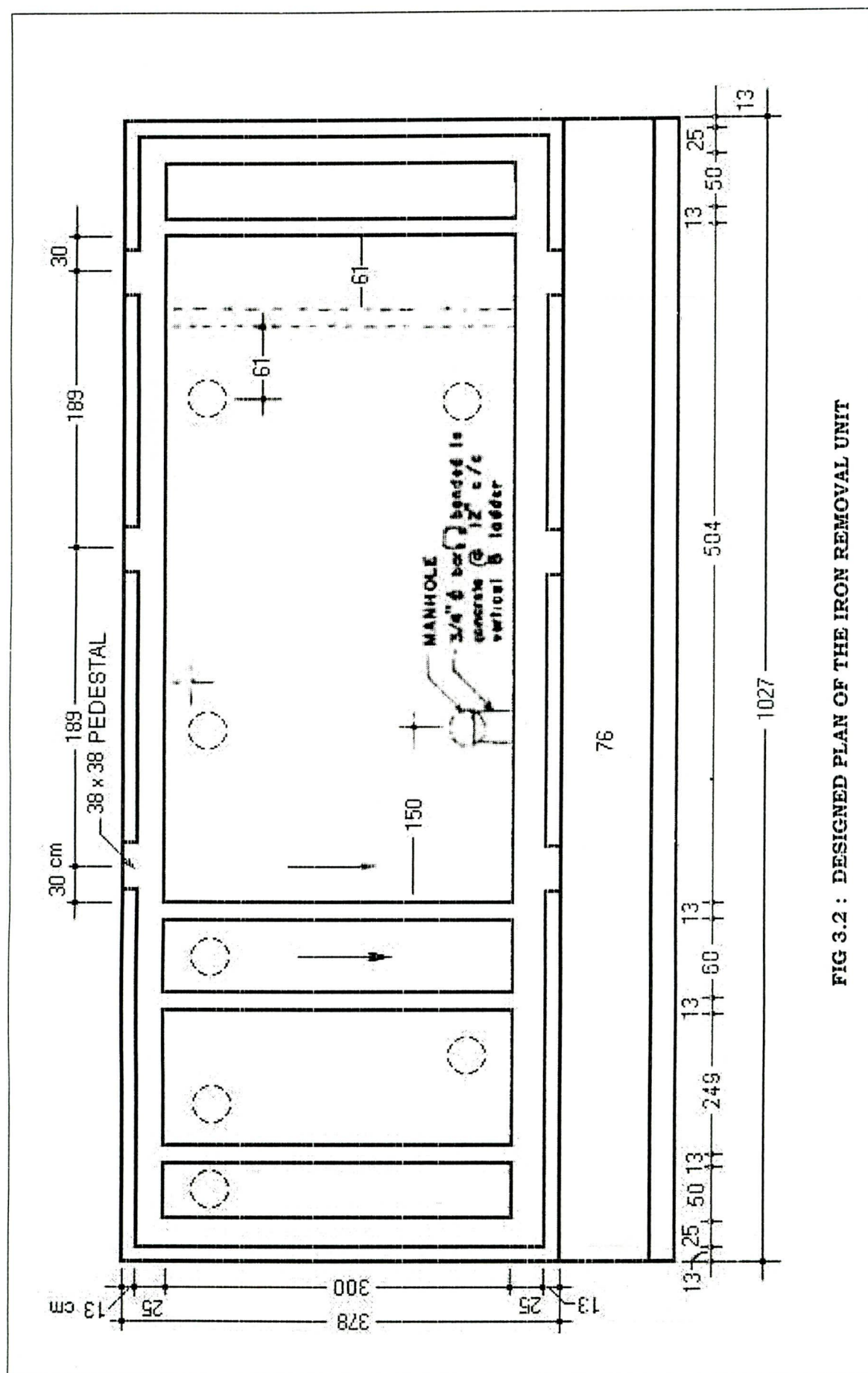


FIG 3.2 : DESIGNED PLAN OF THE IRON REMOVAL UNIT

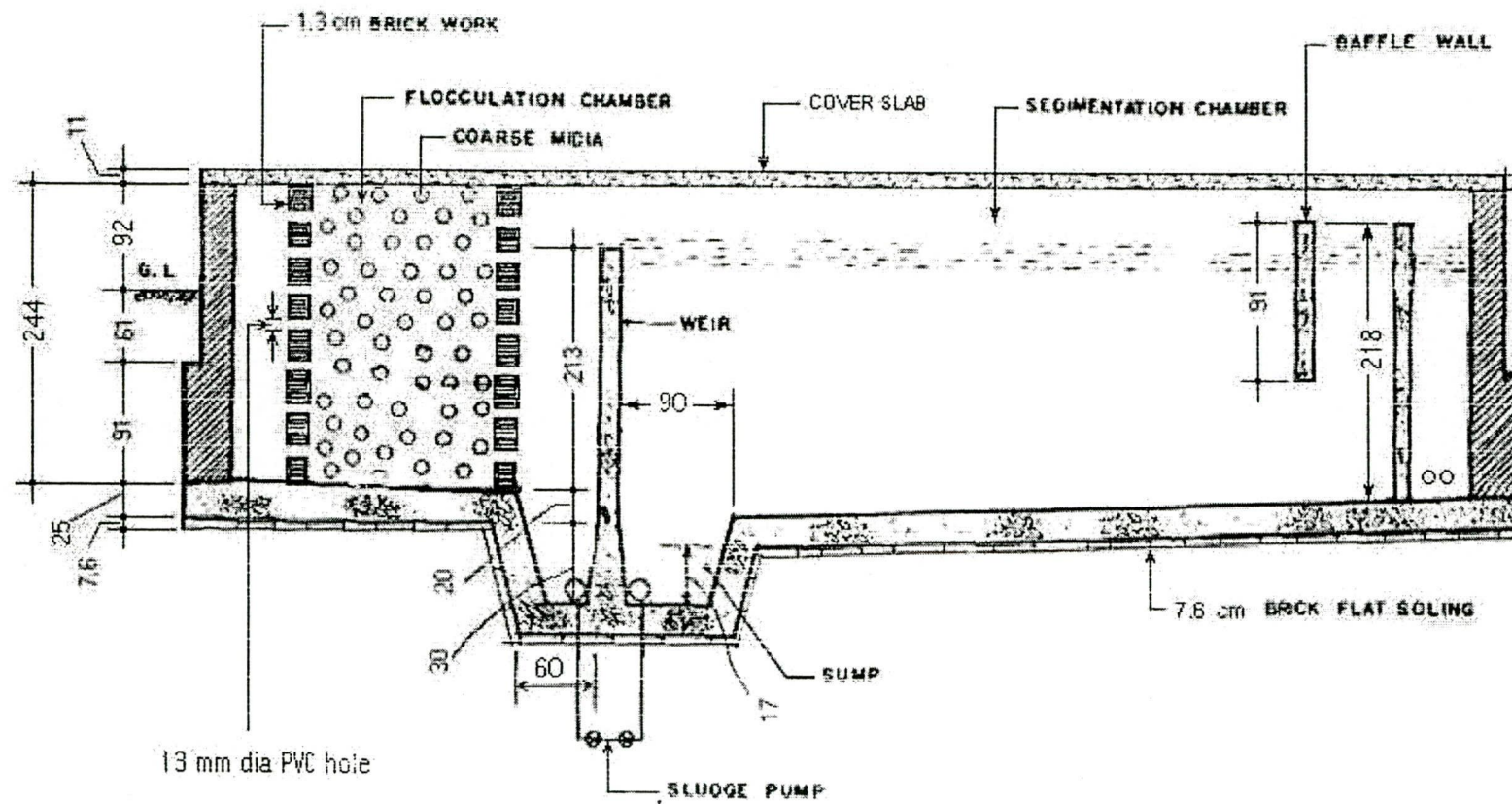


FIG 3.3 : DESIGNED SECTION ON A-A OF THE IRON REMOVAL UNIT

AIR LIFT PUMP FOR DEEP TUBE WELL

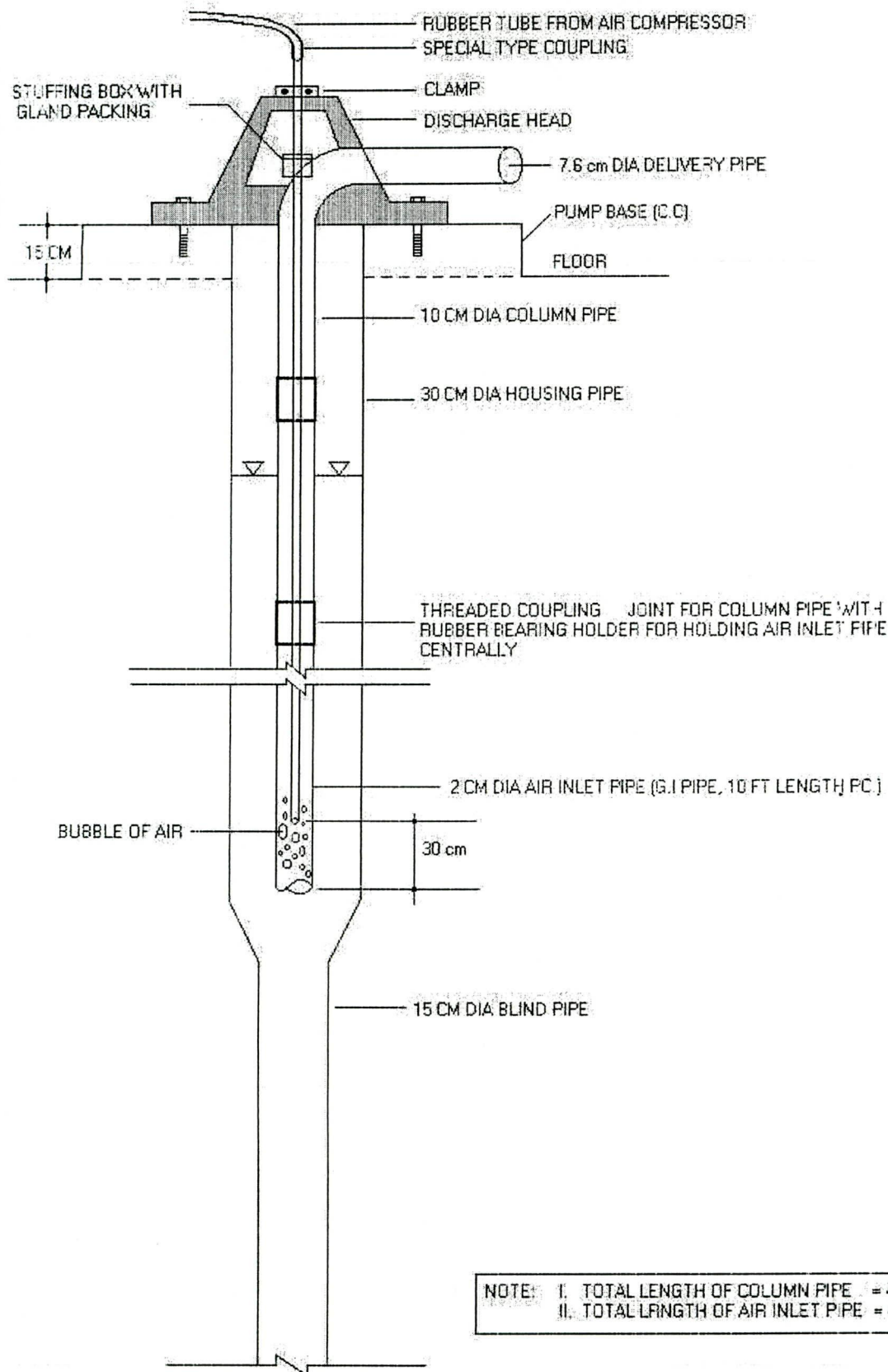


FIG 3.4: Air lift Pump for Deep Tube Well

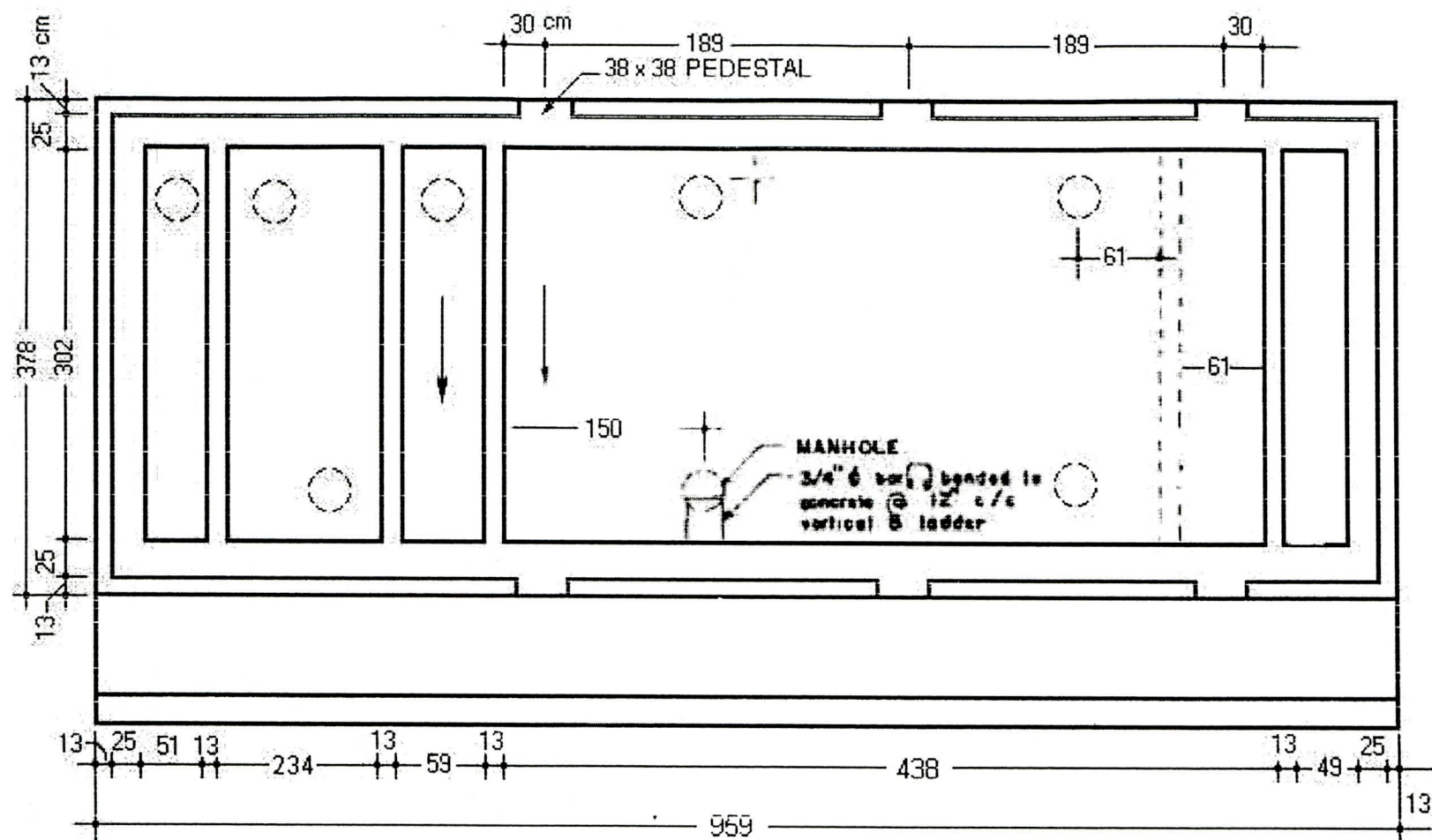
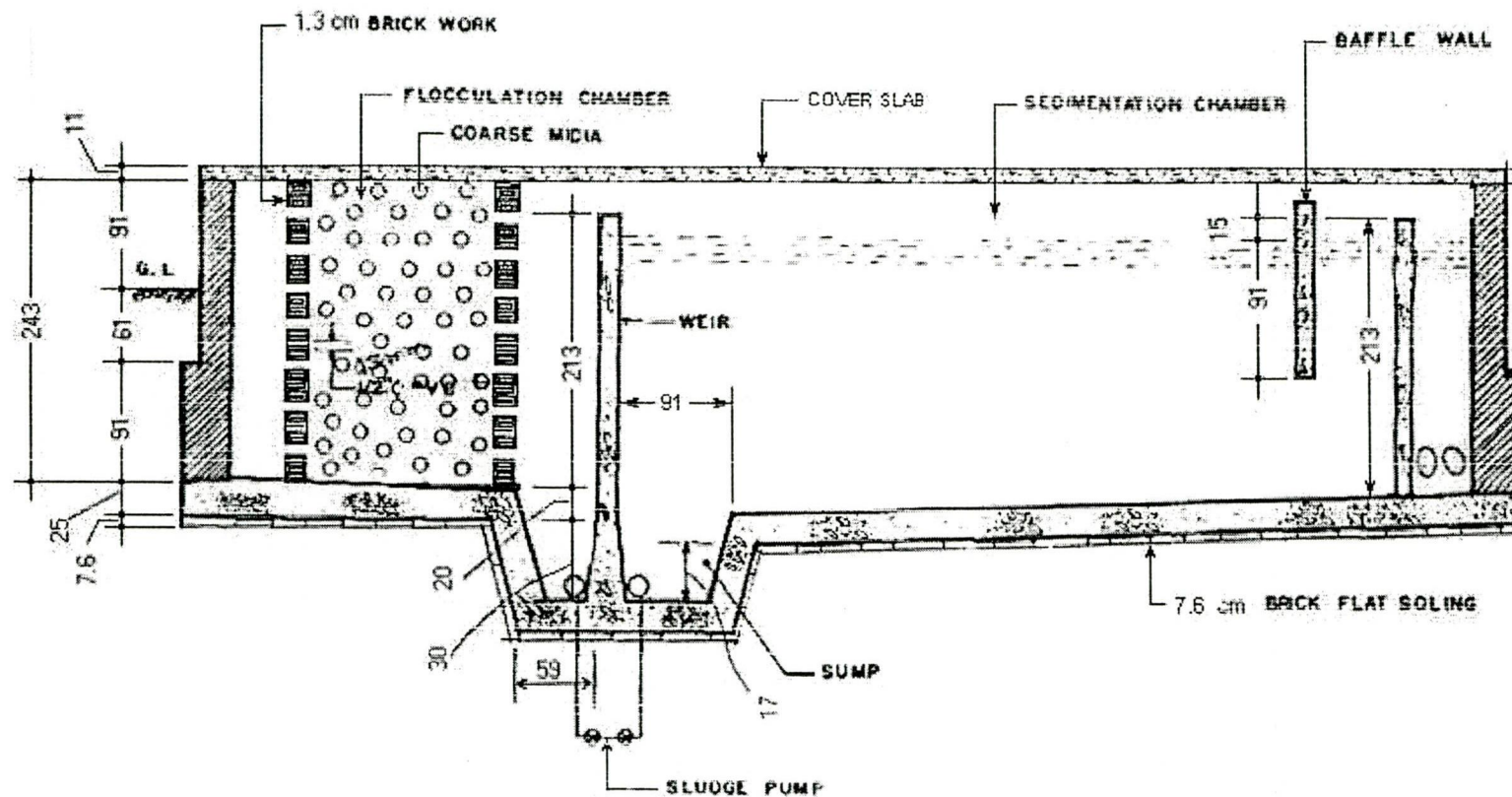


FIG 3.5 : CONSTRUCTED PLAN OF THE IRON REMOVAL UNIT



SECTION ON A-A

SCALE: 6.25 cm = 25 cm

FIG 3.6 : CONSTRUCTED SECTION ON A-A OF THE IRON REMOVAL UNIT

CHAPTER IV.

METHODOLOGY.

4.0.0. General

The methodology includes investigation of the design and construction of the existing as well as modified iron removal unit of the pilot plant. This includes various investigations through field test as well as laboratory test. This also includes measurement of tube well discharge; the existing iron concentration of tube well water; sampling of water at different points of flow of the removal unit; laboratory test and of data analysis. The regeneration of the flocculation chamber as well as iron encrusted tube well are also analyzed.

4.1.0. Water Sampling and sampling points

A sample is a part collected or taken from a large quantity of an item and is presented as the representative of the whole. As the subsequent conclusions, decisions and actions depend on the result of the sample initially collected, the sampling technique must assure that the representative samples are collected and observed accurately. Sampling location is the point from which a sample is collected to represent the characteristics of the whole amount at that particular point. In the present case, three locations were selected to collect water samples. These were:

- Point-i: End of flocculation chamber.
- Point-ii: End of sedimentation chamber.
- Point-iii: End of the outlet chamber of the IRU.

Samples from the end of the flocculation chamber and sedimentation chamber provide the characteristics of water after flocculation and sedimentation respectively (point-i & ii). The last sample (point-iii) provides the characteristics of finally treated water.

4.1.1. Sampling procedure and sampling frequency

Samples were collected from the selected three locations during first run. An additional point at the pump discharge pipe was included to get sample after aeration during the second run. The samples were kept in clear plastic bottles with caps. Hydrochloric acid was mixed with the samples for preserving it in stabilized position up to the time of testing.

The samples for determining iron concentration were collected with regular interval of a day and for 30 days for each run.

4.2.0. Tests of Samples

The sample collected from different locations of the plant were transported to the BUET laboratory. On the other hand field test of certain parameters were done at site.

4.2.1. Laboratory Tests of Samples

The sample collected were tested in the BUET laboratory for iron concentration in various chambers through extensive laboratory analysis.

Measurement of Iron concentration

The laboratory analysis to find out iron concentration was done with the help of digital spectrophotometer. The detail procedure is presented in appendix III-B.

4.2.2. Field Tests

Some field tests were conducted for dissolved oxygen(DO) content and pH of water. The dissolved oxygen content was measured with the help of an DO meter (Make & model: Oxygen meter OX 20 WPA). The meter was calibrated in the BUET laboratory. A sample of water was taken. The probe of this meter and the probe of another newly calibrated meter (HACH) were immersed simultaneously in the beaker containing water. Trial was made to bring the digital display of both the meter to show the same reading in ppm of O₂ content of the water sample - the meter was thus calibrated. Only disadvantage of this meter was that it has no thermometer. For this temperature knob had been adjusted by taking water temperature with the help of a thermometer prior to measure the oxygen content.

The Hach pH meter was calibrated by immersing its tip into buffer solution by adjusting the reading 7.0, through screwing on its back every time prior to take reading of a sample. The meter was then immersed in water sample collected to measure its pH content.

However water sample after aeration was collected and was brought to BUET laboratory for dissolved CO₂. The observation made is presented below:

Location of observation	Temperature, °C	Oxygen content, ppm	pH	CO ₂ content, ppm
After aeration	24.9	4.5	5.5	50
After flocculation	25.0	4.4	5.9	
After sedimentation	25.0	4.4	6.0	

Table 4.1: Observation of tube well water for different parameters by field test

4.3.0. Measurement of plant yield

The discharge from the airlift pump is intermittent. Hence it is difficult to measure the water discharge by usual methods, such as pipe orifice method; coordinate method of determining velocity of jet, etc. The flow measurement is necessary when the plant is in running condition. The separating wall between the flocculation and sedimentation chambers inside the iron removal unit was modified and was considered as a weir. The well known Francis formula (King, H.W., et. al.1948) for weir discharge, expressed in FPS unit, $Q = 3.33LH^{3/2}$ has been used.

It was decided that for the particular weir, the discharge would be measured by volumetric method for the first time. The discharge, thus measured, would then be compared with the Francis formula of discharge measurement by rectangular weir. The subsequent flow measurement would be made after filling the flocculation chamber with coarse media flocculator by the weir formula.

4.3.1. Yield measurement by volumetric method

The yield of the plant was measured by Volume method right after regeneration of the flocculation chamber. When the uniform flow of water coming from flocculation chamber to the sedimentation chamber, the water level was measured with the help of a measuring tape suspended from a fixed datum point at the man hole end in the sedimentation tank. A small iron block was tied at the free end to keep it straight. The time reckoning was started when the water level touched any graduated marking of the tape and the tank was let to be filled with water for some time. The time was reckoned in the similar way when the water level rose a suitable height, say 10cm height of the tape. In other words, time to fill 10cm depth of the sedimentation chamber was calculated. The rate of water flow was then measured by the formula as the discharge rate, Q , liters/sec = (Volume of the tank to fill 10cm depth, liters) / (time required to fill, sec).

The calculated discharge is shown in the following table:

Time duration, sec	Volume of the chamber					Discharge, Q LPS
	Length, cm	Breadth, cm	Depth, cm	Vol., cm ³	Vol. liter	
197	437	302	10	1319740	1319.74	6.7.
181	437	302	10	1319740	1319.74	7.3

TABLE: 4.2. Calculation of water discharge by volumetric method.

4.3.2. Comparison of discharge obtained by volumetric method with that of Francis weir formula

Efforts were taken to find out easy method to measure the water discharge by the airlift pump. The discharge was measured by using weir. The top surface of the weir was 127mm wide and was uneven. It was flat-crested with square upstream corner. The existing weir was submerged i.e. the elevation of the downstream water surface was higher than the crest of the weir. Subsequently the height was modified to such an extent that the water surface remains up to the edge of the crest normally and as soon as the pump started the water flows over the crest making free flow.

The well known weir formula,

$$Q = 3.33LH^{3/2} \text{ based on } Q = C LH^{3/2}$$

Where, Q, discharge in cfs;
L, length of the weir, ft;
H, height of water flow over the weir, ft.

The 'H' was measured at one feet distance in ahead of the weir crest with the help of a narrow ms rod (used in umbrella hood) taking the man-hole cover edge as the datum.

Here, L = 302cm = 9.91 ft.
H = 13mm = 0.013m = 0.042653 ft.

Now, Q = 3.33X9.91 X (.042653)^{3/2}.
= 0.2578 cfs.
= 0.291 X 28.316 = 8.24 LPS.

With this method, when compared with other flows, found to be varied. Hence the volumetric method was considered dependable in this case. However the upper discharge rate 7.3LPS found by volumetric method was taken as standard for the plant with the airlift pump.

Since it is difficult to measure the water depth H in ft, because of irregular crest of the weir, the subsequent flow measurement was done by volumetric method. Before taking measurement, the water in the sedimentation chamber was pumped out by the sludge pump for about half meter depth. When water flow began to flow over the weir, time was reckoned to fill a depth of 10cm and volume was found out and thus the water discharge of the airlift pump was measured.

4.4.0. Detention times of different chambers

To determine the detention time of the flocculation chamber, typical porosity of the media was taken to be 0.4 according to Charman. Thus

Detention time of the flocculation chamber:

$$C/Q = (15052.28 \times 0.40)/(7.3 \times 60) = 13.74 \text{ min.}$$

Detention time of the sedimentation chamber :

$$C/Q = 28110.46/(7.3 \times 60) = 64 \text{ min.}$$

The detail calculation is shown in appendix II-H.

4.5.0. Analysis of the Data

The data found in the field as well as in the laboratory test were analyzed and different curves were plotted to show the variation of iron concentration with duration of time; the percentage removal of iron with detention time, and the yield of the tube well.

4.5.1. Performance of the Iron Removal Unit

The Iron removal unit was tested with single type of coarse media flocculators. This was brick khoa but with two different sizes. Each of the sizes was tested for single flow rate of the tube well. As such the flocculators have two runs and the water samples were collected every day for 30days for each run.

4.5.1.1. First observation

The brick khoa of size 4.5 to 5cm was used as the coarse media flocculator in the first run. The water flow rate was 7.3LPS and the iron concentration of the raw water was 12 ppm.

The treated water samples were collected from three different sampling points of the unit after flocculation, after sedimentation and at inlet of the reservoir at a regular interval of a day and tested in the laboratory for iron concentrations. These are being presented in graphical form in figure 4.1. The cumulative percentage of iron removal is presented in figure 4.2.

4.5.1.2. Second observation

In the second run the coarse media flocculators used were brick khoa of 3 to 4cm size range. In this run the same water flow rate was maintained. The treated water samples were collected from four different sampling points of the plant at a regular interval of 24 hours and tested in the laboratory for iron concentrations. These are being presented in the figure 4.3 and those of cumulative percentage of iron removal are presented in figure 4.4.

4.6.0. Determination of the characteristics of iron precipitates in the voids of the coarse media flocculator

Loose iron precipitates along with water from the pores of the brick khoa of a clogged flocculator were drained out carefully by gravity in a large measuring cylinder. The iron precipitates attached to khoa surface were gently washed with clean water and collected in a separate measuring cylinder. In each cases the precipitates were allowed to settle completely and the volume occupied and concentration of iron in the settled sludge were determined.

Designated type	Description	Sphericity Ψ	Average dia, d, cm	Shape factor $S=6/\Psi$	Volume of khoa, cm ³
First run, F ₁	Irregular, worn out.	0.78	4.5-5.0cm	7.7	15052284
Second run, F ₂	Irregular, worn out.	0.78	3-4cm	7.7	15052284

TABLE: 4.3. Characteristics of coarse media flocculator (brick khoa).

Designated type	Direction of flow	Cross section of flocculator,	Length of flocculator, L cm	Cross sectional area, a, cm ² .	Construction Materials.
F ₁	Horizontal	302 X 213	234	64326	Brick built.
F ₂ .	Horizontal	302 X 213	234	64326	Brick built.

TABLE: 4.4. Characteristics of coarse media Flocculation chamber.

In the present case, when the voids became filled up with iron deposits or sludge, head loss become more. Subsequently the pump was adjusted to a lower discharge.

The following steps were followed to measure the sludge volume, % of voids remain after iron deposition. Subsequently two separate trials were performed taking almost undisturbed coarse media along with sludge deposit one from top portion and the other from the bottom portion of the flocculation chamber. Comparison was made from the findings.

Trial: I.

The sludge and coarse media flocculator were collected from the top portion of the flocculation chamber.

- The coarse media almost undisturbed along with sludge were taken from the flocculation chamber in a 24000ml plastic bucket.
- Clean water was added to it with a measuring cylinder of 250ml capacity to fill up to the brim of the bucket. The water volume would be the volume of void. The volume of water was found $[30 \times 250 + 100] \text{ ml} = 7600 \text{ ml}$. Thus the volume of Sludge and khoa in a 24000ml bucket was $(24000 - 7600) = 16400 \text{ ml}$.
- The khoa was washed in the bucket were simply transferred to another bucket in such a way that the loose sludge left behind but the attached iron deposits remained with khoa. The water was separated to another bucket from the top when the sludge-water mixture settled. The sludge volume was measured with the help of the 250ml cylinder and it was found $(250 \times 10 + 150) = 2650 \text{ ml}$. Hence volume of khoa without voids became $(16400 - 2650) = 13750 \text{ ml}$.
- Sludge vol + water vol = $2650 \text{ ml} + 7600 \text{ ml} = 10250 \text{ ml} = 10.25 \text{ L}$. Sludge vol, % = 25.85; Water vol, % = 74.15.
- Percentage of volume of voids before sludge deposition.

$$= [1 - (\text{khoa volume without voids} / \text{bucket volume})] \times 100$$

$$= [1 - (13750 / 24000)] \times 100 = 42.7 \%$$
- Sludge deposition efficiency of the bed: $= [\text{Sludge volume} / (\text{bucket volume} \times \% \text{volume of voids})] \times 100 = [2650 / (24000 \times 0.427)] \times 100 = 25.85 \%$.

TRIAL:II

The sludge and coarse media flocculator were collected from the bottom portion of the flocculation chamber.

- The coarse media almost undisturbed along with sludge were taken from the flocculation chamber in a 24000ml bucket.

- Clean water was added in 250ml glass cylinder to the bucket to find out the volumes of solids in the bucket. The water volume was $(250\text{ml} \times 22 + 30) = 5530\text{ml}$.
- Separated the brick khoa by hand to a second bucket leaving behind the brick chips & iron sludge. The volume of sludge and brick chips was measured with the help of a measuring cylinder when the mixture settled and was found 5020ml.
- Thus the volume of brick khoa without voids was found $(24000 - 5530 - 5020) = 13450\text{ml}$.
- A wire net was taken to sieve the solids and thus brick chips were separated. This was 2500 ml. The brick chips were then added to the brick khoa. Hence the volume of iron sludge found was $[5020 - 2500] = 2520\text{ ml}$.
- The brick khoa was thoroughly washed in the water in the bucket. Sludge attached to khoa was found to be $(250 \times 4 + 180) = 1180\text{ ml}$ by separating khoa and water and subsequently measured with the help of a 250ml glass cylinder. Thus total Khoa volume without voids became $[13450 - 1180 + 2500] = 14770\text{ ml}$.
- Total solids thus observed:Khoa volume without voids:14770 ml.Sludge vol:2520ml.Sludge attached to khoa = 1180mlTotal sludge volume = $2520 + 1180 = 3700\text{ml}$
- Sludge vol + water vol = $3700\text{ ml} + 5530\text{ ml} = 9230\text{ml} = 9.23\text{L}$.Sludge vol, % = 40.08; Water vol, % = 59.92.
- Percentage of volume of voids before sludge deposition.= $[1 - (\text{khoa volume without voids} / \text{bucket vol})] \times 100 = [1 - (14770 / 24000)] \times 100 = 38.46\%$.
- Sludge deposition efficiency of the bed= $[\text{vol. of sludge} / (\text{bucket volume} \times \% \text{volume of voids})] \times 100 = [3700 / (24000 \times 0.3846)] = 40.08\%$.
- The settled sludge was collected in a 250ml graduated glass cylinder to a volume of 150ml. Dilute 100ml of HCl was added to the sludge and the mixture was thoroughly stirred and kept for half an hour. The iron salt in the sludge dissolved showing a decrease in sludge volume and ultimately it became to a volume of 23ml. Hence the iron salt content in the settled salt became: $[(150 - 23)\text{ml} / 150\text{ml}] \times 100 = 84.67\%$.
- The iron salt concentration in sludge + water mixture: $(3.700 \times 0.8467) / 5.53 = 56.65\%$

Trial no.	Constituents		precipitates	
	Name	% of volume occupied	Nature	% of volume occupied
TRIAL: I.	Iron sludge	25.86	Attached to khoa surface	100
			Loose hydrophobic.	
	Water	74.14		
TRIAL: II.	Iron sludge	40.08	Attached to khoa surface	50.15
			Loose hydrophobic.	49.85
	Water	59.92		

Table 4.5. Characteristics of iron precipitates in the interstices of the coarse media.

4.7.0. Length of run between cleaning of the coarse media

The pores of the coarse media gradually clogs with iron precipitates or sludge.

Since the iron removal performance varies with the length of run, periodical cleaning of sludge would be necessary. Time required for clogging is a function of iron concentration, the flow rate of water, the pore volume, space occupied by iron precipitates and the removal efficiency of the coarse media bed itself.

A portion of the sludge remains attached with the coarse media surface and the remaining precipitations occupy spaces within the interstices of the coarse media.

Ahmed (1995) carried out laboratory investigation on gravel bed flocculators to find out the characteristics of iron precipitates in the pores of the gravel. He introduced an equation to calculate the length of run between cleaning. Assuming uniform removal with time, total amount of accumulated iron precipitates within the pores is,

$$CF = \text{Iron load, } (L_i) \text{ in mg/hour} \times \text{length of run } (t_L) \text{ in hour.}$$

$$\therefore t_L = CF/L_i \text{ hours,}$$

where, CF = Total pore volume (f_v) in ml $\times$ concentration of iron ppt. in pores in gm/L.

L_i = Rate of flow of water, Q in ml/sec $\times$ Iron conc. in raw water in mg/L $\times E_f$.

E_f = Efficiency of the coarse media bed.

However the units have been adjusted as follows:

$$CF, \text{ gms} = \text{Total pore volume in cc} \times \% \text{ of pores in which iron ppt. deposit} \\ \times \% \text{ of iron concentration in sludge and water mixture} \times 2.8 \text{ gm/cc.}$$

$\text{Li, gms /day} = \text{Rate of water flow, in LPS} \times \text{Iron conc. in raw water in mg/L} \times \text{Ef, efficiency of bed} \times (3600\text{sec/hr} \times 1\text{gm}/1000\text{mg}).$

If the plant runs for 03 hours every day the length of run between cleaning of the coarse media becomes $(100.54/3) = 33$ days.

4.8.0. Regeneration of the encrusted deep tubewell in iron problem areas

Proper operation and maintenance of the tube wells are necessary to have a longer life with full efficiency. Encrustation in well cause decreased specific capacity accompanied by a larger draw down in the well. It is caused by precipitation on or near well screens of materials carried in solution by ground water. The encrustation is generally caused from the presence of oxygen in a well, which can change soluble ferrous iron to insoluble ferric hydroxide. Slime forming organisms can also block screens by forming jelly-like bacterial slime. The sudden pressure drop associated with water entering a well under heavy pumping can release carbon-DI-oxide and cause precipitation of calcium carbonate in some areas. The most common form of chemical or bacteriological clogging in Bangladesh is iron and manganese hydroxide encrustation.

The success of the subsurface aeration technology depends on how efficiently regeneration of the tube well is possible as oxygenation is accomplished inside the tube well and thus more precipitation is anticipated in the tube well components as well as around the aquifer.

4.8.1. Method adopted in regenerating the tube well with the plant under observation

A treatment unit was constructed with the tube well to remove its iron content. Within a short period of time its yield decreased resulting higher draw down. Assuming that gradual clogging of the strainer openings caused the well's flow resistance to increase, resulting in a decrease of its yield and efficiency, it was proposed to regenerate the tube well. To accomplish this, it is required to wash out the incrustations formed on openings of the strainer, resulting in the full use of the openings for water to enter into the well-thereby minimizing the draw down against a anticipated discharge.

A standard dose of a chemical to be used or the method to be applied to regenerate wells is a complicated job. It has been reviewed that most form of clogging of wells can be removed effectively by treating the well effectively with chemicals in combination with mechanical agitation.

By reviewing the results of the DPHE's effort to regenerate their tubewells, it has been apprehended that regeneration by applying sodium hexameta-phosphate in iron problem areas would be the appropriate method for the tube well adopting subsurface aeration technology for iron removal. An air lift pump is there in the tube well to pump as well as to aerate water. Hence the regeneration of the tube well may be done by the detergent type chemical treatment followed by surging and airlift pumping using the same airlift pump.

DPHE tried to express the doses of chemicals on the basis of length of the strainers of a particular tube well. It has also been known that the chemicals were applied arbitrarily by the DPHE without considering the iron content of the tube well.

It may be helpful to relate the dose of the chemical against Fe content in a particular tube well prior to regeneration.

4.8.1.1. The procedure adopted to find out the dose of Sodium Hexameta Phosphate to disperse Iron encrustation

In a tube well drilled in aquifer enriched with high iron content, a layer of iron deposit is formed throughout the inner wall of the tube well components as well as pump column pipes. Moreover it may be recalled that with the Vyredox method, iron is oxidized and is being retained in the aquifer when aerated water is injected in to the tube well. In the present case also, it is apprehended that the same method works to some extent. When airlift pump starts, it lifts water to the surface and during lifting aeration is being accomplished. But as soon as the pump shuts off the aerated water column above the static water level drops down and creates a back flow of aerated water in to the aquifer. The water sample, collected from the delivery pipe of the pump, showed that about 25% - 40% iron has been removed. Hence there is every chance of iron deposition on the inside wall of the tube well components; pump components as well as around the aquifer.

Hence it has been decided to find out the dose of sodium hexameta phosphate (dispersing agent) required to disperse the iron deposits in the strainer area. The dose required to disperse the iron deposits on the pump column pipe, may be used as the dose to clean the encrustation or precipitation formed in the screen area of the tube well as well as in the aquifer.

The steps adopted to find out dose to clean the iron deposits in and around the pump column pipe are as follows:

- i. With a view to examine the iron deposition and find out the chemical dose to disperse those deposition, the pump column pipes and airline pipes after withdrawal from the tube well. Specific capacity was recorded prior to withdrawal of the pump were kept for observation. Four column pipes (305cm long; 10cm dia.) were selected at random and were put them horizontally on wooden pegs in each of the four pits dug on the ground surface in ahead of the pump withdrawal.
- ii. Each pit was dug on the ground surface in dimensions of 1' B X 1' H X 11' L to accommodate one column pipe. Polyethylene sheet of proper size was spread over the full inner surface of the pit to prevent any seepage of water from the pit. Water from the tube well was collected and poured in a 14 L bucket into the pit in measured volume to make the column pipe submerged under the water thus similar iron content in the pit water was maintained.
- iii. The sodium Hexa-metaphosphate powder was measured in a scale and poured slowly inside water in a 14 L buckets & was stirred vigorously. When it mixed with water thoroughly, it was then poured in the respective pits in different doses in water in each of the pits and that is shown in table: 4.6. The pipes were kept immersed for about 36 hrs.

Bed no.	water in the bed, L	Fe content, mg/L	Chemical applied, gm	Chemical application, gm/L	Chemical applied, gm/L/ ppm	Result
1	2	3	4	5=(4/2)	6=(5/3)	7
A	168	12	1600	9.52	0.8	best.
B	182	12	900	4.95	0.4	
C	140	12	1200	8.57	0.7	
D	168	12	2000	11.90	1.0	

Table: 4.6. Chemical application in four different experimental beds to find out the appropriate dose for it.

- iii. After taking out from the pit, it was observed that all iron deposit from the inside and outside wall of the pipe, treated in pit-A ; C; D had been removed. The dose given in pit-A was taken as the optimum.

The optimum dose thus obtained to clean the iron slime from inside and outside wall of the column pipe in pit-A was considered to be the base dose of the detergent to be applied inside the well. The dose was found 9.52 gm./L of water. Thus a relation may be achieved with mg/L of iron content with gm/L of chemical dose.

4.8.1.2 The Procedure for the regeneration of the encrusted tube well

The dose of Sodium Hexameta Phosphate found to disperse the deposited Iron on and around the column pipe as described in art 4.8.1.1 was applied in the tube well for removing iron encrustation from the strainer.

The calculation of water content inside tube well was done in a way described in table 4.7a and 4.7b. The doses of chemical applied is shown in table 4.8.

Housing pipe length, cms.	SWL, cms.	Submerged Housing pipe length, cm.	Housing pipe dia.cm.	Volume of submerged housing pipe, Liter.
1	2	3=(1-2)	4	5
3048	532	2516	35.56	2498.76

Table : 4.7.a: Calculation of water volume inside the deep tube well (continued....).

Screen length, cm.	Blind pipe length, cm.	Bail plug length, cm.	Screen and blind pipe dia, cm.	Volume of screen plus blind pipe & bail plug, Liter.	Reducer, (30.48X15.24) Length cm	Volume of the reducer, Liter.
6	7	8	9	10	11	12
2329	4115.5	150	15.24	1202.93	100	50.67

Table: 4.7.b: Calculation of water volume inside the deep tube well.

Vol. of water in housing pipe, L	Vol. of screen + blind pipe + bail plug, L.	Volume of reducer. L.	Total vol. of water inside tubewell. L.	Chemical applied gms/L/p pm. (gms/mg)	Fe. content ppm.	Chemical applied, gms/L of water inside tubewell	Chemical applied, Kgs.
1	2	3	4=(1+2+3)	5	6	7 = (5x6)	8=(7x4)/1000
2498.76	1202.93	50.67	3752.36	0.80	12	9.60	36.0
2498.76	1202.93	50.67	3752.36	0.74	12	8.88	33.3
2498.76	1202.93	50.67	3752.36	0.56	12	6.72	25.0

Table: 4.8. Use of Sodium Hexametaphosphate in the project tube well for regeneration.

The steps adopted for the regeneration are as follows:

- i. The water inside of the tube well was calculated to be 3752.36 L equivalent to the inside volume of the tube well under static water level (Table: 4.8). Hence for 3752.36 liters of water inside the tube well $9.52 \text{ gm.} \times 3752.36 \text{ L} = 35.72 \approx 36\text{kg}$ chemical was applied at the time of first treatment.

Solutions of sodium Hexa-metaphosphate was prepared in a bucket and applied through 3/4" dia. GI pipe to the strainer area of the well. The same pipe was used for chemical application those had been in use as an airline pipes.

- ii. The water inside the well was stirred vigorously by the compressed air to produce air surge so that the chemical mixes with water uniformly and breaks the incrustations etc. deposited on the wall as well as on the strainer openings.
- iii. The tube well is thus kept under chemical treatment for about 36 hrs. Air surge was applied to break the incrustations.
- iv. The airlift pump is then operated to lift and pump water out of the well. Thus the tube well was made cleaned from the encrustation by use of the pump. At this stage the specific capacity of the tube well was measured.

- iv. The treatment was repeated for 03 times.

4.8.2.0. Costs of Regeneration:

The cost of regeneration including the cost of chemical is only Tk. 27,273.00 with the method as was followed to regenerate the pilot plant tube well. The detail of the cost calculation is shown in appendix : IV-C.

CHAPTER V.

RESULTS AND DISCUSSIONS.

5.0.0. General.

Relevant literatures on chemistry of iron content in water, theories and conventional practices of iron removal techniques adopted both in and abroad; techniques followed in DPHE tube wells regeneration; pumping by airlift arrangement have been reviewed in chapter II. The results achieved by bringing under operation and conducting tests in the iron removal plant using sub-surface aeration technology and discussion thereof as per objective of the study have been presented in the subsequent paragraphs. The modifications made in various components of the plant and the performances on modified plant are also studied under varied flow condition.

5.1.0. Performance of the Iron Removal Plant (IRP).

The Iron Removal Unit (IRU) of the plant consists of flocculation and sedimentation chamber that receives aerated influent ground water in its inlet chamber. The effluent water from it after flocculation and sedimentation actions goes to the underground reservoir through its outlet chamber. To observe the respective performances of each of the sub units of the IRU, water samples were collected after flocculation chamber, after sedimentation chamber and after outlet chamber in a regular interval of a day and subsequently tested in the laboratory for their iron content. In the field test, the performance of IRU was observed on varied sizes of the coarse media flocculator initially. The brick khoa was the coarse media and two batches were observed with two sizes of it. The average size ranges of the coarse media were 4.5 to 5cm dia and 3.5 to 4.0cm dia in the first and second batches of observation respectively.

The laboratory test results of the iron concentrations in mg/l obtained through the observations are presented in tabular form in appendix II-A; II-B.

To know the iron removal performance by the flocculation and sedimentation actions the cumulative percentages of the iron removal were also worked out for both the observations and are shown in appendix II-C and II-D respectively.

The graphical presentation of each of the observations on variations of the iron content and those of cumulative percent removal of iron are being shown in fig., 5.1; 5.2; 5.3; 5.4 respectively. On the basis of the obtained results the flocculation and sedimentation performance of iron removal unit (IRU) has been observed.

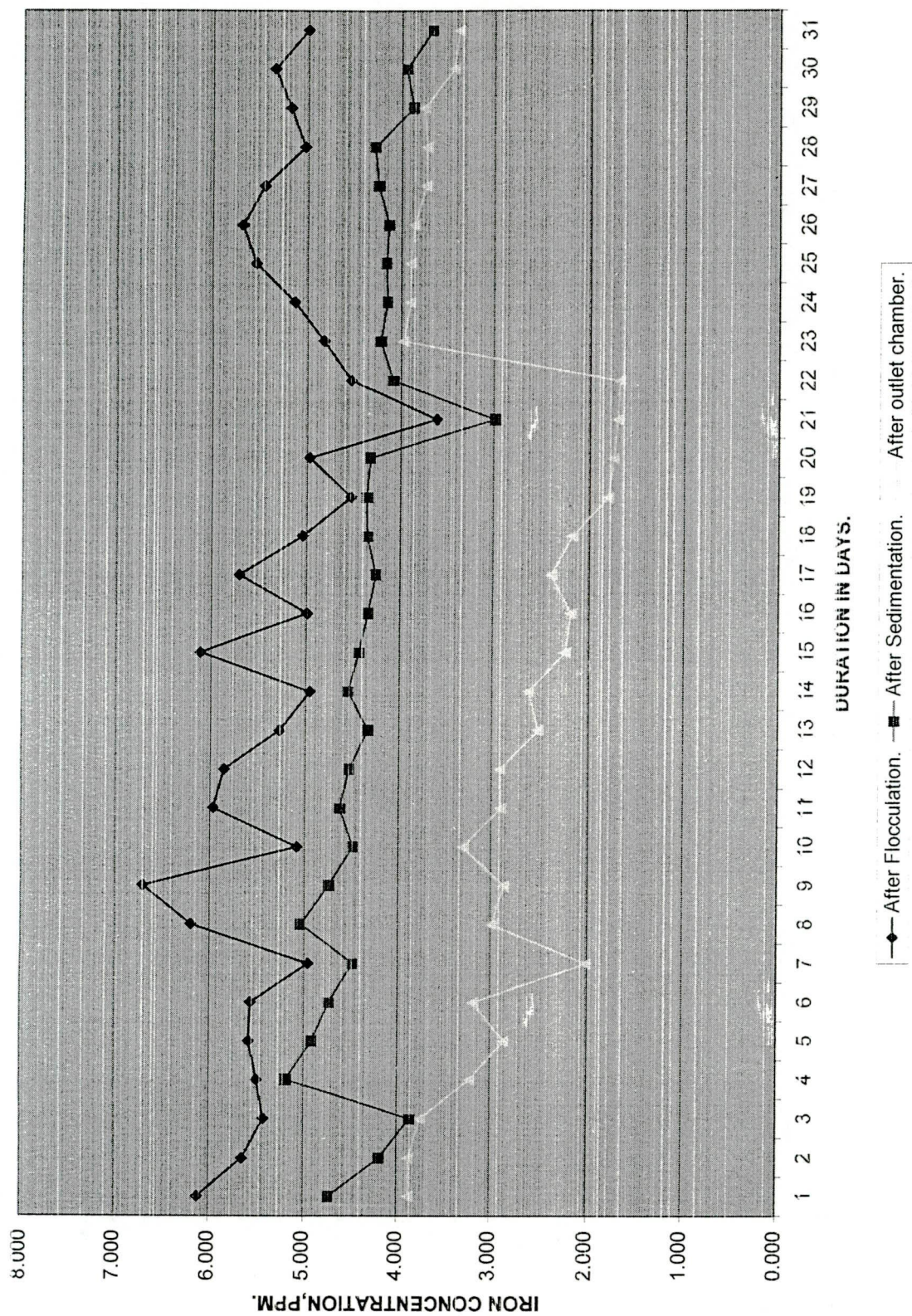


FIG 5.1: VARIATION OF IRON CONCENTRATION (FIRST OBSERVATION).

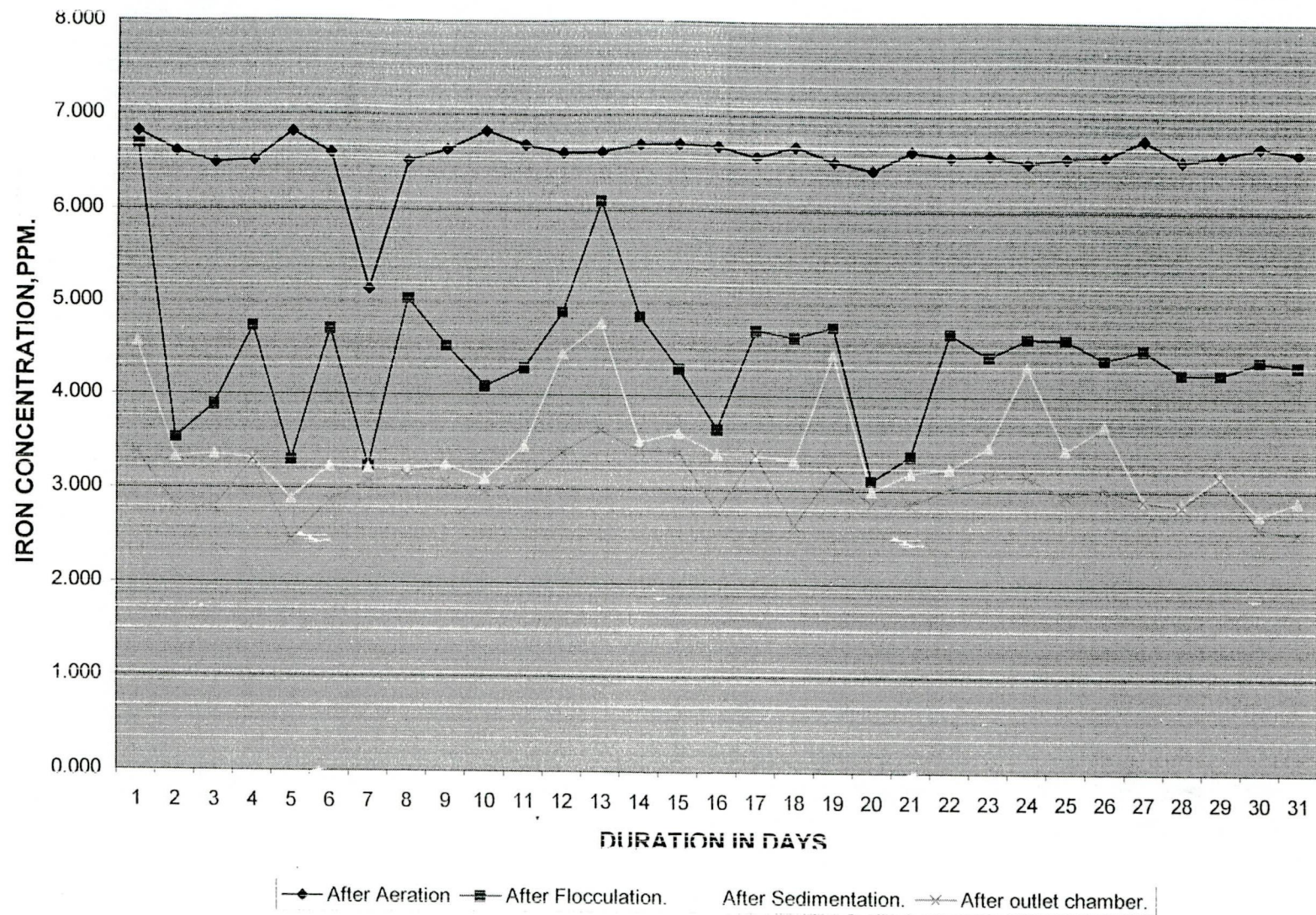


FIG 5.2: VARIATION OF IRON CONCENTRATION (SECOND OBSERVATION).

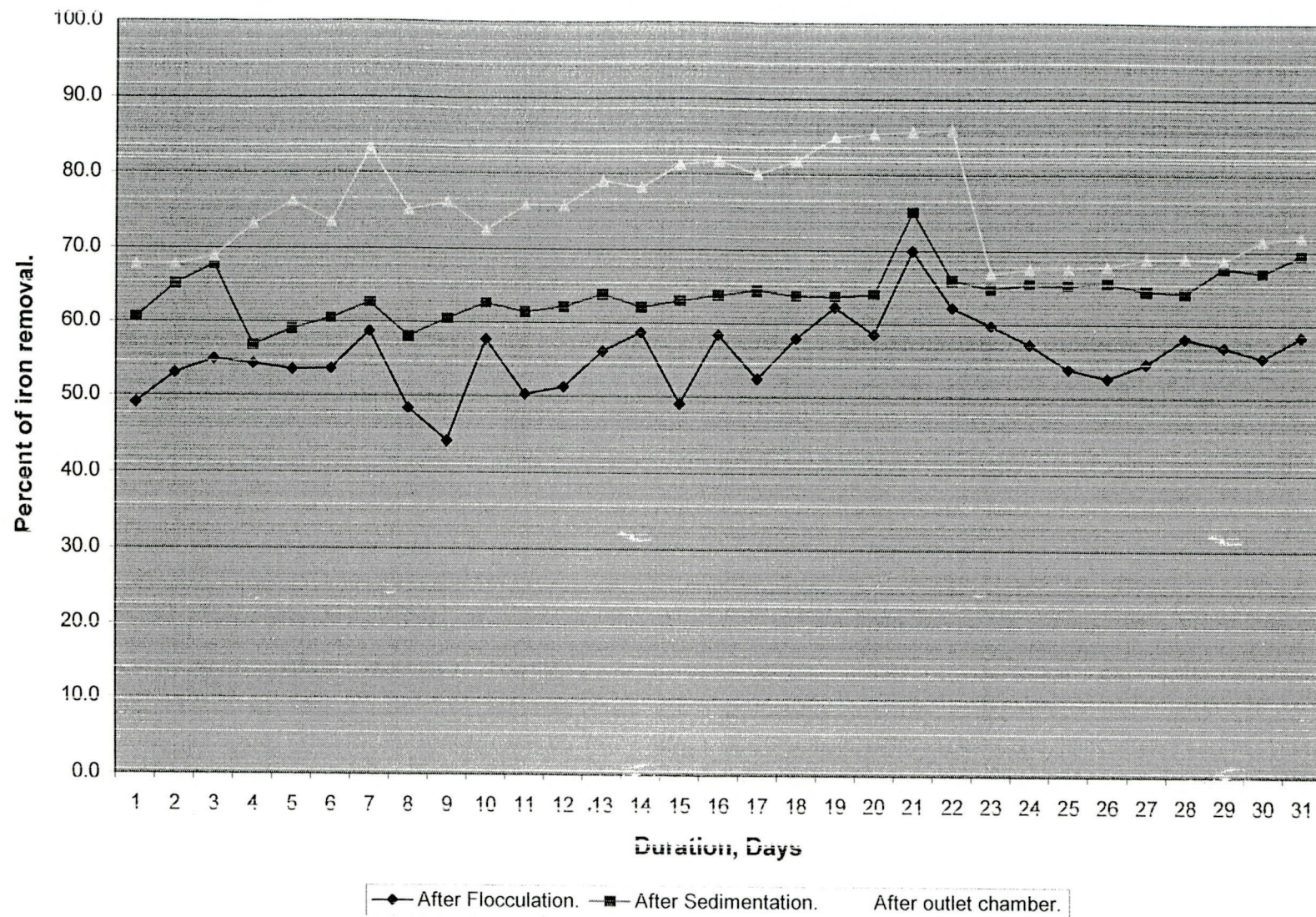


FIG 5.3: CUMULATIVE PERCENT REMOVAL OF IRON (FIRST OBSERVATION)

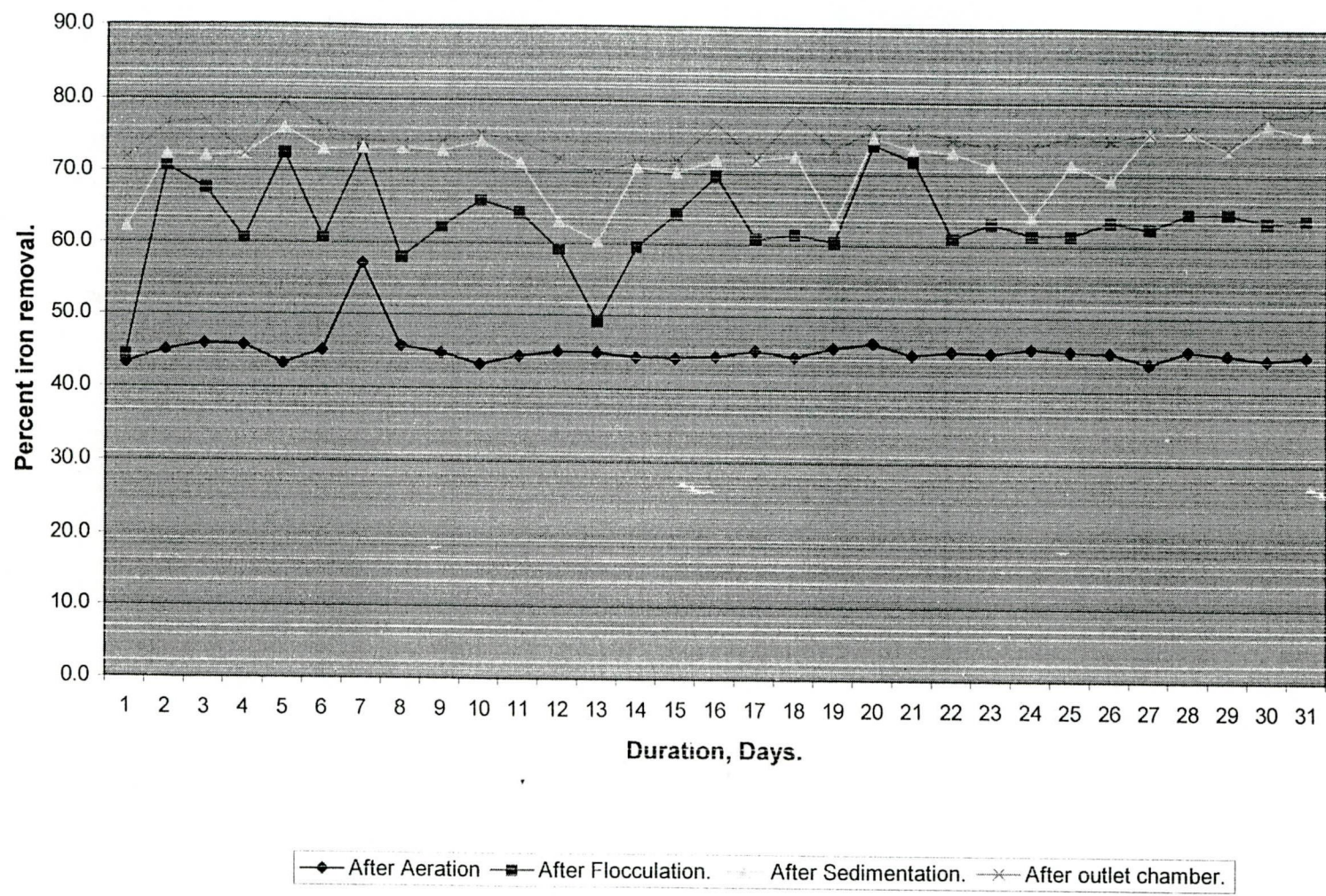


FIG 5.4: CUMULATIVE PERCENT REMOVAL OF IRON (SECOND OBSERVATION).

5.1.1. Flocculation performance of the IRU under varied sizes of the coarse media flocculators.

The iron concentrations of water samples collected after flocculation varied from 6.705ppm to 3.604ppm in the first observation (fig.5.1) and 6.685ppm to 3.1ppm in the second observation (fig.5.2). On the other hand those of cumulative percentage of iron removal varied from 42% to 70% in the first observation (fig. 5.3) and 44% to 74% in the second observation (fig.5.4). The observed 'G' and 'Gtd' values obtained are presented in table 5.1.

Parameters	First observation	Second observation
Size (dia) of the coarse media, cm.	4.5 to 5	3.5 to 4.0
G sec ⁻¹	3.70-4.1	4.6-5.3
Gtd.	1343-1209	1727-1512

Table: 5.1. The values of G and Gtd under varied sizes of coarse media.

The aerated water is passed through the flocculation chamber for floc formation that can be readily removed by subsequent sedimentation. A stirring action results in the hydraulic flocculator and more sinus movement is anticipated in a relatively smaller sizes of the coarse media. Hence it has been observed that relatively more removal of iron was accomplished in the second observation. At the start of both the observations the iron concentrations were higher but dropped down within one to three days operation. The gentle collision between the already formed flocs that made them adhered together due to adsorption. As the operation continued iron flocs got deposited on the surface of the coarse media and subsequently more flocs were being trapped due to the action of adsorption. The period of retention and degree of agitation are critical factors in the operation of flocculation. As the flow is similar in both the observations, the flocculation performance depended on the degree of agitation which seemed to be higher through the voids of relatively smaller sizes of coarse media. Since the observed values of 'G' and 'Gtd' against smaller sizes of coarse media came closer to the recommended values of those (table 5.1), the flocculation performance was also seen to be relatively more under smaller sizes of coarse media.

In the figs. 5.1, 5.2., it is seen that iron concentration after sedimentation varied with the variation of its concentration after flocculation. But on 9th, 15th, 17th days in the first observation and 8th, 22nd day in the second observation, iron concentration rose without any effect on the subsequent sedimentation action. This might be due to spill of floc saplings those were collected in the water samples resulting higher concentration. The water samples after flocculation were in a decreasing tendency of iron content with time due to the effect of adsorption of already settled flocs on the surface of the coarse media. Again from 7th to 21st day in the first observation and 1st to 22nd day in the second observation, the iron concentration varied abruptly but beyond the days and up to 31st day of both the observations the variation was almost stable. Furthermore the percentage removal of iron up to flocculation chamber during the observations might be doubtful at the first sight. The probable causes behind are explained below

- i. The abrupt variation of iron concentration from 7th to 21st day of first observation and 1st to 22nd day in the second observation might have several causes. The process of adsorption to some extent continued up to the date. But when this came to a position not to adhere more flocs, the effluent concentration came to almost stable state. The variation trend during 1st to 7th day in the first observation was almost similar and varied afterward abruptly. As the interstices of the coarse media became filled up slowly with the deposition of iron sludge, the flow decreased resulting overflow of water through man hole of the inlet chamber. Efforts were obviously taken to clean the coarse media flocculators with the help of jetting action of water by a hose pipe and this might be the cause of the variation occurred afterward.
- ii. The cause behind the smaller variation of iron concentration with time in the first observation might be that the collection of the water samples started at the time when the interstices between the coarse media had already been filled up with iron sludge.
- iii. The iron content of the effluent of the flocculation chamber during second observation dropped to about 55.7% from 29% on the second day and continued the status almost same for the rest of the period of the observation. As the more iron flocs got attached to the surface of the coarse media, the concentration decreased in subsequent days due to adsorption.

- iv. The iron concentration is considerably reduced in the second observation showing that more flocs had been settled in the flocculation chamber. The observation was started just after the changes of the coarse media, thereby more flocs had been developed and trapped due to adsorption.
- v. During the observation, the effluent water after flocculation contain higher concentration of iron on some days without subsequent effect in the sedimentation action, it might be due to "spill" of certain torn flocs coming out from the flocculation chamber.
- vi. With the smaller sizes of the coarse media the removal of iron was increased during the second observation.
- vii. If the water discharge of 7.3lps flow through the flocculation chamber was maintained continuously, the flow would get 13.74 minutes detention time. The pump was operated two times a day – in the morning and in the afternoon. Hence the flow was not continuous throughout the day. The fact was that the samples collected might have several hours additional detention time. Thus the flocs developed settled inside resulting more removal of iron. The iron flocs deposited on the surface of the coarse media, the rate of such deposition would increase with the increased effect of adsorption and longer detention time.
- viii. The iron removal up to flocculation chamber gives some facts that
 - a. The process of floc formation started earlier.
 - b. Some sort of settling effect had been accomplished in the flocculation chamber.
 - c. The effective aeration had been accomplished by the airlift pump during lifting water from the tube well, with less detention time requirement.
 - d. some sort of removal occurred in ahead of entry of water into the flocculation chamber
- ix. When the pump column pipe and airline pipes were withdrawn from the tube well, it was observed that a thick layer of iron sludge had been deposited in and around the wall of the pipes. Hence it is also ascertained that the iron sludge was deposited on the inner wall of the submerged wall of the tube well. The effect of incrustation over the strainer was taken into account and subsequent actions were carried out.

- x. If Vyredox method of in situ iron removal within the aquifer is recalled, it can be ascertained that some removal had been occurred around the aquifer in the vicinity of the strainer.

Samples were not taken into account after aeration in the first observation, however it was taken in the second observation and collection of samples after aeration in further observations was carried on to ascertain the iron content after aeration.

5.1.2. Sedimentation performance of the IRU under varied sizes of the coarse media.

The variations in the iron concentrations both after sedimentation chamber and outlet chamber of the IRU (inlet of the reservoir) show settling effect. The iron concentration varied from 5.187ppm to 2.98ppm in the first observation (fig. 5.1) and 4.772ppm to 2.752ppm in the second observation (fig. 5.2). The cumulative percentage removal of iron up to sedimentation chamber varied from 75.2% to 56.8% in the first observation and 76% to 60.2% in the second observation. The fact is effective floc formation ensures effective removal of it through the action of sedimentation. Sedimentation is dependent on flow and the plan area of the basin itself. Again sedimentation can be accelerated by increasing the size or decreasing the distance a floc must fall. Since all other variables were constant in two observations, it can be concluded that due to increased size of floc formation, the sedimentation was more in the second observation. It indicates that iron floc developed after flocculation had more settling effect and thus iron removal after sedimentation increased with time. Up to sedimentation, the iron concentration decreased gradually with time. These may happen due to two reasons.

- i. As the rate of deposition of iron flocs due to the effect of adsorption as well as settling decreased in the flocculation chamber, more flocs settled down in the sedimentation chamber during its flow through it. The settling of more flocs, influenced the smaller flocs to settle during the time these finished their run inside the sedimentation chamber.
- ii. The other reason might be that the decrease of the water flow. As the interstices of the coarse media were filled up with iron sludge, the overall water discharge decreased to some extent resulting in the decrease of flow in the sedimentation basin. This ultimately increased the rate of settlement.

The variation of iron concentration after outlet chamber depends on the sedimentation action in the preceding basin i.e. the sedimentation basin. Actually effective flocculation ensures effective removal through the action of sedimentation. And there would be ideally no variation in iron concentration between the samples collected after sedimentation basin and at the outlet of the chamber. The variation and subsequent reduction proved that the outlet chamber of the treatment unit after the sedimentation chamber had considerable settling effect.

The settling effect in the sedimentation chamber was more during the second observation and this was possible due to effective floc formation with smaller diameter coarse media. But total efficiency remained the same in both the observations. The anticipated design of the cumulative percent removal up to sedimentation chamber was 87% but achievement was 75%.

The overall iron removal is in the range of 65% to 85% during the observations. However the treated water contains less than 5mg/L of iron, which is acceptable in Bangladesh context.

5.2.0. Some aspects on the observations made.

- i. The rate of iron removal was accomplished up to flocculation in the observation seemed to be higher. If Vyredox method of in situ water purification is recalled, it would be clear that some removal was accomplished around the aquifer in the vicinity of the strainer. For this iron concentration in water samples after aeration were taken in second observation onward.
- ii. Only variable between the run was the size of the coarse media flocculator.
- iii. The day to day variations were very much irregular. This might be due to sample collection procedure. If sample was collected from a location after a specific time of pump start every day, there would probably be a clear picture on every days variation. In this case what might happen that one sample was collected just in ahead of pump shutoff and on the other day, it might be collected after some time of pump start. It is anticipated that the second sample would show a less iron content from the first one because it had much detention and settling time.

- iv. The fact is that stagnant water volume inside the IRU get sufficient detention time for settlement. Moreover the attendant mixed HCl without maintaining the exact volume of it. Hence with the variation in iron concentration it is hard to reflect properly the efficiency of different chambers when water was in flowing condition following the path aeration- flocculation – sedimentation.
- v. Samples collected after pump start especially after aeration and after flocculation may contain torn iron flocs (sapling) expelled either from the deposition of inner wall of pump column; delivery pipe or from outlet passage of flocculation chamber and becomes invisible due to action of HCl and subsequently show higher abnormal iron concentration. This may be proved by taking samples at two stages- one right after pump start and the other just in ahead of pump shut-off.

5.3.0. Problems encountered and modifications made in the plant.

5.3.1. Problems encountered:

The problems encountered in the performance of the plant are explained as follows:

- Since plain sedimentation was adopted in the design, due to lack of proper workmanship in construction of the whole iron removal unit, the percentage removal by the sedimentation chamber itself was low.
- The major problem was that the water flow was restricted through coarse media when only 25-30 % pores clogged with iron precipitates. The water overflows from the inlet chamber. Thus the discharge became irregular.
- The GI airline pipes could not be adjusted to match the submergence with the dynamic water level due to seasonal variation of static water level. Because the airline connecting sockets could not play up and down through the rubber bearings in the column pipe coupling.
- It has been observed that the weir crest cum dividing wall of the basin remain submerged under water for a height of 4.0cm even when there was no flow.

When the flow started the water came directly from the flocculation chamber to the sedimentation chamber through 13mm dia holes with a higher velocity. Thus process of plain sedimentation might be hampered. The efficiency of the sedimentation process found was less. Hence it was decided to raise the height of crest to such an extent that its surface would be exposed at the time of no flow. The weir can stabilize the flow prior to its entrance into the sedimentation chamber.

- Water flows over the baffle wall crest resulting problem of floc settlement. If it is increased, the flow over it would be stopped. It can then be able to divert the flow direction downward thereby directing the iron flocs towards the bottom of the sedimentation chamber for settling. It may trap the iron scum, if any, during the run.
- Yield variation occurs due to seasonal variation of water level as well as due to clogging of flocculation chamber. Overflow from the inlet chamber occurs when flocculators clog with deposited sludge. The proper monitoring of tube well discharge along with seasonal water table variation with draw down is necessary. These parameters show the condition of the tube well as well as the flocculation chamber. The specific capacity show the condition of the tube well and low discharge at the weir crest and overflow from the inlet chamber reflects the condition of the flocculator.
- The delivery pipe of the pump is connected to the inlet chamber from the sidewall of the IRU through a wall hole. Hence as soon as the interstices of the coarse media become filled up to some extent, the water spills outside from around the delivery pipe. Thus a huge water loss occurred besides less efficiency of the sludge deposition by the beds.

5.3.2. Modifications made in the plant.

The modifications made in the plant are as follows:

- The pump base was raised to such an extent that the delivery pipe end enters the inlet chamber from the top instead of existing intrusion of it from the sidewall, thereby increased volume of the chamber is achieved with increased head. This would enable better flow through the flocculation chamber.

- The out let of the airline bottom was fixed at a raised height at a depth of 27.43m from the pump base, keeping the column pipe end at a depth of 30.48m from the same datum. Hence water is ensured to flow up through the column pipe.
- More holes through the partition walls of the flocculation chamber were made by drilling through the masonry wall with 13mm dia drill bit for better flow.
- The height of weir crest was raised to 4.0cm height hence its surface was made exposed at the time of no flow. The efficiency of the sedimentation process is increased. The weir can stabilize the flow coming from the flocculation chamber prior to its entrance into the sedimentation chamber. It is used to measure the water discharge flowing over it.
- The baffle wall crest is increased so that flow over it is stopped. It can divert the flow direction thereby directing the iron flocs towards bottom of the sedimentation chamber for settling as well as can able to trap the iron scum, if any, during the run.

5.3.3. Care for collecting water samples from sampling points.

Water samples had been collected from all locations just in ahead of pump shut off each day in the morning. To ascertain that the water samples collected in proper time of continuous run of the airlift pump and whether any variation exist when the collection of samples is done just after pump start, samples were collected in a day for two times - morning and evening, one just after pump start and another just before pump stoppage. The table below shows the difference

Location	Morning time		Evening time	
	Pump Start, ppm	Pump Stoppage, ppm	Pump Start, ppm	Pump Stoppage, ppm
After Aeration	10.170	6.840	9.066	6.748
After Flocculation	2.919	4.765	3.340	4.784
After Sedimentation	2.984	2.990	4.084	3.327
After outlet chamber	4.150	3.598	3.193	3.551

Table: 5.2. Variation of iron concentration in water samples collected at different stages of pump operation.

It is evident from the table 5.2., that samples collected just before shutoff of the pump would show the actual performance of the IRU. Thus it is confirmed that the time of data collection earlier were ok. The reasons behind have been explained in art 5.2.0.

The experience achieved in the study indicated that after the pump being started and detention time of the chambers is over, the samples collected would be representative of continuous operation.

Water sample was collected in 500ml plastic bottles every day. One must be very much careful when collecting samples. One ml. HCl may be mixed to the sample bottle instead of 5 ml or more. A disposable syringe (3ml.) may be used with confidence.

5.4.0. Observations on performance of the modified Iron Removal Plant (IRP) under varied flow condition

The design of the iron removal unit of the pilot plant was calculated assuming a water flow rate of 7.0 lps having iron concentration of 12.00ppm. When actually constructed unit was compared with that of the designed one, a number of deviations were detected and have been presented earlier (art 3.4.0). The dimensions of the chambers were not as per from those obtained through design calculation. After some modifications made but without modifying the dimensions of the unit, the performance of the IRU was carried out under varied water flow conditions. The variation of iron concentration; turbidity & CO₂ content were observed under varied flow condition with three different flows. Thus the iron removal efficiency of different stages of flow condition was obtained, keeping size of the coarse media similar. The observations are being presented in subsequent tables.

The variation of water flow was obtained by changing the length of airline pipe of the airlift pump inside the tube well. As it was not possible to vary the airline depth alone, the column pipes were also withdrawn as per requirement. The airline and the column pipe were withdrawn 3m at each stage for three different stages from the present 27.43m depth from the pump base. The calculation of discharge was made by adopting volumetric method as discussed in art 4.3.

Airline depth, cm	Duration of time, sec	Discharge volume (sedimentation chamber)					Discharge Q, lps
		Length, cm	Breadth, cm	Depth, cm	Vol., cm ³	Vol. liter	
2438	330	437	302	14.00	1847636	1847.64	5.60
2133	256	437	302	10.00	1319740	1319.74	5.16
1829	277	437	302	10.00	1319740	1319.74	4.76

Table 5.3. Plant yield obtained by changing the air line depth.

Observation was also made at delivery pipe of the airlift pump the effect of aeration and is presented in table 5.4

Observation	Water temperature, °C	DO Content, mg/l	pH
I	25	4.6	6.9
II	25	4.63	6.7
III	25	4.5	6.8

Table 5.4: Aeration effect of water sample.

The O₂ demand as per design to oxygenate a water discharge of 7 lps with iron concentration of 12 ppm is 11.998mg/sec. Considering 10% gas transfer efficiency the airflow requirement for the purpose would be 26 lpm. The air lift pump compressor has the capacity of 1600lpm discharge at ambient pressure. Hence with the help of the well known relation $P_1V_1 = P_2V_2$, the air compressor is anticipated to discharge 800 lpm against 2kg/cm² pressure. Therefore as far as the efficiency of aeration is concerned, the subsurface aeration technology has been found suitable for aerating ground water.

This observation on the variation of plant yield under varied depth of air line was also made and is presented below in fig 5.5

Airline pipe depth, cm	Static water level, cm	Pumping water level, cm	Submergence, %	Q, lps	Pressure, kg/cm ²
1	2	3	$4 = \frac{(1-3)}{1} \times 100$	5	6
2438	369	574	76.46	5.60	1.91
2133	417	645	69.76	5.10	1.52
1829	384	555	69.65	4.76	1.32

Table 5.5: Submergence of the airline pipe and plant yield obtained by changing the air line depth.

It was found difficult to measure the pumping water level with the help of an AVO meter because the water discharge by the air lift pump was intermittent thereby the PWL was always unstable. Another reason was that when the free end of the probe touches the water surface, the needle of the AVO meter deflects but may remain in that position even this is being lifted from water. Due to surface tension, water drop at the end of the probe maintains the circuit of the meter thus may show false depth. The pressure meter of the compressor was not graduated in smaller ranges.

5.4.1. Variation of iron concentration under varied flow condition.

The graphical presentation of the variation of iron concentration after aeration; after flocculation; after sedimentation and after outlet of the iron removal unit under varied flow condition are shown in fig 5.5; 5.6 & 5.7. The cumulative percent removal of iron are also made and being shown in fig. 5.8; 5.9 and 5.10., respectively.

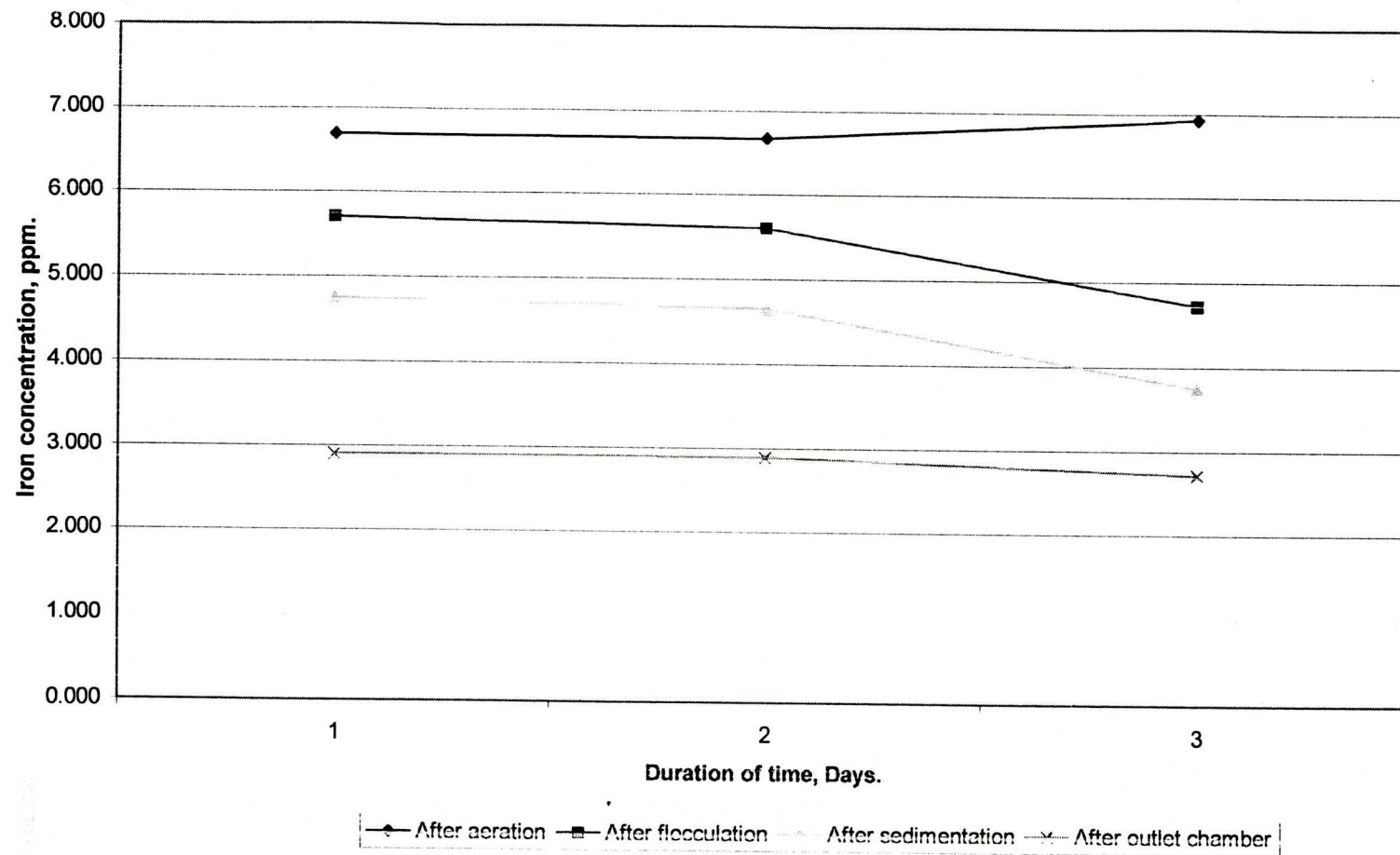


FIG 5.5: VARIATION OF IRON CONCENTRATION UNDER VARIED FLOW (Flow rate: 5.60 lps).

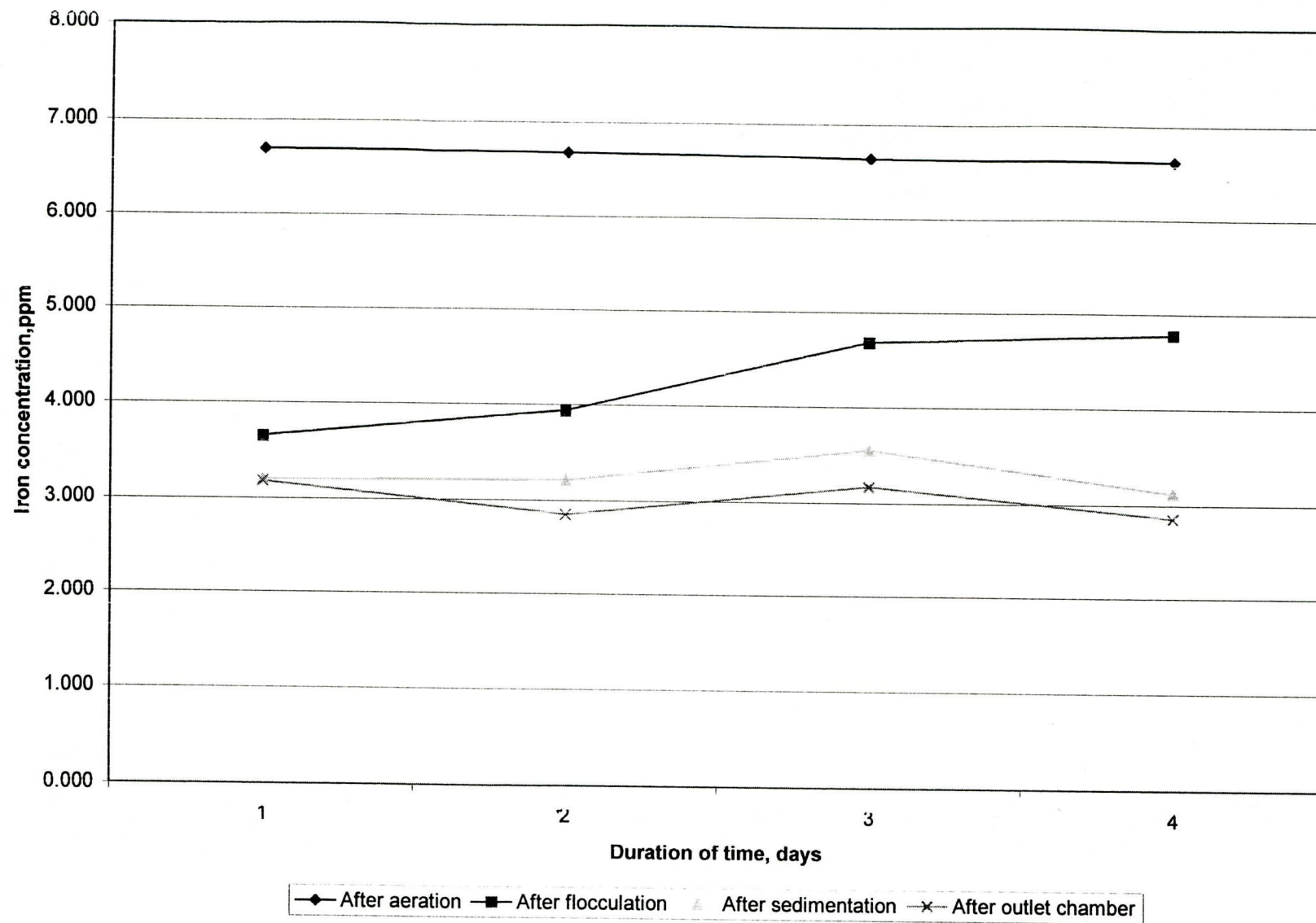


FIG 5.6: VARIATION OF IRON CONCENTRATION UNDER VARIED FLOW (Flow rate: 5.16 lps)

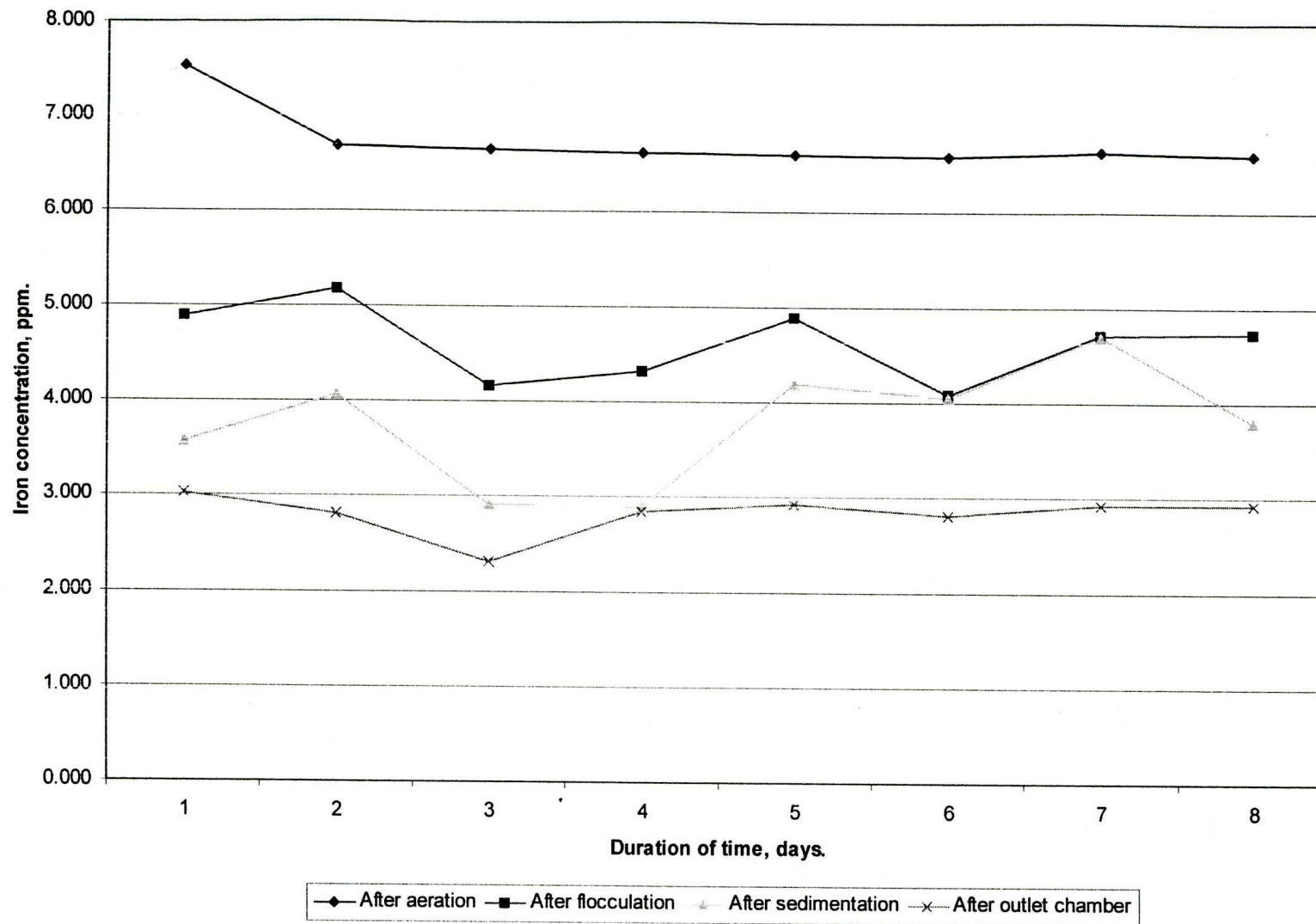


FIG 5.7: VARIATION OF IRON CONCENTRATION UNDER VARIED FLOW (Flow rate: 4.76 lps)

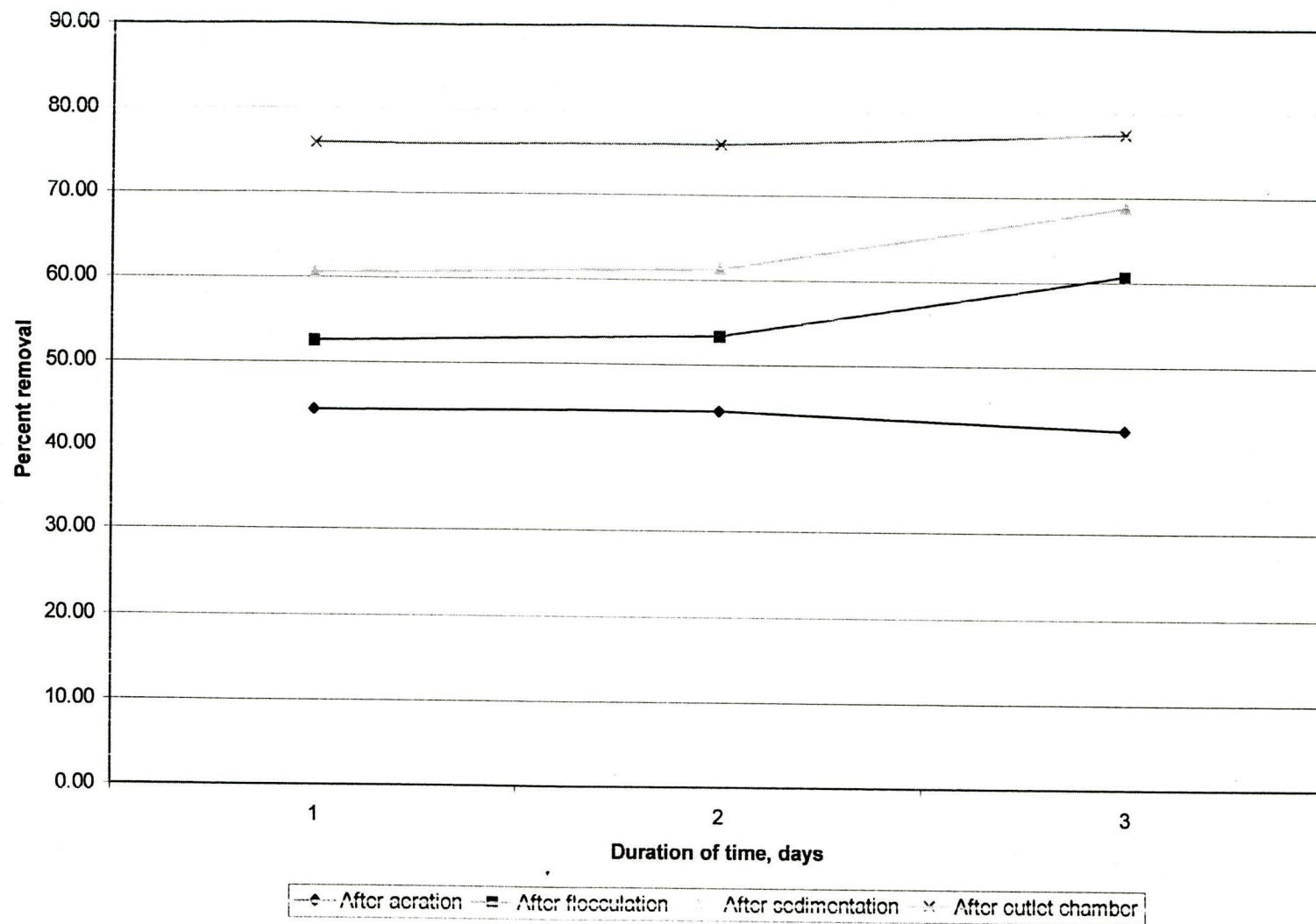


FIG 5.8: CUMULATIVE PERCENT REMOVAL OF IRON UNDER VARIED FLOW (Flow rate: 5.60 lps)

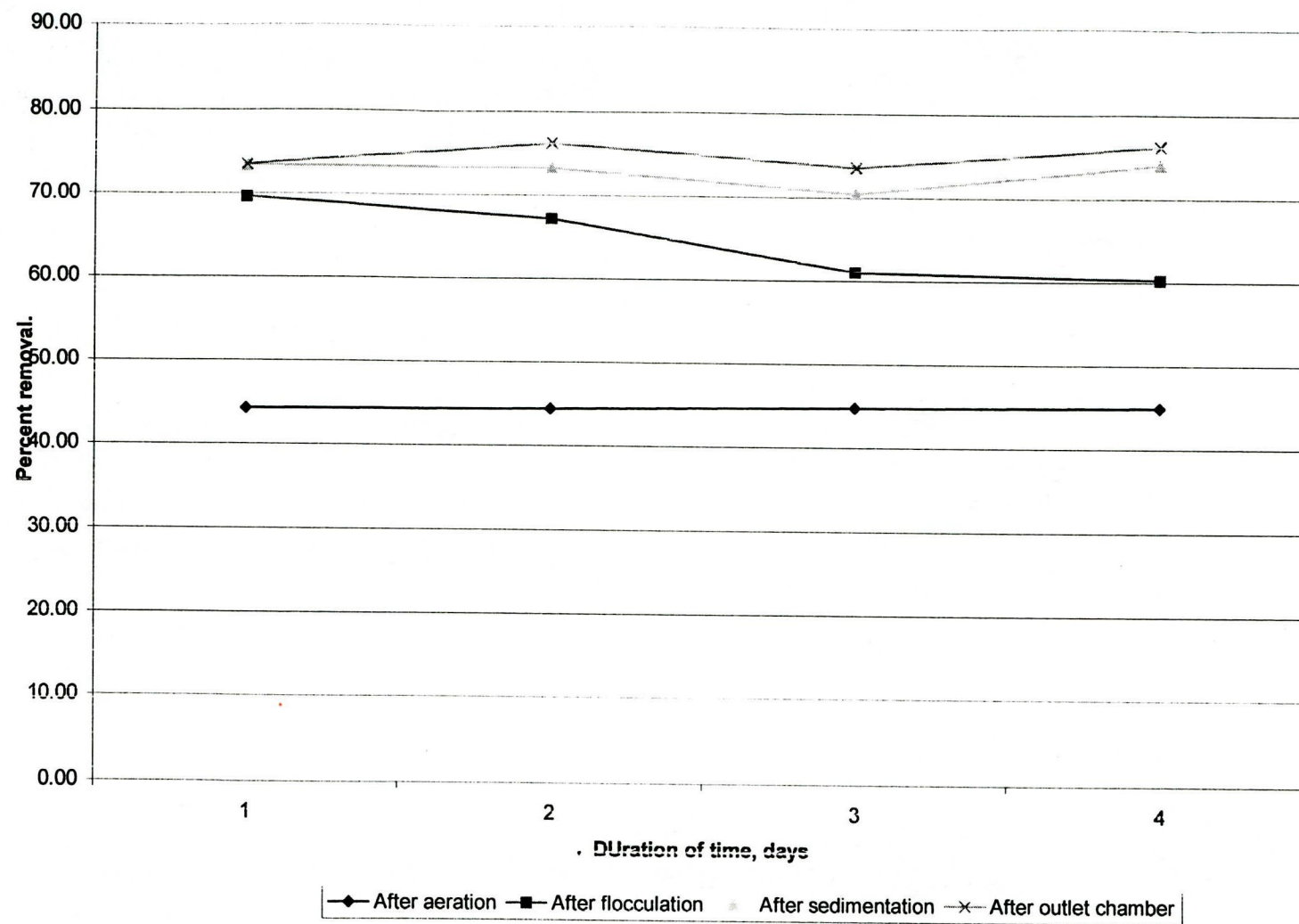


FIG 5.9: CUMULATIVE PERCENT RMOVAL OF IRON UNDER VARIED FLOW (Flow rate: 5.16 lps).

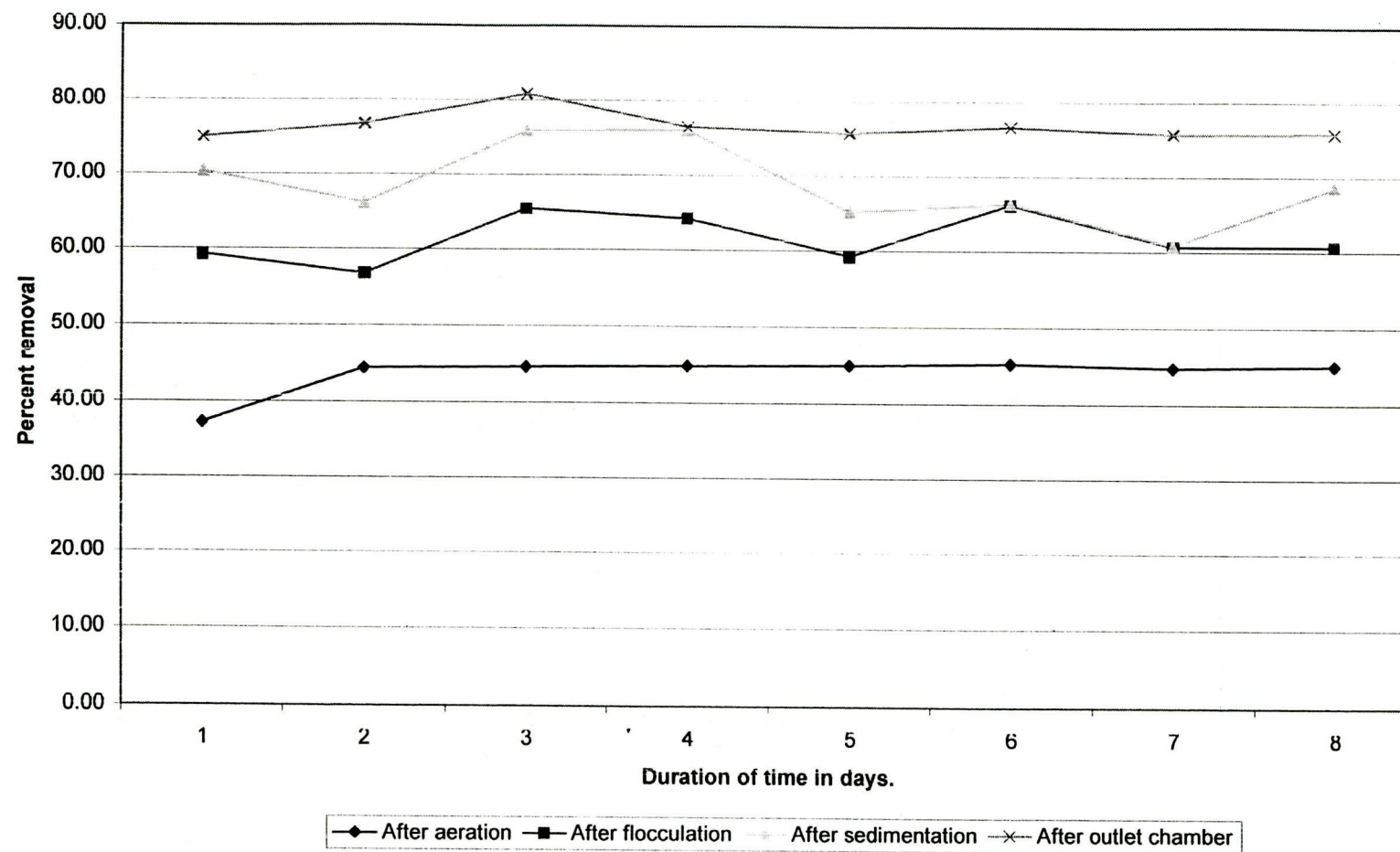


FIG 5.10: CUMULATIVE PERCENT REMOVAL OF IRON UNDER VARIED FLOW (Flow rate: 4.76 lps)

5.4.2. Variation of turbidity content under varied flow condition.

Another observation was also made on the variation of turbidity content under varied flow condition. Non acidified water samples were collected from sampling points and were taken in the beaker of the turbidimeter at the laboratory. Samples were taken on 3 subsequent days under each discharge rates. When it was made 'on' the reading of the turbidity content of the sample was displayed directly in 'NTU'. The observation made is shown in table 5.6.

Discharge rate, lps	No of observation	After aeration, NTU	After flocculation, NTU	After sedimentation, NTU
5.60 (I)	a	31.0	35.0	24.0
	b	30.0	34.0	22.0
	c	25.0	29.0	21.0
5.16 (II)	a	21.0	22.0	17.4
	b	20.5	21.0	16.0
	c	19.0	20.0	14.0
4.76 (III)	a	2.2	4.0	2.3
	b	2.0	3.5	1.8
	c	1.9	3.0	1.7

Table :5.6 Status of turbidity in NTU under varied flow condition.

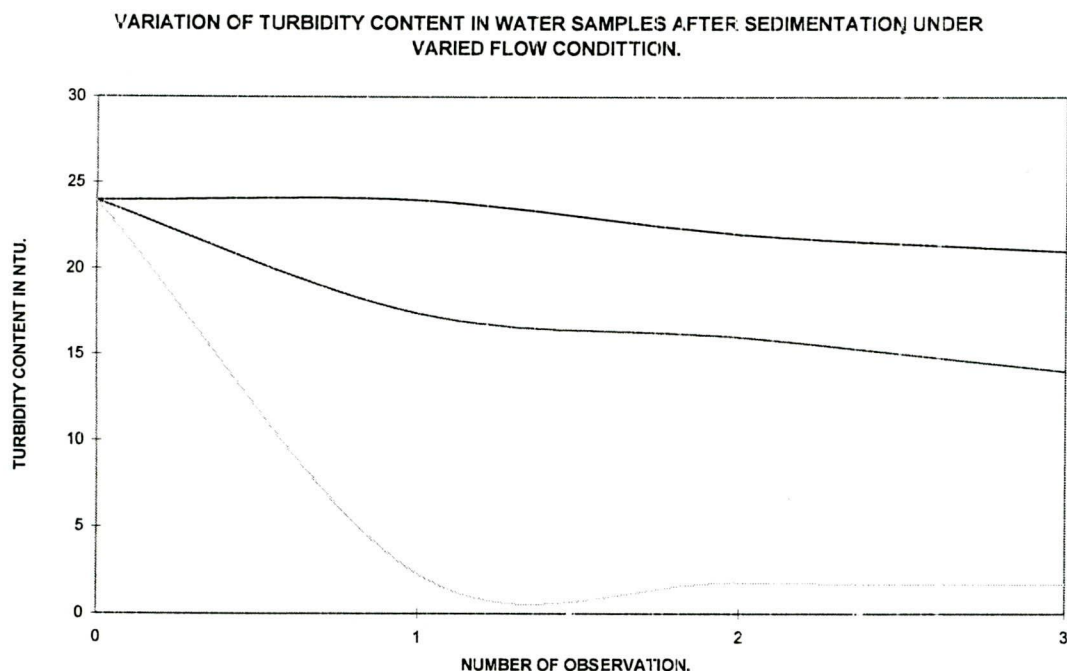


FIG 5.11: Variation of Turbidity Content in Water Samples after Aeration under varied flow condition.

VARIATION OF TURBIDITY CONTENT IN WATER SAMPLES AFTER FLOCCULATION
UNDERVERIED FLOW CONDITION.

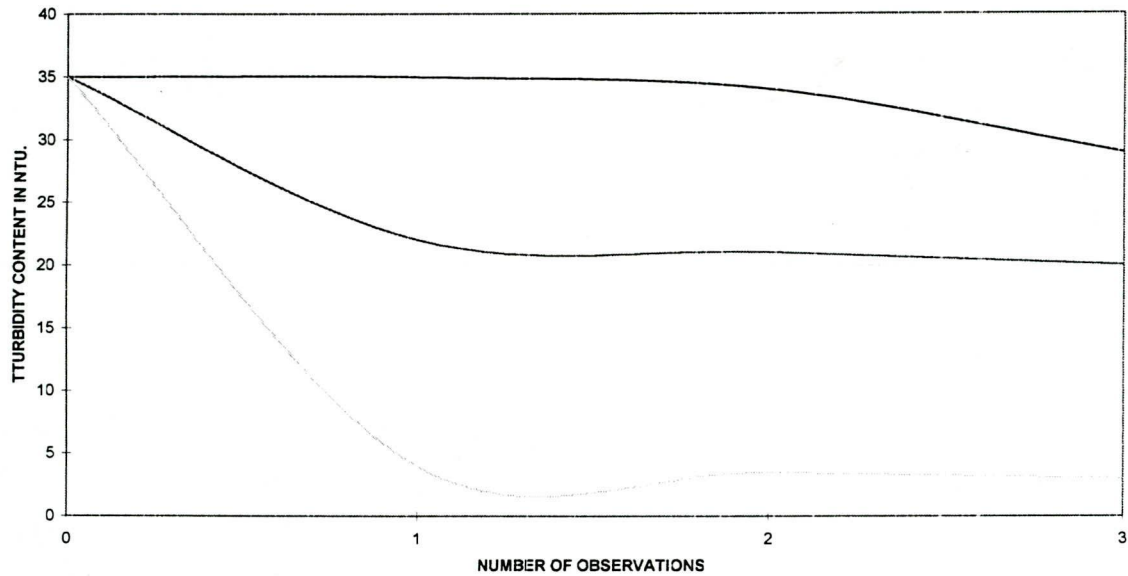


FIG 5.12: Variation of Turbidity Content in watersamples after flocculation under varied flow condition.

VARIATION OF TURBIDITY CONTENT IN WATER SAMPLES AFTER SEDIMENTATION UNDER
VARIED FLOW CONDITION.

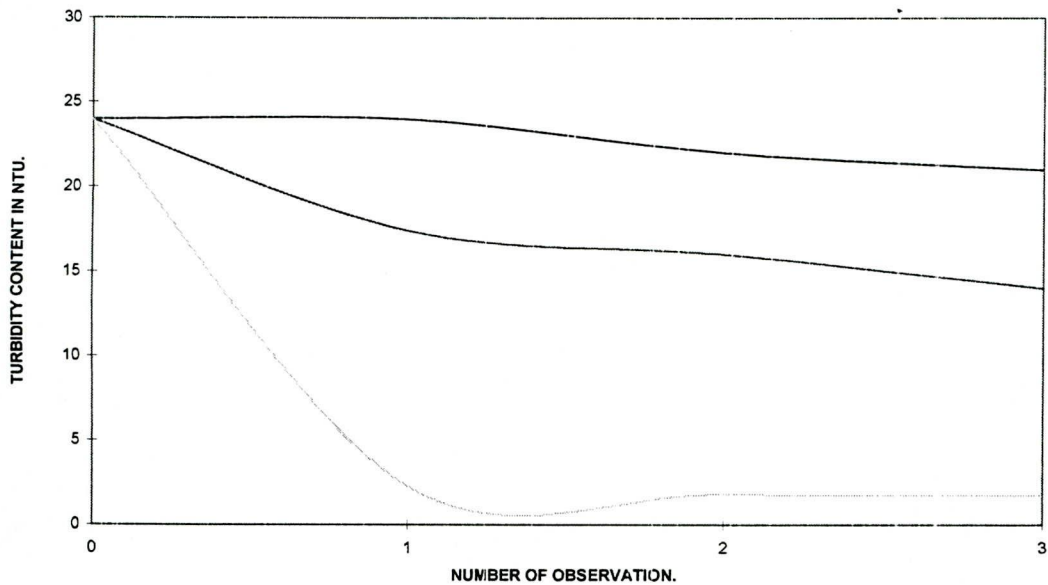


FIG 5.13: Variation ofTurbidity content inwater sampes after sedimentation under varied flow condition.

5.4.3. Variation of carbon-di-oxide content under varied flow condition.

Observation on the carbon-di-oxide content of the water samples was made under varied flow condition. The findings on CO₂ in ppm is shown in table 5.7. The observation of the 3rd sample was failed due to extended mixing during titration.

Discharge rate, lps	After aeration	After flocculation	After sedimentation
5.60	10 mg/l	4 mg/l	8 mg/l
5.16	17 mg/l	13 mg/l	12 mg/l

Table 5.7. Status of CO₂ in mg/l under varied flow condition.

5.5.0. Observation and Discussion on the performance of Iron Removal Plant (IRP) under varied sizes of coarse media as well as under varied flow condition.

The performance of the IRU itself may be observed at the various stages of continuous flow under varied parameters.

The table 5.8. showed the percent of iron removal by each of the sub unit under three varied flow.

Observation	After flocculation, %	After sedimentation, %	After outlet of the IRU, %
I	8.26-18.34	7.92-8.10	8.64-15.35
II	15.40-25.38	3.79-13.81	0.16-3.18
III	12.43-20.91	0.15-11.93	0.39-14.93

Table 5.8. Percentage of iron removal by each sub unit of the IRU.

5.5.1. Aeration and Airlift pump.

With the aeration the performance of IRU as well as the performance of the subsurface aeration technology may be observed. It is evident that in situ iron removal has been accomplished in the aquifer. The portion of the iron concentration that is being removed from the aerated ground water due to the action of flocculation and subsequent sedimentation would show the performance of the IRU. The aerated ground water at the discharge point of the airlift pump has shown almost similar iron concentration under varied flow condition. Hence it may be considered that the IRU has received the aerated water with almost similar load of iron concentration.

In situ removal of iron from the ground water proves that aeration has been accomplished to an extent to oxygenate the water properly and efficiently. Proper aeration reduces the dissolved CO_2 in water and thus the pH value is increased. Table 5.7 shows the status of CO_2 under varied flow condition at various stages of the IRU. It is seen that about 37% to 62% CO_2 was removed with a rise of pH 6.6 to 6.8 up to the point of discharge of the pump. The DO content was elevated to 4.5 ppm. The DO content of raw water could not be measured because of the installed airlift pump. A transfer efficiency of 10% was assumed during design because at that level of efficiency, the air flow required is adequate to meet the oxygen demand in most biological system. For air diffusers submergence is typically maintained at 5 to 6 m (McGhee, T.J. 1991). With the airlift pump, the submergence of the air line under water is beyond 15m. Deeper submergence improves gas transfer, since the partial pressure is increased and the air bubble would have a longer contact time as it rises to the surface. It has been established that gas transfer was accomplished efficiently.

5.5.2. Flocculation and Flocculation chamber.

Observations were made on varied sizes of coarse media and the findings have been presented in art. 5.1.0. Further studies were carried out subsequently with varying rate of flow of water. CAMP number "Gtd" and mean velocity gradient "G" are the important parameters for the control of flocculation process thereby controls the iron removal efficiency of iron removal plant. Modifications in the IRU were made only to improve the sedimentation performance resulting improved overall iron removal performances. Hence the result obtained up to flocculation process under varied sizes of coarse media have been considered for subsequent discussion. The mathematical expression for "G" and "Gtd" developed by Ahmed (1995) were subsequently verified under laboratory condition to determine their applicability in the design of coarse media flocculator (Ahmed 1995). Efforts have been made to compare the parameters under field condition with those obtained under laboratory condition for the applicability of the developed criteria in designing iron removal plants.

CAMP number and Iron removal Efficiency of the IRU.

Ahmed(1995) calculated different values of CAMP number in the laboratory for iron removal performance in the flocculation process using two types of gravel as the coarse media flocculator ($d=1.84-0.76$ cm; $S=6.25-6.82$).

From the developed curve (Ahmed 1995) CAMP number verses iron removal (in percent), the values were picked up to compare those with this field trial in the IRU. For the present study, different values of CAMP number were calculated with the following expression (Ahmed, 1995) for the two observations under varied sizes of the coarse media.

$$Gtd = 3.354 (S/d) \times L \quad [5.1]$$

The coarse media used were brick khoa. In the first observation the size ranges of brick khoa were 4.5 to 5.0cms and those in the second observation were 3.5 to 4.0cm. With S (shape factor: $6/\Psi$; Ψ , being the sphericity:0.78) = 7.7 and L, the length of flocculation chamber = 234cm, the values of Gtd have been calculated against varied sizes of the coarse media. It has been observed that some percent of iron removal was accomplished as has been detected from the samples collected after aeration in the present subsurface aeration technology. Hence to study the flocculation performance using coarse media, the iron removal (in percent) by the flocculation chamber itself only was considered. The percent iron removal against each value of calculated Gtd is presented in table 5.9. The detail calculation is shown in appendix II-F.

Observation	d, cm	Gtd=3.354(S/d) X L	Iron removal (percent) after sedimentation
I	4.75	1272 $\approx$ 1300	20.90
II	3.5	1727 $\approx$ 1700	32.78
	4.0	1511 $\approx$ 1500	15.33

Table 5.9. Iron removal (in percent) against calculated "Gtd" using brick khoa as the course media flocculator.

The variations of iron removal efficiency with CAMP number and that obtained in laboratory (after Ahmed 1995) is presented graphically in fig., 5.14.

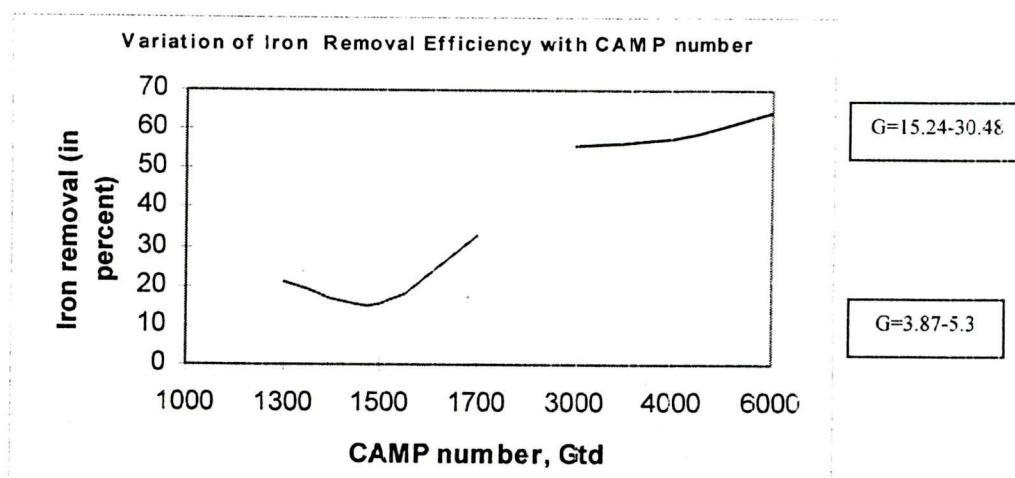


FIG 5.14: Variation of Iron Removal Efficiency With CAMP Number.

The results indicate that iron removal performance increases with increased value of CAMP number. The fig., 5.11., also compares the results achieved under laboratory environment with those under field condition. Again this also verifies the applicability of the expression developed for CAMP number.

In continuous process of flocculation, the increase in iron removal is more and at a faster rate than in any other process. This is due to the fact that the whole bed is effective for flocculation process with coarse media bed and a portion of precipitated and flocculated iron trap inside the coarse media bed flocculator, resulting in a high total removal after settling. However the clogging of the pores of the coarse media cause an increase in head loss and thereby an increase in CAMP number. Comparing the curves in fig 5.14, a higher removal can be obtained at a higher value of CAMP number in a coarse media bed flocculator and this can be obtained by using relatively smaller sizes of coarse media. On the basis of the results obtained through laboratory test result, Ahmed (1995) recommended that a range of CAMP number between 3000 and 6000 may be considered optimum for the design of coarse media flocculator in the iron removal process. It is also observed & established in the fig., 5.14.,

5.5.3. Mean velocity gradient 'G' and Iron removal Efficiency of the IRU.

Under varied flow condition, different values of mean velocity gradient, G, were obtained by varying the face velocity, according to the following expression developed by Ahmed (1995).

$$G = 8.38 [(Q/a) \times S/d] \text{ sec}^{-1} \quad [5.2].$$

The related parameters obtained against each of the flow have been shown in table 5.10.

parameters	First observation	Second observation	Third observation
Size (dia) of the coarse media, cm.	3.5 to 4.0	3.5 to 4.0	3.5 to 4.0
Q, lps	5.60	5.16	4.76
Q/a, cm/sec	0.219	0.202	0.186
G sec ⁻¹	3.77	3.48	3.20
td, sec	1070	1161	1259
Gtd	4034	4037	4029

Table: 5.10. "G" and "Gtd" value at three flow condition.

The obtained and calculated values of different parameters have been shown in table, 5.10. To compare iron removal efficiency with G in the field test with those obtained in laboratory study by Ahmed (1995) for continuous process of flocculation using coarse media, the necessary data were picked up from graph developed by Ahmed. Subsequently comparison being shown in fig., 5.15.

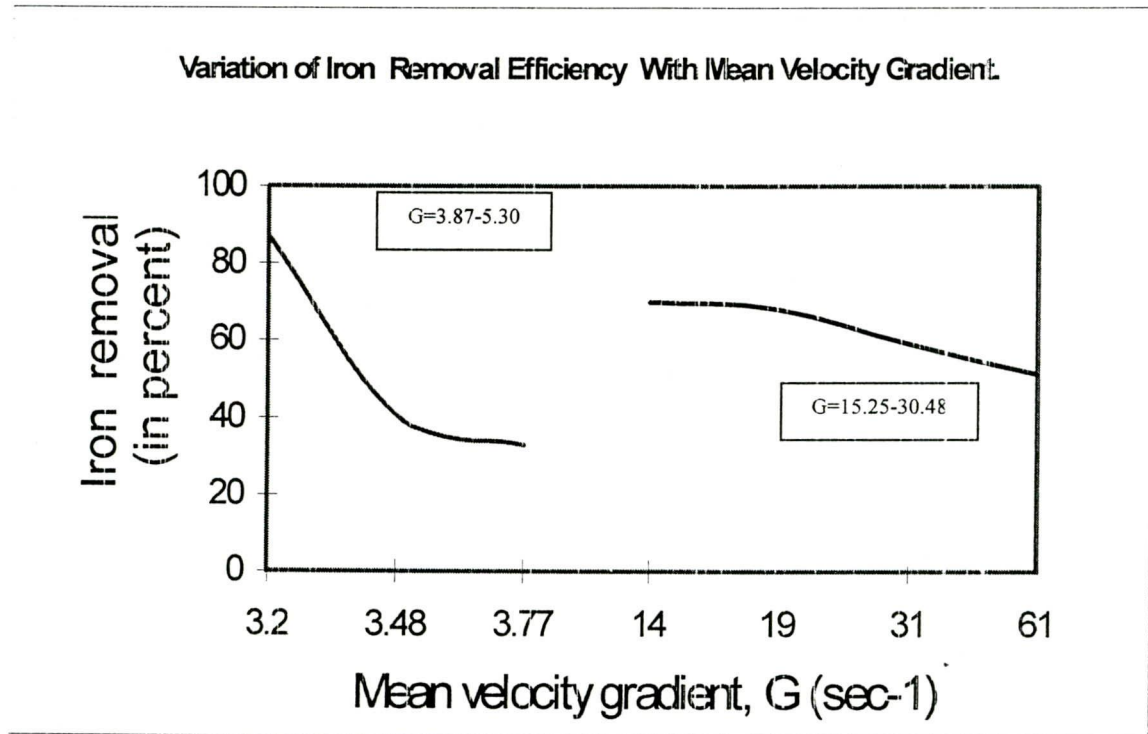


Fig. 5.15. Variation of Iron Removal Efficiency With Mean Velocity Gradient

The variation of iron removal efficiency with different values of G . Fig 5.15., indicate that similar to the laboratory study results , for a specific range of CAMP number, an increase in mean velocity gradient causes a gradual deterioration in iron removal performances. Again longer displacement time, t_d through increasing the length of flocculator may provide better iron removal performances.

Comparing the continuous study results it may be concluded that the expression developed for G may be used for the design of coarse media flocculator in the iron removal process.

Since for a particular size and shape of coarse media, face velocity is the main factor that controls the mean velocity gradient, G , the lower the face velocity, the better is the iron removal performance. According to the fig, 5.15 for a range of G values, face velocity varies for about 0.1 to 0.3 cm/sec, which is close to the rate of flow usually maintained in rapid sand filters (Davis and Cornwell, 1991). Since the pores of the bed usually clog causing an increase in head loss, the mean velocity gradient G , will also increase with time as it is the function of head loss incurred. For this the pore volume will also decrease with time causing an increase in td .

It should be noted that due to the deposition of iron precipitates on the gravel surface, the total effective size of gravel will vary causing a variation in G and CAMP number.

5.5.4. Sedimentation and sedimentation basin.

The variations of iron concentration show that the settling effect is maximum during lowest water flow due to higher settling effect among the observations (Table: 5.6; 5.7; 5.8; 5.9; 5.10).

The ultimate aim of the design was to remove 87% iron up to the sedimentation chamber so that effluent water with 1 ppm iron content is achieved considering that no removal would be accomplished after aeration. The table shows that the percentage of iron removal by individual sub unit is not at all at desired level. The SOR against each flow may be calculated to check the desired performance of the sedimentation chamber.

Observation	I	II	III
Plan area, m^2	3.02 X 4.38	3.02 X 4.38	3.02 X 4.38
Q , m^3/day	483.84	445.82	411.26
Detention time, hour td . ($H=2.12m$)	1.39	1.51	1.63
$SOR=Q/(wL)$ m/day	36.58	33.70	31.09

Table, 5.11. The SOR value of the sedimentation basin under varied flow.

A typical surface overflow rates, detention times which have been used in water treatment are presented for the purpose of comparison (T.J. McGhee 1991).

Type of basin	Detention time, h	SOR, m/day.
Standard basin following coagulation and flocculation	2-8	20-33

Table 5.12. Typical SOR for standard sedimentation basin (after T.J. McGhee 1991)

If the SOR values obtained in the IRU (table 5.11.) are compared with those of typical SOR values in table 5.12., it is clear that among the flows only the 4.76 lps flow fall within the typical range but none of the flows conform the typical detention time.

The basins are usually designed to remove particles with settling rates of 0.3 to 0.7mm/s. Within the design range the basins can provide suspended solids removals from 30-60%. Considering detention time from 1 to 2 h at peak flow, a SOR rate 0.3 to 0.7mm/s yields a depth of 1 to 5 m but practical basins are made with 2-5m depth(T.J. McGhee 1991). The pilot plant has the depth of 2.12m that falls within the range.

Again optimum tank proportions have not been established in the design criteria, but existing plants typically have length-to-width ratios in the range of 4:1, but the pilot plant has only $(438/302)= 1.45:1$.

The most important thing may be to be looked into is that the floc forming efficiency of the flocculation chamber which is in ahead of the sedimentation chamber. This may be ascertained by the turbidity content of the influent and effluent water of the basin.

Flow, LPS	After flocculation, NTU	After sedimentation, NTU	Removal (in percent)
5.60	35	24	31
	34	23	32
	29	21	28
5.16	22	17.4	21
	21	16	24
	20	14	30
4.76	4	2.3	43
	3.5	1.8	49
	3	1.7	43

Table 5.13: Percent difference of the Turbidity content, NTU of water samples collected after flocculation and after sedimentation under varied flow condition.

The percent difference of the turbidity content reflects the efficiency of removal by the sedimentation action and adsorption of the already formed flocs.

According to WHO specification, the maximum limit of turbidity content in potable water is 5 NTU but for Bangladesh the limit is 25 NTU. Higher turbidity content proves that though iron content in water had properly been oxygenated and soluble iron content in water had been precipitated into insoluble particles of sub micron size range but due to inefficient floc forming capability of the flocculation chamber these particles did not form flocs. Though with the present plant iron removal has been accomplished to come up to the range of the Bangladesh context, it would show better performance if smaller size coarse media flocculators are used. Moreover the dimensions of the chambers were not as per design and to achieve better performance these should be modified accordingly.

5.5.5. Outlet of the IRU

The observations show that The settling effect of the preceding sedimentation chamber guides the efficiency of the IRU but efficiency of the chamber itself remains almost similar.

The outlet of the rectangular basin consist of the weir located toward the discharge end of the basin. Weir overflow rates range from 120 to 370 m³/day per meter of weir length (T.J. McGhee 1991). In the pilot plant the end wall of the sedimentation basin acts as the weir having overflow rates under varied flow condition to be 160.21; 147.62 ; 136.18 m³/day per meter length of the weir. These values also fall within desired range.

It has also been observed that during the first and second observation, the weir overflow rates was 200 m³/day per water length of weir which was within the discharged length.

5.6.0. Regeneration of the flocculation chamber as well as the tube well.

In iron problem area, if iron removal plant is installed especially with subsurface aeration technology to extract potable water from the ground source, the question of blockage due to deposition of iron sludge comes out of simple conception to at least three components (a) the aquifer (b) the tube well (c) The flocculation chamber filled with coarse media.

The aquifer permeability will not be affected until after many years of the life span of the tube well and has been shown by a simple calculation in the subsequent article (5.8.0). The regeneration of only the flocculation chamber and the tube well are only necessary as per requirement and depend on a particular site condition. Obviously the frequency of regeneration of the flocculation chamber would be more.

5.6.1. Regeneration of flocculation chamber.

The blockage of voids in the coarse media flocculators is a regular phenomenon. The sludge deposited between the interstices of the media is to be removed/ cleaned and thus can be regenerated.

5.6.1.1. Problems encountered with the flocculation chamber.

The problem encountered with the present IRU are given below:

- The major problem was the water flow ceased through the coarse media when only 25-30% pore volumes clogged with iron precipitates. The water overflows from the inlet chamber through manhole as well as from around the openings of the delivery pipe and thus yield becomes less.
- The maintenance is done by removing the whole lot of the coarse media from the flocculation chamber. It is difficult to take out the huge quantity of flocculators from the flocculation chamber using only two manholes.
- The brick khoa has been proved to be unsuitable as coarse media floccuator for longer time use, especially when these remain always under water. The khoa is usually lifted from the flocculation chamber when heavy sludge deposition occurred between the interstices of the khoa, restricting the desired water flow from the inlet chamber to sedimentation chamber. It resulted overflow from the inlet chamber. This made longer time pumpage to meet the consumer water demand. When the optimum time is reached it is desirable to wash the khoa and remove the iron sludge or replace the lot.

- It has been observed that about 61.44 cubic meter height of the chamber remain empty when repacked the flocculation chamber with the coarse media after washing, i.e. this volume of khoa has been lost. In other words out of $(3.02 \times 2.43 \times 2.13) = 15.63 \text{ m}^3$ khoa, used as coarse media flocculator, $(3.02 \times 2.43 \times 0.6144) = 4.48 \text{ m}^3$ khoa is washed away with the iron sludge. Percentage loss of brick khoa becomes $(4.48/15.63) \times 100 = 28.66\%$.
- Thus the cost of regeneration may be calculated on the basis of the cost of khoa and labour charge for withdrawal, washing and refilling in the flocculation chamber.

Item	Q'ty	Unit price	Total price, Tk
Khoa	(4.48m ³ X35.31)	18.00/cft	2348.00
Labour	5+10+5=20 man-day	90.00/man-day	1800.00
Carrying & handling	LS	LS	200.00
Total:			Tk. 4848.00

Table: 5.14. Calculation of the cost of regeneration of the flocculation chamber and the coarse media.

- Setting of airline pipe with seasonal variation of static water level is not possible. Efficient use of air compressor would make higher flocculator run and in situ washing of the flocculators.

5.6.1.2. Modifications made in the flocculation chamber.

- It is recommended to use gravel of proper size instead of brick khoa as the coarse media flocculator to take care the losses of brick khoa during washing.
- If it is desired in situ cleaning of the coarse media flocculator, it can easily be done by using the air compressor of the airlift pump with simple modification. If airline is installed with several openings at the bottom of flocculation chamber, air surge may be applied in the chamber to break the sludge deposition and the dispersed sludge may be bailed out by the sludge pump. Airflow blow for regeneration of the flocculators would act as preventive maintenance through in situ washing of the coarse media, resulting increase in length of run between cleaning.

With the idea a $\frac{3}{4}$ " dia G.I. airline pipe is installed to connect with $\frac{1}{2}$ " dia G.I. pipe having nine upward open ends at different places at the floor of flocculation chamber, so that air surge may be applied in the chamber to break the sludge deposition and the dispersed sludge may be bailed out by the sludge pump. Thus in situ washing of the coarse media is possible, resulting increase in length of run in several folds between cleaning. The detail is shown in plate 40.

5.6.1.3. Performance of the in situ regeneration technique adopted for the flocculation chamber.

Usually after 30-40 days operation, the inlet chamber over flowed from around the delivery pipe in the side wall due to blockage of voids with iron sludge. The delivery pipe intrusion through the side wall has been closed. When water began to over flow from the top through the manhole, the sludge pump is started to make empty only 20-30cms height of the flocculation chamber. The compressed air is then directed to the flocculation chamber through the piping network. Air pressure is developed to about 5kg/cm² at the compressor and suddenly the cock is opened. The air surge agitates the iron sludge and sludge pump is being started again. The iron sludge came out of the flocculation chamber and thus the chamber became cleaned and over flow from the top of the inlet chamber stopped.

With this operation, the overall cleaning was postponed about a year. Necessary refilling of brick khoa is done as per requirement. However it is still under observation. It is anticipated if gravel are used instead of brick khoa, the regeneration of the chamber by taking out all the coarse media out side the chamber would not be required at all.

5.6.2. Regeneration of the tube well in iron problem areas.

The incrustation in tube wells cause decreased specific capacity accompanied by a larger draw down in the well especially in iron problem areas. It has been observed that when regenerating or cleaning the well with the airlift pumps, the discharge is desired to be started at a very low rate and brought up gradually. The airflow should be slowly increased in proportion to what appears to be the increase in water flow into the well from the water-bearing formation.

5.6.2.1 Results of Regeneration of the DPHE tube wells

DPHE had a programme to regenerate its tube wells throughout Bangladesh to improve their efficiency adopting various methods.

The effects of the different chemicals on the improvement of the specific capacity of 58 wells have been investigated (DPHE). The result observed is shown in table 5.15.

SL. No.	Chemicals applied.	No. of wells	Av. Dose per well applied, Kgs	Improvement, %.
1	Sodium hypochlorite.	18	950	350
2	Calgon + bleaching powder.	24	90+40	180
3	Calgon + Sodium hypochlorite combined.	14	1040+100	250
4	Hydrochloric Acid.	2	200	Not evaluated

Table: 5.15. Results of Regeneration of the DPHE tube wells (1993) using chemical treatment.

An analysis on the Mechanical Treatment.

The effect of the different mechanical treatment was studied for about 58 wells. The relative results of different agitation methods is presented in table 5.16

SL. No.	Method adopted in mechanical treatment	Av. % of improvement
1	Rawhiding	182
2	Water Jetting	137
3	Pressurizing with air	200
4	Section wise cleaning	161

Table: 5.16. Improvement achieved by adopting mechanical treatment methods(DPHE., 1993).

Overall Result of DPHE well Regeneration:

It is a common practice to evaluate the effectiveness of well regeneration by comparing the specific capacity (discharge per unit draw down) of the well before and after treatment. 163 wells were regenerated during 1988 to 1993. The result achieved are shown in table 5.17.

Phases	Discharge, M ³ /hr (av.)		Draw down M(av.)		Specific capacity (av.)		Improvement in %
	before	after	before	after	before	after	
Phase I (78 wells)	52	86	11.3	8.96	4.6	9.6	210
Phase II (85 wells)	43	74	8.77	6.27	4.9	11.8	240

Table: 5.17. Overall results of DPHE well regeneration(DPHE., 1993).

It was also confirmed from discussion with DPHE officials as well as their consultants that both types of the treatment (Mechanical & Chemical) were applied simultaneously in a particular tube well to achieve fruitful result.

The cost of regeneration of DPHE tube well.

The cost of regeneration has been calculated to be Tk. 65,000.00 including depreciation(DPHE., 1993). The breakdown is shown in table 5.18.

SL. No.	Item of cost	Total cost, Tk.
1	Chemicals	15000.00
2	Personnel	25000.00
3	Fuel	10000.00
4	Depreciation	15000.00
	TOTAL:	65000.00

Table 5.18. Breakup of DPHE regeneration cost.

5.6.2.2 Observation and discussion on methods adopted in regeneration of DPHE tube wells

Among the mechanical treatments, adopted by the DPHE, it is to be seen which method is the simplest in respect of technology and may be used with the help of semi skilled man power in the iron problem area of the country. Moreover the method should be cost effective and should require lesser downtime though improvement in results is also a point to be considered.

In rawhiding, overhead tank is required. It is effective where static water level is generally higher, that allows higher water column head. However, it adds additional costs. It is claimed that, the same turbine pump may be used to pump water directly up to the tank and to clean the wastes from the inside of the tube well. But the pump with higher head is required for the purpose. This also adds costs for the pump as well as for the prime mover.

Water jetting & pressurizing with air and section wise cleaning require special devices as well as skilled laborer for achieving fruitful result. The methodology can be easily understood from plate 14,15 & 16. The existing pumping unit is to be withdrawn prior to start the process. Hence the down time is higher which is also a constraint.

Among the chemical used, the detergent type Sodium hexameta phosphate is readily available in the market. It is least costly and unskilled workers can handle it. Hence it was decided to investigate the results obtained through use of it.

5.6.2.3. Regeneration of DPHE tube wells using only sodium hexameta phosphate as the dispersing agent

Among the DPHE methods, reviewed in chapter II, the regeneration of tube wells in iron problem areas using sodium hexametaphosphate as the dispersing agent followed by air surging proved to be simple, cost effective, less risky. The semi-skilled man power can easily carryout the regeneration work with this method.

Efforts have been made to find out the dose of sodium hexameta phosphate. To do this, only those tube wells in iron problem areas were selected from the DPHE data in which sodium hexa-metaphosphate as the dispersing agent was used. Only twenty such tube wells were detected. The related data are presented in tables in appendix II-G.a. b&c). The following curves are drawn with the help of the computer to establish whether any relationship existed between various variables. A relationship is seen only with Fe content verses chemical applied when expressed in grams per liter of water per ppm of iron.

- i. The length of strainers, m verses calgon applied, kg., fig.5.16.
- ii. Fe content, ppm verses calgon applied, gm/L of water, fig.5.17.
- iii. Fe content, ppm verses calgon applied, gm/L of water per ppm of iron, fig.5.18

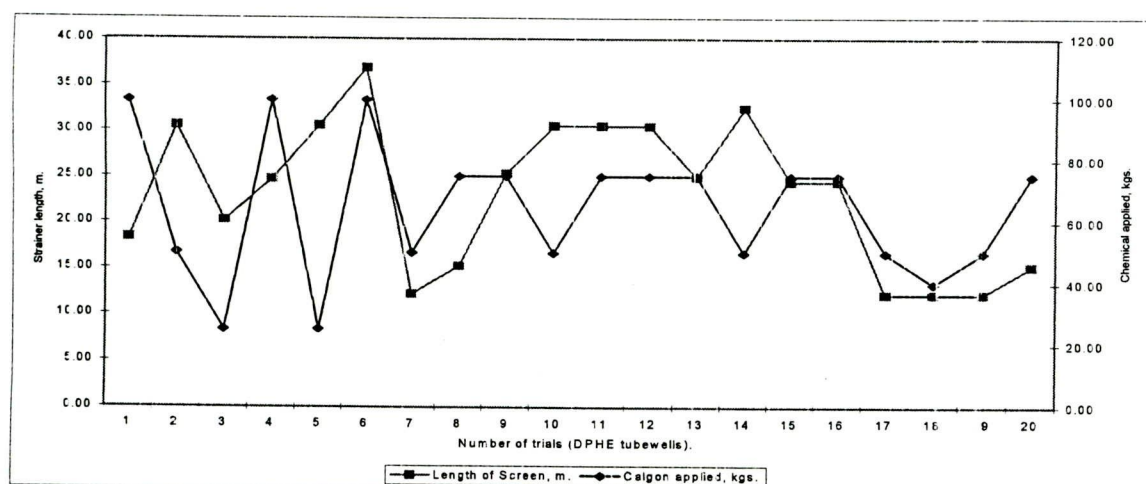


FIG 5.16: Strainer Length, m verses chemical (Calgon), kg applied in the Regeneration of DPHE Tube wells.

FIG 5.17: Iron content in ground water verses chemical applied for regeneration of the DPHE Tube wells.

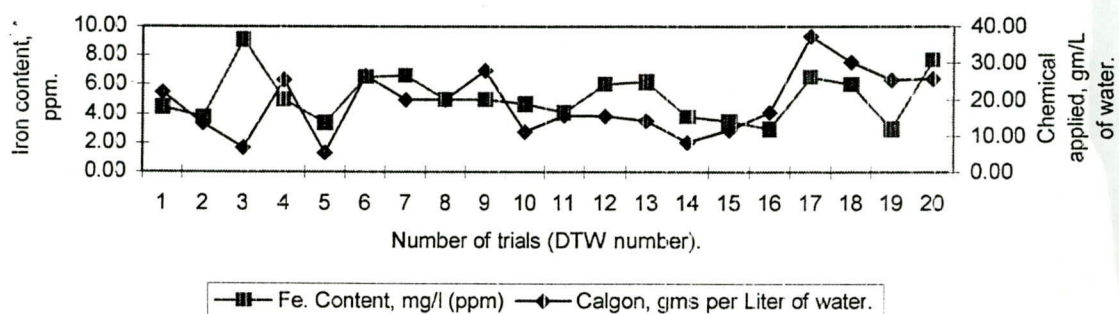


FIG 5.17: Iron content in ground water verses chemical applied for regeneration of the DPHE Tube wells.

FIG 5.18: Iron content in ground water verses chemical applied for regeneration of the DPHE Tube wells.

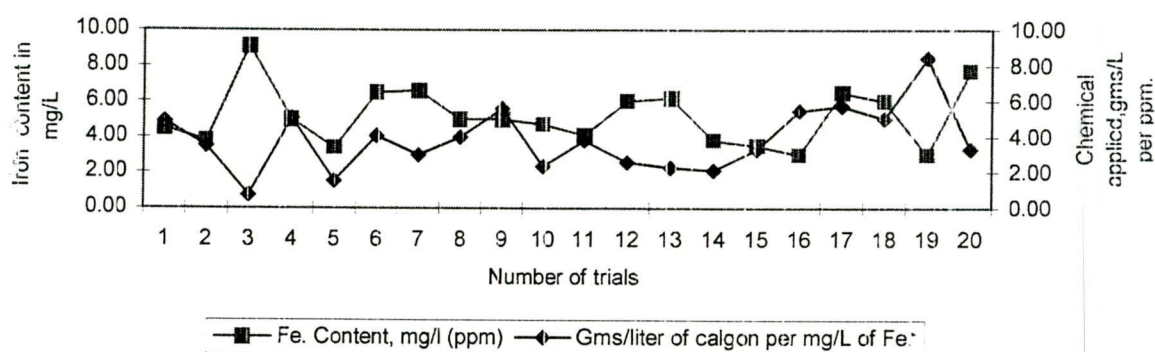


FIG 5.18: Iron content in ground water verses chemical applied for regeneration of the DPHE Tube wells.

The table 5.19. shows that the twenty selected DPHE tube wells have average strainer length of 23.15m/TW (The detail is shown in appendix II-G.a; b&c).

T/W No.	Fe. Content, mg/l (ppm)	Length of Screen, m.	Total volume of water inside well, Lt.	Chemical used			
				kgs.	gms per Liter of water.	kg/M length of screen.	gms/liter per PPM of Fe.
Average of 20 nos. regenerate d DPHE tube wells.	5.17	23.15	3887.16	64.50	16.59	2.79	3.21

Table: 5.19. Use of Sodium Hexameta-phosphate in DPHE tube wells for regeneration.

To regenerate the tube well 64.5kg/TW calgon was applied. In other words calgon was applied at the rate of 2.79kg per meter length of strainer or 16.59gms/liter of water or 3.21gms per liter of water per ppm of iron content.

The DPHE consultants suggested that calgon would be applied on the basis of strainer length. They tried to relate the chemical dose against meter length of strainer. The reason might be DPHE uses similar diameter strainer in all its tube wells. But it has been observed that the chemical applied in DPHE tube well arbitrarily. It has also been established that the chemical applied, gm per liter of water inside well depend on the iron concentration. The fact is the dispersing agent does not know the length of the strainer rather it has to react chemically to disperse certain amount of deposited iron gel under water inside the wells of various diameters.

5.6.2.4. Regeneration of the tube well with the plant under observation

The findings proved that the chemical dose should be determined, gm/L of ground water inside a well per ppm of iron concentration. On this basis, calgon dose was calculated and applied to the tube well under study. The optimum dose obtained by conducting a test above ground for dispersing the iron sludge deposited on the inner & outer wall of the pump column pipe as has been described in art. 4.8.1.1. The consideration made has been followed in the test.

Results of Regeneration of the encrusted tube well under observation

The results of the regeneration of the tube well can be shown by the percentage of change in specific capacity that is the discharge per unit of draw down after the treatment. The detail is shown in the table 5.20.

Treatment	SWL cms	Discharge, Liters/ sec		Pumping Water level. cms		Draw down, cms		Specific capacity, L/cm		Improvement %
		Before	After	Before	After	Before	After	Before	After	
1	2	3	4	5	6	7=(5-3)	8=(6-4)	9=(3/7)	10=4/8	11=[(10-9)/9]* 100
First	532	5.66	7.31	1067	763	535	231	0.010 6	0.3160	197%
second	532	7.31	7.31	763	763	231	231	0.316 0	0.3160	0%
Third	532	7.31	7.31	763	763	231	231	0.316 0	0.3160	0%

Table: 5.20. The improvement achieved due to the action of regeneration against three subsequent treatments.

Only the first dose was applied on the basis of test result conducted above ground. The subsequent doses were made arbitrarily. Actually a total of 100 kg calgon in 25 kg bags were procured for the study. Three bags containing 75 kg of calgon were expended for conducting tests for its doses above ground as well as first two doses in the tube well. The result showed some requirement against the application of second dose but on the basis of the experience gathered during test, it is believed that extended mechanical agitation along with first dose would reach the improvement without application of the second dose. The table 5.20 also shows the same. No improvement was achieved following second and third treatment. Hence conclusion has been drawn to use 0.8 gms of calgon per liter of water per ppm of Iron content for treatment of encrusted tube wells.

5.6.2.5. Comparison of Results of Regenerated project tube well with those of Regenerated DPHE tube wells

It is established that calgon is to be applied in gms per liter of water inside the incrustated tube well per ppm of iron content. It is also found that only 0.8gms per liter of water per ppm of iron is enough to handle the incrustation problem. With the dose the calgon requirement for the DPHE tube wells would be $0.8 \times 150\% \times 5.17 \times 3887.16 = 24.12 \text{ kg/TW}$ (Taking 150% dose) but calgon actually applied was 64.5kg/TW which was double the required amount.

5.6.2.6. Calculation of doses of Sodium Hexa-meta Phosphate as dispersing agents of iron incrustation

The calgon dose may be calculated for regenerating a tube well in iron problem areas as per steps below:

- a. The soluble iron content in ppm of the tube well water is to be found out.
- b. Multiply ppm of iron with 0.8 to get grams of calgon to be mixed per liter of water inside the tube well.
- c. Find out the total volume of water in liters inside the tube well accordingly as shown in tables 4.7a, 4.7b & 4.8.
- d. Calculate the total volume of calgon in kg. required for the tube well.

5.7.0. Discussion on different aspect of the plant.

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 efforts has been made to develop appropriate technology for small communities in developing countries. Few low cost methods, which have been developed so far are based on little theoretical principles and hardly satisfy field demands.

Relevant literatures on chemistry of iron content in water, theories and practices of iron removal techniques and water use pattern in iron problem areas in Bangladesh have been reviewed in chapter II. Some field data obtained through DPHE officials and previous field experience have been utilized for the development of the community type plant using sub-surface aeration technology. Discussion is made below for each of the steps of the developed iron removal technique.

5.7.1. Sub- surface aeration.

Plain aeration by means of rectangular channels in the iron removal plant, built along with the hand pumps for domestic purposes, increases Dissolved Oxygen content (DO content) from a concentration of 0.1 to 3.9 ppm (A, Z., 1990). In sub-surface aeration technology, the increase in DO concentration is more. Effectiveness of aeration can also be proved by comparison of the flocculation results. As the iron removal after flocculation remains same from the beginning, the aeration process may be treated as effective. The increase in removal of iron with the progress of operation is due to adsorption. But in this case, percent removal of iron was higher from the beginning indicating that the aeration action was effective.

In the present sub-surface aeration technology, unlike Vyredox method, aeration is sufficiently made by the compressed air during lifting of water from the tube well by the airlift system. Submergence of airline under

water makes water column being aerated. Moreover the shut off of the pump, creates a backwash effect due to the collapse of air-water column above pumping water level. This effect oxygenates the water inside tube well fixture further. Thus the water gets aerated and has some detention time.

Literatures show that the direct aeration has been discouraged to avoid probable incrustation problem to the strainers. It has been felt that iron may deposit in the vicinity of the strainer openings but no evidence has been seen in support of the problem. Study of specific draw down can show the effect of sub-surface aeration in respect of incrustation problem. If it at all happens, easy regeneration techniques may be adopted as the regular maintenance programme.

However comparison may be made in respect of subsurface aeration between Vyredox method and that of the airlift method as well as in respect of water pumping between the conventional turbine pump with that of the airlift pump in subsequent paragraphs.

5.7.1.1. Comparison between Vyredox method and the present method.

Vyredox method, another subsurface aeration technology, developed in Finland and has been in use in Sweden for removing soluble iron from ground water. The method has been reviewed in chapter II and shown in plate 5,6 & 7. A comparison may be made between the methods as follows.

VYREDOX METHOD OF SUBSURFACE AERATION.	PRESENT METHOD OF SUBSURFACE AERATION.
One main well and several injection well or aeration wells are required. These smaller diameter aeration wells are drilled around the main well in lengths similar to the main well.	Only main well is required.
Water is pumped from the main well or another main well to an aeration room on the ground surface, where the water is being aerated. The aerated water is then forced back to the aquifer through the main well and the injection wells.	An airlift pump is employed. It pumps water and during lifting, the water is being aerated. The aerated water is then pumped to the iron removal unit or the ground for separation of iron flocs.
The insoluble iron is being trapped in the aquifer materials. No flocculation and sedimentation chamber are constructed on the ground.	The aerated water passes through iron removal unit consisting of flocculation & sedimentation chamber.
A secondary pumping is required to extract iron free water from the well.	No such pumping is required.
The aerated water is pumped to the main and injection wells for about 20 hours at a time followed by 4 hours contact time.	No such action is done.
It takes time for the oxidizing zone in the aquifer to become fully efficient. The cycle of withdrawing ground water, aerating and injecting it must be repeated many times. The efficiency increases with number of cycles.	During the operation of the airlift pump, water is being aerated inside the tube well during lifting. When the pump is shutoff, the water column above static water level collapse and goes back to the aquifer. Thus the action of Vyredox method of subsurface aeration is accomplished to some extent.
The efficiency is expressed as the ratio of the amount of iron-free water pumped out of the well to the amount of water that has been injected.	No such efficiency measure is done.
It is not known this method can work with higher iron content in the ground water.	Efficient design can handle any amount of iron content in ground water.
Larger investment is necessary.	Comparatively smaller investment is sufficient.
Technical manpower is required to run such plant.	Semi skilled manpower will be able to run it.
Regeneration of all wells need higher cost.	Regeneration technique is simple and less costly.

5.7.1.2. Comparison between the use of conventional turbine pump and the airlift pump in iron problem area.

Turbine Pump.	Airlift Pump.
Only pumps water from the well.	It pumps water as well as aerate water during lifting from the well.
Pump bowl works under water and iron sludge deposits inside the bowl assembly; inner wall of the column pipes and hence lifting of pump assembly is necessary to clean it.	No moving parts work under water, hence frequent lifting and cleaning is not necessary.
Additional arrangements, structures are necessary and to be built for aeration of extracted water prior to flocculation process.	These are not necessary at all; water is being aerated at the time of lifting.
Larger land area is required for the installation of aeration structure.	Smaller land area is required.
Water pumping efficiency is high.	Water pumping efficiency is low.
Electrical energy runs pump. A 10hp vertical motor is generally employed to run a pump of 1/4 cusec capacity.	Electrical energy runs air compressor. In this case a horizontal motor of 10hp capacity is coupled with the compressor.
Additional detention time is required for the aeration and floc development.	Less detention time is required because aeration is done inside well.
It can be installed in higher diameter well having higher diameter housing pipe.	It can be installed in a uniform diameter well; housing pipe of larger diameter is not required.

5.7.2. Flocculation:

The net length of the chamber was smaller than that may be obtained by the equation developed by (Ahmed, 1995). The flocculation action was found more effective by use of the coarse media flocculators. The voids was found 40% and it became 30% after being filled up with iron deposits.

It may be thought to remove all the coarse media flocculators out of the chamber at the time of maintenance and fill the chamber again with new flocculators. But these may be cleaned by dispersing the deposited iron sludge keeping the flocculators in-situ by the use of sodium -hexa-metaphosphate. When being dispersed by the application of this chemical and subsequent air surging, the water may be pumped out from the chamber. A one horsepower sludge pump has been installed to perform the job.

The water flow enters the flocculation chamber through 1/2 " dia. PVC pipe holes built in the partition walls. Hence the velocity of water flow is higher through the limited numbers of holes. Again the effluent water comes out of the chamber through similar types of openings. If any piece of the coarse media sits just at the mouth of the opening, there is possibility to make the opening closed. Obviously the openings at the bottom have higher velocity than those in the upper side of the wall due to hydrostatic pressure. If the effluent water comes out directly from the flocculation chamber to the sedimentation chamber, the action of sedimentation may probably be disturbed. For this reason a vertical wall was built and its height was modified to make the flow stabilized. The water enters the sedimentation chamber flowing over the wall as a weir.

The survey [Azim, Z., 1990] shows that iron removal efficiency of the flocculation chamber of the plant developed for domestic use along with the hand pump have efficiency of 99.41%. But its length of run is only 1 week. This community type plant has the efficiency of 70% with several months length of run. If the flocculators are correctly chosen, its efficiency will surely increase. Again percentage of removal is not enough to understand the actual removal. Fifty percent removal of 12ppm iron concentration and fifty percent removal of 10ppm concentration is not same.

It would be safe to collect sample just in ahead of the pump being shutoff.

The brick khoa has been proved to be unsuitable as coarse media floccuator for long time use. It is proved to be uneconomic too.

5.7.3. Sedimentation.

The sedimentation basin has the plan area of $302\text{cm} \times 437\text{cm} = 131974\text{cm}^2$. The floor slope has been kept in the direction of flocculation chamber allowing the same sludge pump to bail out the settled flocs from the chambers without emptying the full chamber.

It has been observed in the figures showing the cumulative percentage of iron removal by the sedimentation basin that the removal percentages in the first run and that of second run are about 10% and 15% respectively. As only variable between first and second run was the size of coarse media flocculator, it may be said that proper size of the coarse media controls the

sedimentation characteristics.

The length of run of the basin is also important. The designed length was not maintained during construction of the basin. Thus the flocs developed in earlier stages overflowed to the outlet compartment, built after the sedimentation basin.

5.7.4. Discussion on Regeneration Technique adopted in the present case.

- i. Among the methods of the regeneration technique, the use of hexa-metaphosphate is the best. Only thing is to be looked into is that the chemical must be thoroughly mixed before applied in the tube well. If the powder is applied in water at a time, it becomes gelatinous, sticky substance and takes much time to mix.
- ii. The best technique may be the simultaneous use of Sodium hexa-metaphosphate followed by agitation by the compressed air. This compressor may be used as airlift pump to clean the tube well up to the bottom by extending the airline.
- iii. Number of treatment should be based on the result of first treatment.

5.8.0 Affect on the permeability of the aquifer due to subsurface aeration.

The airlift pump is aerating water underground. The precipitation of iron takes place as the water in the aquifer moves towards the well. Thus blockage of aquifer voids as well as the strainer opening may happen due to the iron precipitation and there will be no other alternative except to abandon the tube well.

Hallberg, R.O. and Martinell, R., (1976), while describing the Vyredox method – the method of in situ purification of ground water in iron problem area, explained the probability of the blockage risk with a simple calculation. The precipitation of iron takes place as the equilibrium is displaced towards the oxidative side, due to addition of aerated water. The iron is deposited in a very large pore volume in the aquifer. Under natural condition deposits of iron accumulate during very long periods of time.

Usually the amount of aerated water, forced down into the aquifer is equal to the average amount pumped out in a day (say q_m cubic meter/day). Hence

q_m cubic meter is the pore space that would be aerated.

Assuming that iron will be precipitated in 50% of the aquifer pores and again assuming that the well must be abandoned when its capacity diminishes due to 50% of these pore volume getting blocked. The amount of iron that must be precipitated before the well can be said to be blocked is therefore $0.5 \times 0.5 \times q_m \times 2.8 \times 10^6$ grams, the density of precipitated iron salt is being 2.8gm/cc (Winterhalter, B., 1966). The years it will take when Fe is the iron concentration in mg/L and water discharge is q_m cubic meter/day $\approx$

$$\frac{(0.25 \times q_m \text{ m}^3 \times 2.8 \text{ gms / cc} \times 10^6 \text{ cc / m}^3)}{(365 \text{ days/year} \times q_m \text{ m}^3/\text{day} \times \text{Fe mg/L} \times 1\text{g/1000mg} \times 1000\text{L/ m}^3)}.$$

≈ 160 years with 12mg/ Fe content.

This is a highly conservative estimate otherwise it can safely assumed that 100% of the aquifer pores take part in the process. Hallberg, R.O. and Martinell, R., (1976), stated that the blockage of the pores had been scientifically studied in iron precipitation zones around wells and in nature, and so far, the correspondence with the theoretical calculation above proved to be very good.

In the present case Fe content is 12 mg/L, and about 40% remained underground and some accumulate on the inside wall of the tube well components and the lifting devices coming in contact with aerated water.

Hence, $(25 \times 2.8 \times 10^4) / (365 \times 12 \text{ mg/L} \times 0.4) = 399$ years would take to declare the tube well abandoned.

This is a simple calculation giving an idea of the enormous length of time that the well with subsurface aeration technology can be expected to provide water.

Such risk is very small, since the permeability is not reduced until after many years due to the fact that the reaction in the ground occurs in a very large volume in the aquifer around the well. There is practically no risk of blockage and the matter is not important.

5.9.0. Financial Considerations Made on the Package Iron Removal Plant.

5.9.1. Cost Estimates.

The developments of engineering plans for water supply and waste water treatment ordinarily involves economic evaluations of alternative schemes, selection of the least expensive satisfactory system, and development of a financing plan. As has been claimed that the subsurface aeration technology is a 'low cost method', the statement should have basis. Hence the 'present value' of production cost of the pilot plant has been evaluated and subsequently compared with iron removal plants in operation in urban areas of the country. DPHE installed 29 nos treatment plant in 22 town throughout the country (appendix: v).

Recently DPHE evaluated the unit cost of production of ground water for the first time (DPHE data book 1998). This reflected the unit cost considering the O&M cost only. The investment cost needs to be taken into account while calculating the unit cost of water. Hence effort has been taken to evaluate the unit cost of water for both the plants -- the DPHE plant and the pilot plant considering the investment cost (capital cost) and the O&M (operation & maintenance) cost. The life is assumed to be 20 years. The 'present value' of cost is calculated with 15% discount rate.

The investment cost or capital cost of the plant depends on the iron concentration of the water source. With 200m³/hr discharge capacity of the effluent water, the capital cost of plants having concentration up to 5ppm is Tk. 80.00 lacs on the other hand, if the concentration is beyond 5ppm the cost becomes Tk. 115.00 lacs (Haq. N 1999). The capital cost of Tk 115.00 is considered here for DPHE plant for comparative observation. The item that has life of 10 years would be replaced in the 10th year. The average unit O&M cost per cubic meter of water for DPHE treatment plants in 22-towns in iron problem area is Tk. 2.55. The pump operation has been considered to be 8 hours per day. Hence total O&M cost per year becomes

$$(\text{Tk. } 2.55/\text{m}^3) \times (200\text{m}^3/\text{hour}) \times (8\text{hours}/\text{day}) \times (365\text{days}/\text{year}) = \text{Tk. } 14.89 \text{ lacs}$$

In case of the pilot plant, the kW-hr to run the airlift pump; the secondary pump- to lift water from the under ground reservoir to overhead tanks and

the sludge pump was observed from the 'meter'. The unit cost of electricity (kWh) has been taken Tk. 2.50. The regeneration of the flocculation chamber is anticipated to be done one time in a year but of a tube well would be once in 5-years, The items that has life of 10-years would be replaced in the 10th year.

The detail of cost calculation is shown in appendix- V & VI. Subsequently these were compared to find the one with lower cost.

5.9.2. Cost Comparisons.

The total discounted cost at 15% discounted rate of the DPHE iron removal plants with 200 m³ /h discharge capacity has been calculated to be Tk. 211.67 laks. Hence the cost of unit volume (01m³) of treated water becomes

$$\begin{aligned} & (\text{Tk.} 211.67 / 20 \text{ years}) \times (1 \text{ year} / 365 \text{ days}) \times (1 \text{ day} / 8 \text{ h}) \times (1 \text{ h} / 200 \text{ m}^3) \\ & = \text{Tk. } 1.81 / \text{M}^3 \text{ of treated water.} \end{aligned}$$

On the other hand the total discounted cost of the iron removal plant using subsurface aeration technology, with 15% discounted rate is Tk. 17.65 laks. Hence the cost of unit volume (01m³) of treated water becomes

$$\begin{aligned} & (\text{Tk.} 17.65 / 20 \text{ years}) \times (1 \text{ year} / 365 \text{ days}) \times (1 \text{ day} / 8 \text{ h}) \times (1 \text{ h} / 25 \text{ m}^3) \\ & = \text{Tk. } 1.20 / \text{M}^3 \text{ of treated water.} \end{aligned}$$

The difference of the unit cost in % = $[(1.81 - 1.20) / 1.81] \times 100$
= 33.70 % i.e. The unit cost of the DPHE plants is 33.70 % higher than that of the plant using the subsurface aeration technology.

CHAPTER: VI

CONCLUSIONS AND RECOMMENDATIONS.

6.0.0. General.

Relevant literatures on theories and practices of iron removal techniques on global basis and iron problem in Bangladesh have been reviewed in chapter II. Some field data obtained through DPHE, BADC officials and previous field experience have been utilized for the modification and subsequent development of the community type plant using sub-surface aeration technology. On the basis of results obtained and discussions made in the previous chapter the following conclusion and recommendations can be drawn.

6.1.0. Conclusion.

6.1.1. Aeration and the Airlift pump.

Gas transfer equation indicates 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 interfacial film. It was observed that when air compressor starts to force air into water to make air-water mixture, these are satisfied properly and in a better way as may be accomplished in any other means of aeration.

Gas transfer efficiency has been considered to be 10% in the design. At this level of efficiency, the airflow required to meet the oxygen demand is adequate (T.J. McGee 1991). The airlift pump for its operation needs 50 to 70% submergence of the airlines along with sufficient amount of air for optimum discharge. Practically deeper submergence under water inside the tube well improves oxygenation through gas transfer, since the partial pressure is increased and air bubble would have longer contact time as it rises to the surface. On the other hand amount of air ensures the amount of oxygen.

As air passes through the air line, the pressure will drop as a result of the friction losses. The pressure drop produces a decrease in density and thus increase in velocity, since the mass flow is constant. This effect is offset to a degree by the decrease in temperature which also accompanies a drop in pressure and which produces an increase in density. In spite of this air being conveyed in closed conduits of constant size will move at increased velocity in the downstream direction. This may not be significant in short airlines of the airlift pump.

The airflow for purposes of design would be the maximum requirement during the design period and should not be based on average flow or pressure. In the airlift pump the pressure requirement was considered the need of the regeneration of the tube well when the free end of the airlift pump would be placed near tube well bottom.

The airlift pump is suitable for wells of uniform diameter size and even for non-vertical wells. Here in this case 100mm dia MS pump column pipes were installed inside a 300mm dia housing pipe. The same airline could easily be installed in 100mm dia pvc column pipe or even 100mm dia tube well using even pvc pipes and strainers of suitable length to get the same discharge. Thus costing of both tube well materials as well as tube well drilling can be substantially reduced.

If 100mm dia well is drilled in zones of higher static water level or in areas where pumping water level of operating tube wells drops below 7m depth, only submersible pumps and jet pumps are capable to pump water from such wells but with less discharge. On the other hand if airlift is installed, this can be able to pump a higher water discharge from the same well. In iron problem areas, though SWL is within suction limit but due to incrustation problem, the PWL of tube wells may drop beyond 7m depth. To satisfy water demand, airlift pump may be recommended in such areas for campus water supply. The aeration of water during lifting would be an added advantage.

The selection of a particular air compressor should be based on design criteria and would vary as per site condition. Air compressors with various specifications both diesel engine and electrical motor driven are available in the local market. Air compressor mechanics are available even in small towns in the country. Hence subsurface aeration technology can be adopted easily with confidence in the country.

As is seen the urban water supply system require high investment as well as high operating cost. Again these need large land area and skilled man power to operate. But it has been observed that with sub surface aeration technology land area requirement for constructing aeration structures is not needed at all. On the other hand, one semi-skilled person may be engaged to operate it. In the pilot plant one office peon operates it and only Tk. 200.00 per month is paid to him. More over its investment and operating cost is less.

6.1.2. Iron Removal Unit(IRU).

The rectangular basin using common wall design offer certain economics in construction for this type of smaller sizes treatment plants.

6.1.2.1. Flocculation and the flocculation chamber.

- i. Although the iron removal performance increases with increased value of CAMP number, a higher removal of iron can be achieved at a lower range of CAMP number in a coarse media bed flocculator. Lower mean velocity gradient value gives better iron removal performance. The field tests indicate that the mathematical expressions developed for CAMP number and mean velocity gradient by Ahmed (1995) can be successfully used for the design of coarse media flocculator. The ranges of CAMP number (3000 to 6000) and that of mean velocity gradient ($10\text{-}20\text{sec}^{-1}$) recommended by Ahmed (1995) may be used for design purpose.
- ii. Since for a given face velocity, mean velocity gradient varies inversely with size of coarse media, the smaller the coarse media, the better is the iron removal performance. To avoid rapid clogging, the size of the coarse media should be selected on the basis of total load of suspended matter. Due to deposition of iron precipitates on the media surface, the total effective size of coarse media will vary, resulting a variation in G and camp number Gtd. The face velocity is the main factor that controls the mean velocity gradient; hence for average size below 1.0cm dia meter coarse media may be chosen with face velocity below 0.3 cm/sec. Although smaller coarse media gives better iron removal performance, to avoid rapid clogging the size of coarse media can be limited to 5mm. The size of the coarse media should be selected on the basis of total load of suspended matter, but a size below 5 mm is not recommended (Shulz and Okun, 1984).
- iii. As the water is flowing horizontally from the inlet compartment to the flocculation chamber a certain head is always required to cause the flow. It has been observed that when about 25% of the voids in the coarse media flocculators become filled up with iron sludge, water flow reduces or even over flows out of the inlet compartment. For this reason, it is recommended to raise the wall height of the inlet chamber to maintain a higher head of water to flow to the flocculation chamber when the pump is under operation.

- iv. Careful design of inlets and outlets is very important for the operation of the flocculation chamber. A near-perfect inlet consists of a very large number of very small openings distributed across the width and depth of the basin. Here 13mm PVC pipes are installed in the 127 mm width brick wall. The number of opening should be increased.

6.1.2.2. Sedimentation and the sedimentation chamber.

Since plain sedimentation was adopted in the design, due to lack of proper workmanship in construction of the whole iron removal unit, the percentage removal by the sedimentation chamber itself was low.

As the flow is almost uniform after the flocculation chamber, the weir must be level and have a free discharge. There must be device to measure water level over the weir from a fixed datum over it.

The size of the chamber should be properly designed to match the water flow. Optimum tank proportions have not been established. The design will be unlike conventional one to achieve better efficiency as there is no filtration chamber after it.

Careful design of inlet and outlets is very important for proper operation of the basin. The ideal inlet reduces the entrance velocity to prevent development of currents towards the outlet, distributes the water as uniformly as possible across the basin, and mixes it with water already in the tank to prevent density currents. Outlets usually consists of weirs which skim the clarified water from the surface and sufficiently long to reduce the local velocity in their vicinity to levels which will not re suspend solids.

The efficiency of the sedimentation chamber depends largely on the floc forming efficiency of the preceeding flocculation chamber. The turbidity content after flocculation chamber as well as after sedimentation chamber explain the situation. Lower value of turbidity after sedimentation means higher efficiency of floc formation and subsequent settlement in the sedimentation chamber.

6.1.3. Regeneration of the tube well.

In iron problem areas, well maintenance has to be given importance to handle the encrustation problem to maintain well efficiency, no matter whether the plant is using sub surface aeration technology or other conventional methods of aeration. It is essential that the screens are to be cleaned at regular interval of time to maintain the well's productivity. Increasing the efficiency of the tube wells can reduce the rising operating cost. The followings were observed in the regeneration process during the study.

Among the methods of the regeneration technique, the use of hexa-metaphosphate is the best as it is less costly, easy to handle and its availability in the market. If the powder is applied in water at a time, it becomes gelatinous, sticky substance and takes much time to mix. Hence mixing of it with water above ground is recommended.

The best technique may be the simultaneous use of Sodium hexa-metaphosphate followed by agitation by the compressed air. If the subsurface aeration technology is adopted the same air compressor may be used for the regeneration. It has been observed in the pilot plant that the airlift pump can be successfully used to clean the tube well up to the bottom by extending the airline.

Number of treatment should be based on the result of first treatment.

In iron problem area, airlift pump can be successfully used for aeration as well as to lift ground water. The same pump can also be used to regenerate the well to free it from incrustation. The subsurface aeration results in accumulation of insoluble iron sludge in the voids of the aquifer to some extent. But the regular regeneration of the well will also clear the adjoining aquifer.

When regenerating or cleaning the well with the airlift pumps, the discharge should be started at a very low rate and brought up gradually.

The following steps may be adopted to reduce or eliminate mineral encrustation problems in tube wells:

- To provide more open area in selecting the well screen for the well. This reduces the entrance velocity of water.

- To reduce draw down by improving well efficiency, utilizing the best design construction and development practices currently known.
- To reduce draw down by limiting pumping rate,
- To provide periodic treatment using the correct chemicals, if required, for the situation.

6.2.0. General comments.

- The design steps or algorithm followed in designing the package plant should be established since there exist no such established steps in designing iron removal plants. Efforts were taken to follow an algorithm in designing the plant in chapter III.
- The removal of iron by the IRU constructed along with the airlift pump as a package of iron removal plant is possible if airlift pump works. The design criteria should be developed for the IRU and is to be established.
- The iron removal plant using sub surface aeration technology was found satisfactory for effective reduction of iron from DTW water. In iron problem areas ground water is used mainly as a source of safe water supply for drinking and cooking. In such areas, especially where iron concentration is found more than 3ppm, iron removal plants are to constructed, so that people do not use contaminated surface water even for other purposes.
- The present effort is to develop iron removal plants using low cost and appropriate technology for campus water supply with medium size water demand in iron problem areas. This plant can successfully be installed in Upazella Health complex; Upazella complex; Palli Biddut Samity complex etc., for campus water supply as well as in areas where pumping water level is beyond 7m depth.
- The effect of iron bacteria in IRU or inside tube well was not done. The sludge samples from filter wash out in various conventional iron removal plants showed that there had been massive growth of iron bacteria that apparently played role in removing iron.
- Bacteriological tests were not done. Since it is the potential source of contamination of treated water, bacteriological quality should be tested to verify the level of contamination and to determine what extent the plant should be flushed out.

- vii. The research and development activities on iron removal plants should continue in all the iron problem areas and the people should be motivated for the acceptance of the plants.

6.3.0. Recommendations for future studies.

Design of the treatment system should be based on laboratory evaluation of the systems as well as field study which are proposed.

6.3.1. The airlift pump and aeration.

- i. As air is a compressible fluid, its volume varies with the variation of the submergence of the airline pipes of an airlift pump. Though amount of oxygen needed for oxidation of water depends on iron concentration, a criteria may be worked out for various heads of the pump, keeping the air line pipe at various depths.
- ii. The airlift pump suitable for both 38mm dia hand pump as well as 150mm dia deep tube well should be tested in iron problem area in respect of pumping as well as oxygenation capability.
- iii. The design criteria of the air compressor of the airlift pump to lift a certain quantity of water from a certain depth should be developed further.
- iv. Study may be carried out by developing pvc pipes as alternative to ms column pipes and using various diameter airline pipe to lift maximum discharge of water with maximum action of aeration.
- v. Amount of water injected vis-a-vis amount of water extracted by installing airline pipe at various depths may be established by using proper air flow meter.
- vi. Proper monitoring of seasonal water variation of the ground water level and consequent pumping water level should be maintained to prepare the maintenance schedule of the well. In the pilot plant, the airline pipe can not move up and down through pump socket, a provision should be made for this.
- vii. A guide line may be developed for particular site condition against calendar months to adjust the air line pipe depth to match seasonal water variation

6.3.2. Iron Removal Unit(IRU).

6.3.2.1. Flocculation and the flocculation chamber.

When the interstices of the coarse media flocculator become filled up with iron sludge, these are generally replaced. In-situ cleaning has been developed and tested using air surge and with brick khoa as the coarse media. The same air compressor of the airlift pump was used for the purpose. Study with gravel as the coarse media may be done. The calgon may be used to disperse the sludge and the compressed air may be used to clean and wash the voids. Finally the sludge pump may be used to pump out the wastes out of the chamber. The efficiency of the air surge in regenerating the flocculators in respect of longer run should be studied further even if subsurface aeration technique is not adopted.

The flocculation chamber may tested for its optimum design in field condition

- a. By varying the size of the coarse media flocculators especially gravel of smaller sizes;
- b. By varying the length of the chamber and reducing the depth of it.
- c. By using alternate separating wall having more passages for easy water flow as influent and effluent of the chamber,
- d. The ferro-cement technology for the construction of separating wall may be tested for this purpose.

6.3.2.2. Sedimentation and the sedimentation chamber.

Further study may be done as follows in respect of sedimentation and the sedimentation chamber especially smaller and conventional type for community use.

- I. The settling rate of flocs may be studied by using tube settlers.
- II. By varying the length thereby the detention time 'td' corresponding to the discharge rate may be studied for optimum efficiency.
- III. By varying the depth of the chamber through false floor to achieve the optimum depth of the chamber for a particular flow as the sedimentation action depends on the SOR not the depth of it. It would surely reduce the cost of IRU.

6.3.4. Regeneration of the tube well.

Adoption of appropriate method for the regeneration or cleaning of the well should be carefully studied. Less work has been done in the field.

The use of hexa-metaphosphate has been found as the best. The procedure to find out its dose(gms of chemical per liter of water inside the tube well per ppm of iron content) has been developed and tested only in the pilot plant. This is to be studied in other field condition with

- a. Various iron content.
- b. Various ages of iron incrustation.
- c. Various specific capacities of well.

The criteria for designing of the airlift pump for the purpose of well regeneration of various diameter should be worked out.

WATER QUALITY OF THE TUBE WELL.

The water quality results obtained by testing water samples collected from the test well.

Parameter	Unit	Test result	WHO	Eangladesh
TDS	ppm	192.00	1000	1500
Turbidity	NTU	97.00	5	25
Colour		10.00	15	30
pH		6.6	6.5-8.5	6.5-9.2
CaCO ₃	ppm	75.0	500	250 (400)
Chloride	ppm	17.0	250	600 (1000)
Floride	ppm	0.3	1.5	1(2)
Iron, Fe	ppm	12.0	0.3	1(5)
Mn	ppm	0.2	.01	0.5
Nitrate, Na	ppm	7.00	10.0	45 (50)
CO ₂	ppm	27.00		
Alkalinity	ppm	86.00		

APPENDIX I-B.**DESCRIPTION OF THE DEEP TUBE WELL.**

The components used and the length thereof are as follows:

Components	Size	Length
MS Housing Pipe	355.6 mm dia.	30.48 m
MS Reducer	355.6 mm X 152.4 mm	1.00 m
GI blind pipe	152.4 mm dia.	41.155 m
Wire-wound stainless steel strainer.	152.4 mm dia; 1 mm slot size	23.29 m
GI bail plug	152.4 mm dia	1.5 m
Total Fixture Length: 97.425 m and the tube well has the capacity of 14 LPS discharge.		

WORKING PRINCIPLE OF THE AIRLIFT PUMP

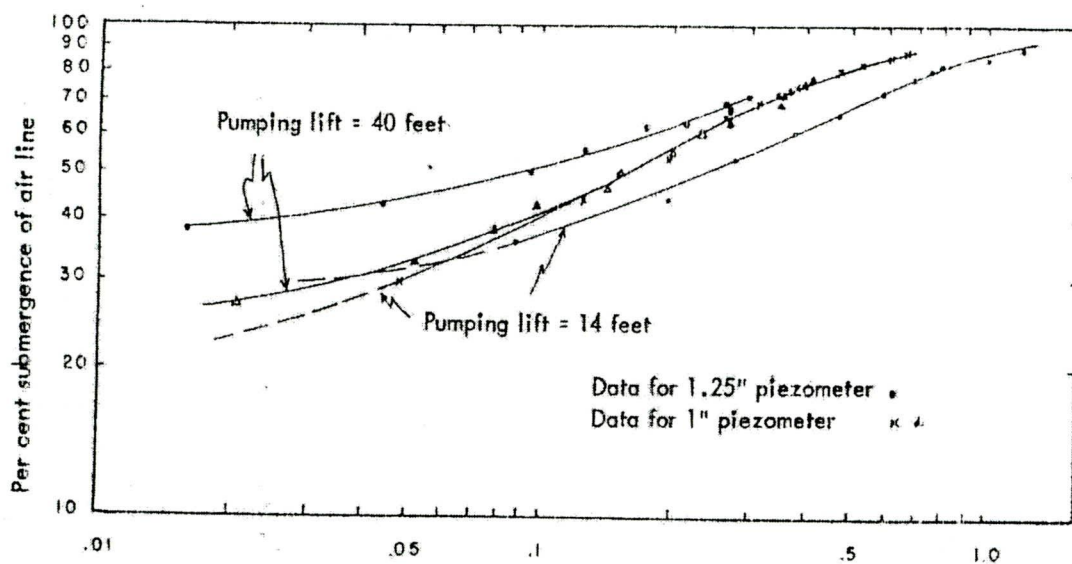
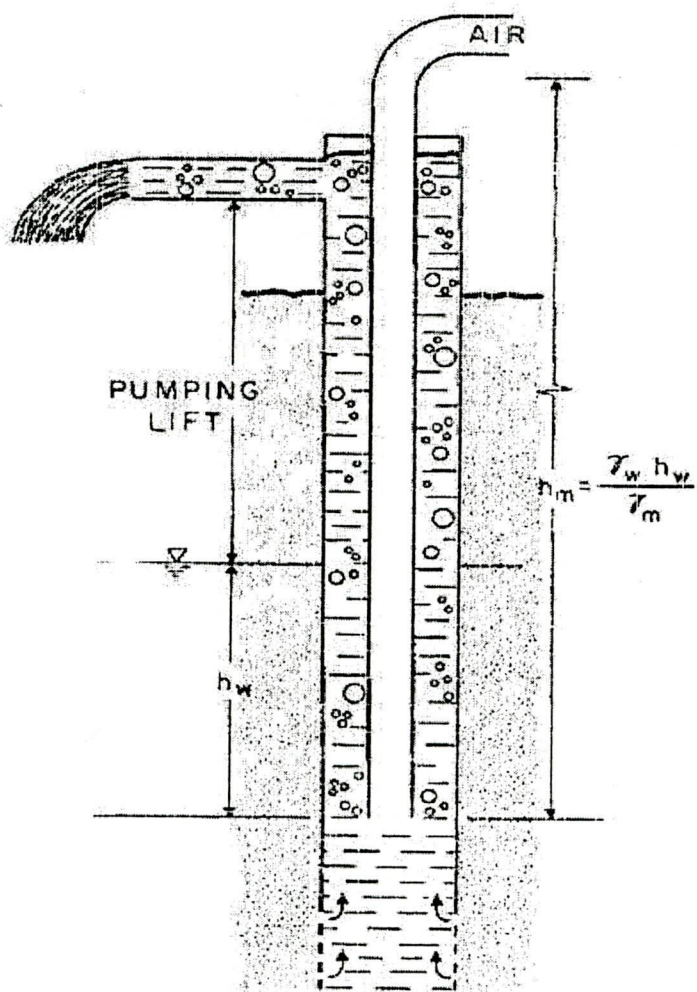
To pump water by airlift method, compressed air from the air compressor is released from the air line pipe below the water level but within the column pipe to create a air-water mixture that has a density less than that of water outside the column pipe. The injection of the air results in a mixture of air bubble and water. This composite fluid is lighter in weight than water so that the heavier column of around the pipe displaces the lighter mixture forcing it upward and out of the discharge pipe. The mixture will rise to a maximum height, h_m given by

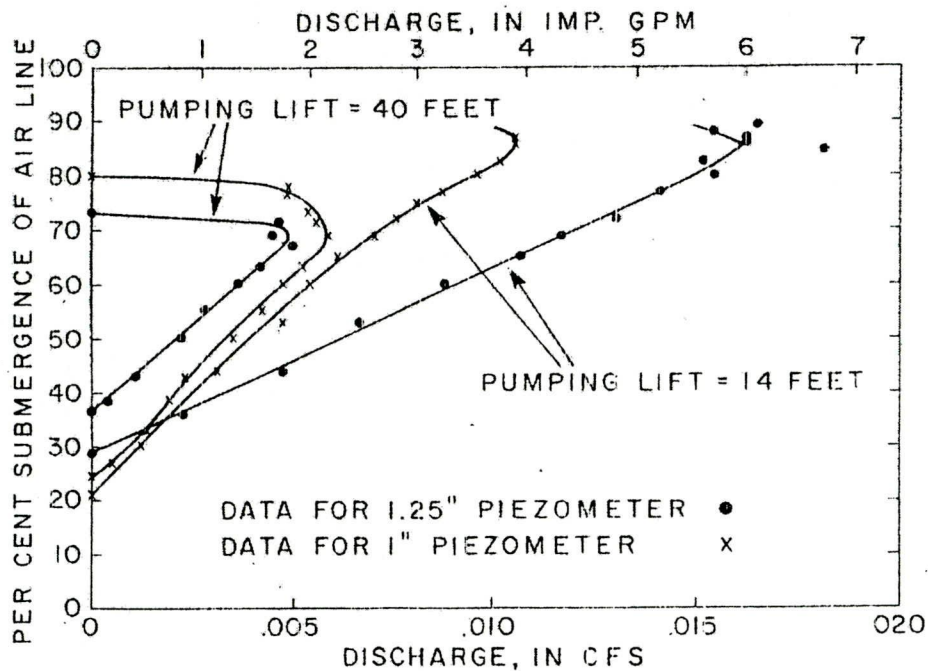
$$h_m = \gamma_w h_w / \gamma_m, \quad (\text{Trescot, P.C., Pinder, G.F., 1978), fig: appendix I.}$$

where, γ_w is the density of water.
 γ_m , is the density of air water mixture, and.
 h_w , is the submerged length of air line,

Discharge occurs when h_m equals or exceeds the pumping lift plus h_w and increases as h_w increases when the ratio γ_w / γ_m , is constant. The density of air water mixture depends on the volume of water contained in the column pipe and on the volume of free air available. For a given air line diameter, volume of free air, pumping lift and percent airline submergence [$h_w \times 100 / (h_w + \text{pumping lift})$], γ_m varies directly with the volume of water and consequently with column diameter. From the above equation, it is apparent that h_m is inversely proportional to column diameter and that with large diameter column pipe, greater submergence is required to initiate discharge at any given pumping lift.

In their experiment (Trescot, PC. Pinder, G., 1978) to extract water from piezometer with compressed air found a relationship among air-line submergence, pumping lift, piezometer diameter and discharge per cfs of free air. This has been shown in fig. I. The relationship of discharge of water in cfs verses percent submergence of airline has also been established.





When the atmospheric free air mixes with the ground water with the help of an air compressor, this adds oxygen and thus aerate water. Considering it only a pump, it has less efficiency but with the consideration of other factors it would be an appropriate technology. Aeration is done with either of the methods described in art. 2.5.1. Diffused air aerators also aerates water but above ground surface. All of these require either extra head or another pump to be employed to pump water over the aeration structures. Again the structures involve large investment cost and require large land area. An air-lift pump would be the best choice to provide sufficient aeration of ground water with less investment cost and without additional aeration structures and land area requirement. Again the same air compressor of an airlift pump can easily be used for removing the incrustation developed on the strainer wall. In an iron treatment plant, maintenance is the main problem. The focculation chamber and other chambers can easily be maintained with the help of the compressor of the airlift pump with simple modification.

The Vyredox method works as per following steps:

- The pump in the well needing treatment is stopped.
- Water is pumped up from another supply well through the aerator.
- It is then forced back into the well needing treatment along with the surrounding injection wells. This normally goes on for 20 hours.
- A four-hour contact time follows.
- Purified (iron free) ground water can then be pumped up out of the treated supply well and transferred directly to the mains.
- After 2-weeks to 1-month depending on actual circumstances, the uprising water will begin to show slight traces of Fe or Mn indicating that the well has to be treated over again.

It takes time for the oxidising zone to become fully efficient. The cycle of withdrawing groundwater, aerating and injecting it must be repeated many times. Plate 07 shows how the efficiency increases with the number of cycles. The efficiency is best expressed as a ratio- the amount of iron free water pumped out of the supply well divided by the amount of water that has to be injected.

Resistance factors for air fittings

Fittings	C
Gate valves	0.25
Long radius ell or run of standard tee	0.33
Medium radius ell or run of standard tee reduced 25%	0.42
Standard ell or run of tee reduced 50%	0.67
Angle valve	0.90
Tee through side outlet	1.33
Globe valve	2.00

EXPRESSION FOR G AND Gtd IN COARSE MEDIA BED FLOCCULATOR.

The mean velocity gradient 'G' has been deduced as

$$G = \sqrt{k} [Q/a] \cdot (1-f)/f^2 \cdot (6/\Psi d) \dots\dots\dots(i).$$

and the CAMP number as

$$Gtd = \sqrt{k} [Q/a] \cdot (1-f)/f \cdot (S/d) \cdot L \dots\dots\dots(ii).$$

where,

k = dimensionless coefficient,

Q = Waterflow, ml/sec.

a = Cross-section area of bed, cm^2 .

f = porosity

Ψ = sphericity of coarse media

(1.0 for spherical and 0.78 for angular material).

d = diameter of coarse media, cm.

G = average velocity gradient, sec^{-1}

td = detention time, sec

L = length of flocculator.

Gtd = CAMP number.

k (Kozeny) is a residual dimensionless coefficient which assumes a magnitude close to 5.0 under most conditions of water filtration (Fair, Geyer and Okun 1968). Typical porosities of granular spherical materials to angular materials vary between 0.38 and 0.43 (Fair, Geyer and Okun 1968). Considering an average bed porosity $f = 0.4$. The mean velocity gradient and the CAMP number can be written as

$$G = 8.38 [Q/a] \cdot [S/d] \dots\dots\dots(iii)$$

$$Gtd = 3.354 [S/d] \cdot L \dots\dots\dots(iv).$$

TO FINDOUT THE AMOUNT OF IRON SALT IN IRON SLUDGE TRAPPED IN THE INTERSTICES OF THE COARSE MEDIA FLOCCULATORS.

TRIAL: I.

- The settled sludge was collected in a 250ml graduated glass cylinder to a volume of 100ml. Dilute 25ml HCl was added to the sludge and the mixture was thoroughly stirred and kept for 30 minutes. The iron salt in the sludge dissolved showing a decrease in sludge volume. It was observed that 0.4ml sludge dissolved. Hence the iron salt content in the settled sludge became: $(0.4\text{ml}/100\text{ml}) \times (2.8\text{gm}/\text{ml}) \times (1000\text{ml}/\text{L}) = 11.2\text{gm}/\text{L}$.
- The iron salt concentration in sludge and water mixture: $11.2/10.25 = 1.09\text{gm}/\text{L}$

TRIAL II.

The procedure was same as trial I.

Trial no.	Constituents		precipitates		Conc. of iron salt in sludge (gm/L)	Conc. of iron salt in sludge mixed water (gm/L)
	Name	% of volume occupied	Nature	% of volume occupied		
TRIAL: I.	Iron sludge	25.85	Attached to khoa surface	100	11.2	1.09
			Locse hydrophobic.			
	Water	74.15				
TRIAL: II.	Iron sludge	40.08	Attached to khoa surface	50.15	16.8	1.71
			Locse hydrophobic.	49.85		
	Water	59.92				

Table : Characteristics of iron precipitates in the interstices of the coarse media.

APPENDIX II-A.

Variation of iron concentration of water samples after flocculation; sedimentation and after outlet chamber of the reservoir of treated water using khoa as the coarse media flocculators and with 7.3 lps discharge [first observation].

Days of operatio n	Raw water (ppm)	Iron Concentration of Treated Water (mg / L).		
		After flocculation	After sedimentation	After the outlet chamber.
1	12	6.114	4.732	3 873
2	12	5.640	4.191	3 872
3	12	5.418	3.860	3 737
4	12	5.488	5.187	3 216
5	12	5.577	4.918	2 858
6	12	5.558	4.739	3 183
7	12	4.958	4.485	2 007
8	12	6.193	5.035	2 987
9	12	6.705	4.743	2 863
10	12	5.079	4.486	3 294
11	12	5.964	4.631	2 898
12	12	5.850	4.535	2 911
13	12	5.269	4.338	2 515
14	12	4.954	4.549	2 615
15	12	6.105	4.436	2 239
16	12	4.991	4.341	2 187
17	12	5.700	4.261	2 393
18	12	5.042	4.353	2 178
19	12	4.533	4.363	1 801
20	12	4.972	4.323	1 745
21	12	3.604	2.980	1 704
22	12	4.533	4.081	1 684
23	12	4.824	4.220	3 968
24	12	5.133	4.149	3 896
25	12	5.529	4.158	3 890
26	12	5.676	4.134	3 856
27	12	5.447	4.253	3 731
28	12	5.028	4.289	3 725
29	12	5.177	3.874	3 748
30	12	5.342	3.946	3 434
31	12	4.997	3.661	3 374

APPENDIX II-B.

Variation of iron concentration of water samples collected after aeration; after flocculation; after sedimentation and after outlet chamber of the reservoir of treated water. Coarse media flocculators: brick khoa of 3.5-4.0cm size range; Pump discharge: 7.3 LPS(second observation).

Days of operation	Iron concentration mg/L.				
	Raw water	After aeration	After flocculation	After sedimentation	At outlet of the chamber.
1	12	6.819	6.685	4.549	3.373
2	12	6.608	3.528	3.323	2.802
3	12	6.492	3.888	3.349	2.783
4	12	6.512	4.734	3.314	3.303
5	12	6.816	3.295	2.886	2.453
6	12	6.595	4.706	3.232	2.864
7	12	5.135	3.226	3.209	3.074
8	12	6.516	5.037	3.194	3.135
9	12	6.629	4.525	3.245	3.069
10	12	6.825	4.089	3.099	2.970
11	12	6.683	4.286	3.442	3.087
12	12	6.604	4.893	4.435	3.383
13	12	6.612	6.097	4.772	3.624
14	12	6.691	4.848	3.503	3.404
15	12	6.697	4.281	3.594	3.389
16	12	6.676	3.642	3.375	2.773
17	12	6.569	4.704	3.369	3.366
18	12	6.674	4.626	3.307	2.622
19	12	6.520	4.743	4.439	3.199
20	12	6.432	3.100	2.991	2.849
21	12	6.632	3.367	3.182	2.844
22	12	6.573	4.676	3.234	3.021
23	12	6.593	4.420	3.457	3.141
24	12	6.517	4.617	4.318	3.147
25	12	6.561	4.612	3.426	2.940
26	12	6.579	4.397	3.689	3.021
27	12	6.761	4.503	2.899	2.898
28	12	6.541	4.245	2.877	2.838
29	12	6.601	4.241	3.160	3.136
30	12	6.685	4.374	2.752	2.612
31	12	6.621	4.332	2.896	2.547

APPENDIX II-C.

Variation of cumulative percent removal of iron concentration of water samples collected after flocculation; after sedimentation and after outlet chamber of the reservoir (First observation).

Days of operation	Cumulative percent removal of Treated Water [mg / L]		
	After flocculation	After sedimentation	After outlet chamber.
1	49.1	60.6	67.7
2	53.0	65.1	67.7
3	54.9	67.8	68.9
4	54.3	56.8	73.2
5	53.5	59.0	76.2
6	53.7	60.5	73.5
7	58.7	62.6	83.3
8	48.4	58.0	75.1
9	44.1	60.5	76.1
10	57.7	62.6	72.6
11	50.3	61.4	75.9
12	51.3	62.2	75.7
13	56.1	63.9	79.0
14	58.7	62.1	78.2
15	49.1	63.0	81.3
16	58.4	63.8	81.8
17	52.5	64.5	80.1
18	58.0	63.7	81.9
19	62.2	63.6	85.0
20	58.6	64.0	85.5
21	70.0	75.2	85.8
22	62.2	66.0	86.0
23	59.8	64.8	66.9
24	57.2	65.4	67.5
25	53.9	65.4	67.6
26	52.7	65.6	67.9
27	54.6	64.6	68.9
28	58.1	64.3	69.0
29	56.9	67.7	68.8
30	55.5	67.1	71.4
31	58.4	69.5	71.9

APPENDIX II-D.

Variation of cumulative percent removal of iron concentration of water samples collected after aeration; after flocculation; after sedimentation and after outlet chamber of the reservoir (Second Observation).

Days of operation	Iron concentration mg/L.			
	After aeration	After flocculation	After sedimentation	At outlet of the chamber.
1	43.2	44.3	62.1	71.9
2	44.9	70.6	72.3	76.7
3	45.9	67.6	72.1	76.8
4	45.7	60.6	72.4	72.5
5	43.2	72.5	76.0	79.6
6	45.0	60.8	73.1	76.1
7	57.2	73.1	73.3	74.4
8	45.7	58.0	73.4	73.9
9	44.8	62.3	73.0	74.4
10	43.1	65.9	74.2	75.3
11	44.3	64.3	71.3	74.3
12	45.0	59.2	63.0	71.8
13	44.9	49.2	60.2	69.8
14	44.2	59.6	70.8	71.6
15	44.2	64.3	70.1	71.8
16	44.4	69.7	71.9	76.9
17	45.3	60.8	71.9	72.0
18	44.4	61.5	72.4	78.2
19	45.7	60.5	63.0	73.3
20	46.4	74.2	75.1	76.3
21	44.7	71.9	73.5	76.3
22	45.2	61.0	73.1	74.8
23	45.1	63.2	71.2	73.8
24	45.7	61.5	64.0	73.8
25	45.3	61.6	71.5	75.5
26	45.2	63.4	69.3	74.8
27	43.7	62.5	75.8	75.9
28	45.5	64.6	76.0	76.4
29	45.0	64.7	73.7	73.9
30	44.3	63.6	77.1	78.2
31	44.8	63.9	75.9	78.8

APPENDIX II-E.

A. Variation of iron concentration of water samples collected after flocculation; after sedimentation and after outlet chamber of the reservoir of treated water under varied flow condition.

Observation	After aeration	After flocculation	After sedimentation	After outlet chamber
I	6.685	5.694	4.741	2.899
	6.671	5.600	4.65	2.890
	6.921	4.720	3.748	2.711
II	7.538	4.894	3.551	3.006
	6.676	5.184	4.052	2.793
	6.653	4.160	2.904	2.300
	6.623	4.308	2.877	2.830
	6.605	4.894	4.185	2.920
	6.576	4.067	4.045	2.807
	6.636	4.724	4.706	2.914
	6.599	4.725	3.787	2.913
III	6.695	3.650	3.195	3.176
	6.682	3.941	3.205	2.851
	6.639	4.682	3.549	3.168
	6.619	4.771	3.114	2.853

B. Cumulative percent removal of iron concentration of water samples collected after aeration; after flocculation; after sedimentation and after the outlet of the reservoir under varied flow condition.

Observation	After aeration	After flocculation	After sedimentation	After outlet chamber
I	44.29	52.55	60.49	75.84
	44.41	53.33	61.25	75.92
	42.33	60.67	68.77	77.41
II	37.18	59.22	70.33	74.95
	44.37	56.80	66.15	76.73
	44.56	65.33	75.30	80.83
	44.81	64.10	76.03	76.42
	44.96	59.22	65.13	75.67
	45.20	66.11	66.29	76.61
	44.70	60.63	60.78	75.72
	45.01	60.63	68.44	75.73
III	44.21	69.58	73.38	73.53
	44.32	67.16	73.29	76.24
	44.68	60.98	70.43	73.60
	44.84	60.24	74.05	76.23

Observation	Individual efficiency of Iron Removal (in percent)				
	After aeration	After flocculation	After sedimentation	After outlet chamber	Total
I	44.29	8.26	7.94	15.35	75.84
	44.41	8.93	7.92	14.67	75.92
	42.33	18.34	8.10	8.64	77.41
	43.68	11.84	7.99	12.89	76.39
II	44.21	25.38	3.79	0.16	73.53
	44.32	22.84	6.13	2.95	76.24
	44.68	16.31	9.44	3.18	73.60
	44.84	15.40	13.81	2.18	76.23
	44.51	19.98	8.29	2.11	74.90
III	37.18	22.03	11.11	4.63	74.95
	44.37	12.43	9.35	10.58	76.73
	44.56	20.78	10.47	5.03	80.83
	44.81	19.29	11.93	0.39	76.42
	44.96	14.26	5.91	10.54	75.67
	45.20	20.91	0.18	10.32	76.61
	44.70	15.93	0.15	14.93	75.72
	45.01	15.62	7.82	7.28	75.73
	43.85	17.66	7.11	7.96	76.58

Table A: Individual efficiency of Iron Removal (in percent)

Observations	Gtd	Iron removal (in percent) after flocculation
1	3000	55.5
2	4000	57.7
3	6000	64.5

Table B: Iron removal (in percent) against calculated "Gtd" using gravel as the coarse media flocculator (Ahmed 1995).

Observation	"G"	Iron removal (percent)
1	14.09	70
2	19.09	68
3	30.9	59
4	60.9	51

Table C: Iron removal (in percent) against "G" using gravel as the coarse media flocculator (Ahmed 1995).

APPENDIX II-G.a.

Sl. No.	Town	T/W No.	Date of regeneration	Total depth, M	Housing pipe Length; M	Housing pipe Dia; mm.	Screen Length M.	Screen dia mm.	Reducer Length/ LJ Lapping, M	Blind Pipe Length, M.	SWL depth M.	Type of Joint
1	Rangamati	04-001-002	12.3.90	117.35	36.58	355.00	18.28	152	1	61.49	5.77	Reducer
2	Rangamati	04-001-003	26.2.90	109.12	39.02	381.00	30.49	152	1	38.61	17.64	Reducer
3	Khagrachari	04-002-004	8.8.91	82.29	26.38	381.00	20.11	152	1	34.80	3.25	Reducer
4	Khagrachari	04-002-005	17.2.90	60.65	29.25	381.00	24.63	152	1	5.77	0.00	Reducer
5	Khagrachari	04-002-006	14.8.91	86.68	37.00	380.00	30.49	150	1	18.19	2.93	Reducer
6	Khagrachari	04-002-007	12.2.90	83.81	30.18	381.00	36.88	152	1	15.75	5.90	Reducer
7	Bandarban	04-003-001	27.1.90	53.33	36.57	381.00	12.19	152	1	3.57	17.41	Reducer
8	Munshiganj	01-006-003	30.6.93	115.81	34.13	304.00	15.24	152	1	65.44	3.20	Reducer
9	Tangail	01-013-004	17.8.93	70.60	29.71	304.00	25.30	152	1	14.59	3.42	Reducer
10	Tangail	01-013-006	24.11.90	89.60	34.13	381.00	30.48	152	1	23.99	3.38	Reducer
11	Tangail	01-013-007	29.8.93	114.14	34.13	381.00	30.48	152	1	48.53	5.00	Reducer
12	Tangail	01-013-008	6.8.93	110.94	34.13	381.00	30.47	152	1	45.34	3.84	Reducer
13	Chandpur	03-002-001	25.4.91	210.25	33.53	304.00	24.88	152	1.5	150.34	2.91	LJ
14	Chandpur	03-002-002	7.4.91	206.60	30.48	384.00	32.44	152	1.5	142.18	3.23	LJ
15	Laxmipur	03-008-001	23.7.91	206.29	32.00	380.00	24.39	152	1.5	148.40	1.70	LJ
16	Sylhet	03-012-005	12.9.93	101.25	32.32	380.00	24.40	150	1.5	43.03	1.57	LJ
17	Gopalganj	02-005-001	4.11.92	33.50	18.50	300.00	12.20	150	1	1.80	3.75	Reducer
18	Gopalganj	02-005-002	12.11.92	33.50	18.50	300.00	12.20	150	1	1.80	4.02	Reducer
19	Rajbari	02-009-004	27.4.92	34.30	19.66	381.00	12.20	150	1	1.44	4.86	Reducer
20	Rangpur	07-007-005	1.10.93	74.36	24.38	355.00	15.23	152	1	33.75	4.31	Reducer

TABLE: 1. Full fixture of the regenerated DPHE tube wells, [regenerated by using Sodium Hexameta Phosphate

APPENDIX II-G.b.

T/W no.	Housing pipe (HP) length, M.	Housing pipe dia, mm	SWL, M.	Vol. of housing pipe under water ,L.	Reducer Volume,L.	Length of LWC + Screen,M.	Dia. of LWC + Screen, mm	Vol. of LWC + Screen,L.	Total vol, liter.
1	2	3	4	5	6	7	8	9	10
04-001-002	36.58	355	5.77	3049.57	50.47	79.77	152	1447.49	4547.53
04-001-003	39.02	381	17.64	2437.52	50.47	69.10	152	1253.88	3741.87
04-002-004	26.38	381	3.25	2637.03	50.47	54.91	152	996.38	3683.88
04-002-005	29.25	381	0.00	3334.76	50.47	30.40	152	551.63	3936.86
04-002-006	37.00	380	2.93	3863.93	50.47	48.68	150	860.25	4774.65
04-002-007	30.18	381	5.90	2768.14	50.47	52.63	152	955.02	3773.63
04-003-001	36.57	381	17.41	2184.42	50.47	15.76	152	286.00	2520.89
01-006-003	34.13	304	3.20	2245.00	50.47	80.68	152	1464.00	3759.47
01-013-004	29.71	304	3.42	1908.22	50.47	39.89	152	723.84	2682.53
01-013-006	34.13	381	3.38	3505.78	50.47	54.47	152	988.40	4544.65
01-013-007	34.13	381	5.00	3321.09	50.47	79.01	152	1433.70	4805.26
01-013-008	34.13	381	3.84	3453.34	50.47	75.81	152	1375.64	4879.45
03-002-001	33.53	304	2.91	2149.91	-	174.72	152	3170.44	5320.35
03-002-002	30.48	384	3.23	3040.06	-	174.12	152	3159.55	6199.61
03-008-001	32.00	380	1.70	3322.96	-	172.29	152	3126.35	6449.31
03-012-005	32.32	380	1.57	3374.00	-	66.93	150	1182.75	4556.75
02-005-001	18.50	300	3.75	1042.62	50.47	14.00	150	247.40	1340.49
02-005-002	18.50	300	4.02	1023.53	50.47	14.00	150	247.40	1321.40
02-009-004	19.66	381	4.86	1687.34	50.47	13.64	150	241.04	1978.85
07-007-005	24.38	355	4.31	1986.52	50.47	48.98	152	888.78	2925.77

TABLE: 2. Calculation of total volume of water inside the DPHE regenerated tube wells on the date of regeneration.

APPENDIX II-G.c.

T/W No.	Fe. Content, mg/l (ppm)	Length of Screen, m.	Total volume of water inside well, Lt.	Chemical used			
				kgs.	gms per Liter of water.	kg/M length of screen.	gms/liter per PPM of Fe.
04-001-002	4.50	18.28	4547.53	100.00	21.99	5.47	4.88
04-001-003	3.80	30.49	3741.87	50.00	13.36	1.64	3.51
04-002-004	9.10	20.11	3683.88	25.00	6.78	1.24	0.74
04-002-005	5.00	24.63	3936.86	100.00	25.40	4.06	5.08
04-002-006	3.40	30.49	4774.65	25.00	5.23	0.82	1.54
04-002-007	6.50	36.88	3773.63	100.00	26.50	2.71	4.07
04-003-001	6.60	12.19	2520.89	50.00	19.83	4.10	3.00
01-006-003	5.00	15.24	3759.47	75.00	19.95	4.92	3.99
01-013-004	5.00	25.30	2682.53	75.00	27.95	2.96	5.59
01-013-006	4.70	30.48	4544.65	50.00	11.00	1.64	2.34
01-013-007	4.10	30.48	4805.26	75.00	15.60	2.46	3.80
01-013-008	6.00	30.47	4879.45	75.00	15.37	2.46	2.56
03-002-001	6.20	24.88	5320.35	75.00	14.09	3.01	2.27
03-002-002	3.80	32.44	6199.61	50.00	8.06	1.54	2.12
03-008-001	3.50	24.39	6449.31	75.00	11.62	3.08	3.32
03-012-005	3.00	24.40	4556.75	75.00	16.45	3.07	5.48
02-005-001	6.50	12.20	1340.49	50.00	37.30	4.10	5.73
02-005-002	6.00	12.20	1321.40	40.00	30.27	3.28	5.04
02-009-004	3.00	12.20	1978.85	50.00	25.26	4.10	8.42
07-007-005	7.70	15.23	2925.77	75.00	25.63	4.92	3.32
TOTAL	103.40	462.98	77743.20	1290.00	377.64	61.60	76.80
Av.	5.17	23.15	3887.16	64.50	18.88	3.08	3.84

TABLE: 3. Calculation of Chemicals used in kg per meter length of strainer; gms per liter of water volume inside the tube well and in gms per liter of water volume per ppm of iron content of the DPHE tube wells for the regeneration.

COMPUTATION OF DETENTION TIMES OF DIFFERENT CHAMBERS:

Volume of Flocculation chamber (Up to submerged height):

$$302\text{cm} \times 213\text{cm} \times 234\text{cm} = 15052.28 \text{ litres.}$$

Volume of Sedimentation chamber (Up to submerged height):

$$302\text{cms} \times 213\text{cms} \times 437\text{cms} = 28110.46 \text{ litres}$$

To determine the detention time of the flocculation chamber, typical porosity of the media was taken to be 0.4 according to Charman.

Detention time of the flocculation chamber:

$$C/Q = (15052.28 \times 0.40) / (7.3 \times 60) = 13.74 \text{ min.}$$

Detention time of the sedimentation chamber :

$$C/Q = 28110.46 / (7.3 \times 60) = 64 \text{ min.}$$

4.2.1. Measurement of Iron concentration:

4.2.1.1. By Conventional Method:

Reagents used:

- * Dilute Hydrochloric Acid.
- * Potassium permanganate solution.
- * Potassium thiocyanate solution.
- * Standard iron solution.

Procedure:

1. Sample was stirred very well to disperse the iron precipitates uniformly throughout the sample.
2. 100ml sample was taken in a nessler tube.
3. 5 ml of dilute hydrochloric acid was then added to the sample.
4. 2 drops of potassium permanganate were added. A pink colour appeared but if this colour disappeared in 5 minutes more drops were added.
5. By adding 5 ml of potassium thiocyanate, the colour changed to brown.

This colour will then be compared with the colour formed in standard solution, prepared as follows:

- * 100ml of distilled water was taken in a Nessler tube.
- * 5ml of dilute HCl was then added.
- * 5ml of Potassium thiocyanate solution in the tube was added.
- * 0.2ml of standard iron solution at a time till colour of the sample and standard were matched.

Calculation:

Amount of iron present in the sample (mg/l) = ml of the standard iron solution used.

By spectrophotometer:

The analyzer AA-680 at BUET laboratory is composed of the spectrophotometer, the graphic printer PR-5, the gas control unit and the colour graphic CRT display. It is capable of performing quantitative analysis based on atomic absorption and flame emission spectrometry. It employs a microcomputer to the utmost extent.

Measurement procedure.

The procedure to analyze the sample with the instrument is briefed below:

- i. Start of the instrument operation.
 - Supply of 3.5 kg/cm² of support gas and 0.9kg/cm² of fuel gas.
 - Turn on the POWER switch.
 - Establishing the initial condition. This setting is completed in 35 to 140 seconds.
 - Turn on the D₂ lamp (deuterium lamp) switch in the BGC and D₂ lamp modes.
 - Mounting of hollow cathode lamp in the order of use from odd to even numbers.
- ii. For measurement.
 - To select the burner head and to set the BURNER SELECT switch.
 - Temporarily lighting a hollow cathode lamp.
 - Setting the analytical conditions.
 - Setting the sample number, First sample number is composed of 3-digit figure.
 - Selecting concentration calibrating method (normal calibration method or standard addition method. Setting is done through dialog with the printer in the order of lower to higher concentration.
 - Recording the absorbance scale.
 - Turn off the leak check switch and press the IGNITE button to ignite the flame.
- iii. Measuring procedure:
 - Press the START/STOP to start the graphic printer.
 - Measure the standard samples in the order of concentration values, preset. Press the BLANK switch for blank or solvent measurement and the STANDARD switch for standard sample measurement.
 - Preparing the working curve.
 - Checking the working curve. Abnormal calibration points are to be eliminated.
 - Measuring unknown samples. Press BLANK switch for blank or solvent and the MEASURE button for sample.
 - Stopping the graphic printer.
 - Extinguishing the flame by pressing EXTINGUISH button.
- IV. Listing the analytical result:
 - Eliminating unnecessary data.
 - Final concentration value on CRT.
 - Listing the analytical results.
 - Clearing the data.
- v. Operation after measurement:
 - Rinsing burner interior by aspirating pure water.
 - Turn off the pressure and Flame monitors.
 - Stopping supply of fuel and support gases.
 - Setting the BURNER SELECT switch to the STANDARD position.
 - Lighting off the deuterium lamp.
 - Turning off the power source.

APPENDIX IV-A.

COST OF THE DEEP TUBE WELL.

Sl. No	Description of work	Q'ty	Rate, Tk.	Amount, Tk
1	Mobilization of boring equipment and machinery	LS	25000.00	25000.00
2	Excavation of tube well boring by reverse circulation method			
	a. From 0m to 50m	50m	600.00	30000.00
	b. From 51m to 100 m	47.0m	800.00	37600.00
3	M.S housing pipe (6.35mm wall thickness; 300mm dia)	30.48 m	1900.00	57912.00
4	M.S. Reducer (300mmX150mm; 6.34mm wall thickness)	1 pc	1500.00	1500.00
5	G.I blind pipe(150mm dia)	41.155 m	1300.00	53501.50
6	Stain less steel; wire wound strainer(150mm dia)	23.29 m	3660.00	85241.40
7	G. I Bail plug (1.5m length; 150mm dia)	1 pc	1800.00	1800.00
8	Centralizers	10 pc	100.00/p c	1000.00
9	Pea gravel (well graded)	97m	300.00/ m	29100.00
10	Testing & development	LS	16000.00	16000.00
11	Sanitary seal with clay filling	5m	200.00/ m	1000.00
Total:				314654.90

APPENDIX IV-B.

**ESTIMATES FOR THE CONSTRUCTION OF WATER TREATMENT PLANT
ATTACHED TO AIR LIFT PUMP.**

SL No	Description of work	Q'ty.	Unit	Rate in Tk	Amount in Tk
1.	Earth work in excavation in foundation of all kinds of soils including leveling, ramming and preparing the base, bailing out water, shoring, if necessary, providing center line and bench mark pillar (up to depth of 3m) including removal of surplus spoils, jungles to safe distance. Excavated earth to be spread over the land as per drawing, specification & direction of Engineer-in-Charge.	83 cm	cm	24/-	1,992.00
2.	One layer or brick flat soling in foundation or floor with 1st class or picked jhama bricks, preparation of bed & filling the interstices with local sand.	47 sm	sm	83/-	3,901.00
3.	Reinforced cement concrete works (1:2:4) having minimum crushing strength 18 MPa at 28 days (cylinder strength) with cement, best quality coarse sand 50% quantity of best local sand (F.M.1.5) & 5) picked jhama chips in/c. breaking chips, screening, centering, shuttering, placing of rod in position, nixing the aggregates with mixture machine, casting in forms, compacting by vibrator machine & curing (excluding the cost of reinforcement & its fabrication).	20 cm	cm	3498/-	69,960.00
4.	Supplying, fabrication & fixing to details as per design mild steel (Billet) reinforcement in concrete or brick work or wherever prescribed with strengthening & cleaning the rust if any binding in position with supply of 22 BWG G.I. wire, for all floors up to 3rd floor complete as per direction of E/C.	15 quinta 1	quin tal	2100/ -	31,500.00

SL No	Description of work	Q'ty.	Unit	Rate in Tk	Amount in Tk
5.	5" thick 1st class brick work in cement mortar 1:4 with 1/4" dia. wall ties @ 3'-4" etc. horizontal and 1'-0" vertical (staggered) scaffolding racking out joints & curing etc. all complete (sand F.M.1.8).	15 sm.	sm	185/-	2,775.00
6.	Earth filling in plinth & back filling in foundation masonry or R.C.C with earth available at site in/c. ramming & watering etc. complete in layers not exceeding 150mm in thickness.	6 cm.	cm.	27/-	162.00
7.	Brick work with 1st class bricks in cement mortar (1:4) in exterior walls in/c. filling the interstices with mortar, racking out joints, cleaning & socking the bricks at least for 24 hrs. before use and necessary scaffolding, curing at least for 7 days etc. all complete.	20 cm	cm	1457/-	29,140.00
8.	Minimum 20mm (3/4" inch) thick cement plaster (with 2% puddlo) to wall inner surface with coarse clean sand F.M.1.8 & cement mortar 1:4 in/c. neat cement finishing round edges corners & curing etc. all complete as per drawing & direction of E/C.				
	a) with 2% puddlo	106 sm.	sm.	70/-	7,420.00
	b) without puddlo	100 sm.	sm.	54/-	5,400.00
9.	Supply 12mm (1/2" inch) dia. PVC pipe in brick layers of the flocculation chamber's wall @ 9" c/c as per drawings etc, complete.	40 rm	rm	25/-	1,000.00
10.	Supplying & placing of 2 cm' to 1cm size 1st class brick chips for coarse media for the flocculation chamber as per design & drawings etc. complete.	12 cm.	cm.	890/-	10,680.00
11.	Providing 2 kg. puddlo per bag of cement in plaster, CC, brick work, pointing, patent stone or any other works as necessary for water proofing & damp proofing etc. complete (only the cost of puddlo).	110 kg.	kg.	69/-	7,590.00

SL No	Description of work	Q'ty.	Unit	Rate in Tk	Amount in Tk
12.	Supplying, fitting, fixing of MANCO or best approved quality 20"/22" dia. of manhole cover in/c. fitting, fixing all complete as per drawing and direction of E/C.	9 nos.	each	300/-	2,700.00
13.	Supplying, fitting, fixing of 6" dia. M.S. pipe for placing at Water Treatment Plant to underground water Tank as per drawings.	5 rm	rm	1312/-	6,560.00
14.	Providing apron with 2" thick cement concrete (4:2:1) with cement coarse sand picked jhama chips in/c. breaking chips and one layer of brick flat soling at bottom with 1st class or picked jhama brick in/c. cutting earth for preparation of bed and filling the interstices with local sand in/c. finishing the top surface with neat cement finishing, curing etc. as per direction of the E/C.	12 sm.	sm.	215/-	2,580.00
15.	Constructing 1'-0" clear width depth up to 12" brick masonry surface drain with 10" thick check wall in cement mortar (6:1) on 3" thick cement concrete base (6:3:1) over one layer of brick flat soling, the surface having minimum 1/2" thick cement plaster (3:1) and neat cement finishing curing in/c. excavation of all kinds of soils back filling with fine sand consolidating and dressing as per direction of the E/C.	15 m	m	283/-	4,245.00
Total:					1,87,605.00

APPENDIX IV-C.

ESTIMATE OF THE WORK SCHEDULE FOR THE REGENERATION OF THE PROJECT DEEP TUBE WELL.

SL. No.	Description of work.	Rate	Total Tk.
1.	Installation/Lowering of 120 M. of 20mm. dia G.I. pipe inside the tube well step by step connecting upper end of the pipe with the air - compressor of the employer for using the pipes as air-line; with supply of all fitting & fixing, material, chain pulley, chain tong, clamps etc. required for the purpose as well as withdrawal of the same after completing regeneration of the tube well including hire charge of materials & equipment and conveyance etc. all complete as per direction of EIC. This work should be done in two phases : 1st. phase : without using any chemicals. 2nd phase: After application of the chemicals.	LS	2,500.00
2.	Withdrawal of existing column pipes and air-lines from the inside of the tube well and subsequently re-installation of the same after necessary cleaning and washing, including all equipment and materials required for the purpose- all complete as per direction of EIC.	LS	4000.00
3.	Procurement / supply and application of the following chemicals inside the tube well; treatment plant and water tank and cleaning & washing the same including the pipelines as per direction of EIC.		0
	I. Caïgon: - 100 Kgs.	100.00	10,000.00
	II. Bleaching powder. - 50 Kgs.	50.00	2,500.00
	III. High-test calcium hypochlorite - 02 Kgs.	250.00	500.00
4.	Washing of the treatment plant, under ground reservoir, under ground pipelines, tube well pipes with detergent and disinfectant chemicals as per direction of EIC.	LS	1,000.00
5.	Supply of 100mm dia. G.I. column pipe & 20mm dia G.I. pipe - each of 13 M. length on hire basis and fitting those to the lower end of existing riser pipe & air line respectively and installation of the same into the tube well for the work of tube well regeneration and subsequently withdrawal of those after finishing the work as per direction of EIC.		0
	Including carrying & handling etc.,	10/Rm	130.00
	i. 100mm dia. G.I. pipe, 13 M length	7/Rm	91.00
	ii. 20mm dia. G.I. pipe, 13 M length		
TOTAL :		TK.	27,273

APPENDIX V-A.

LIST OF DPHE IRON TREATMENT PLANTS INSTALLED IN URBAN WATER SUPPLY SYSTEM IN 22-TOWNS IN THE COUNTRY ALONG WITH THEIR OPERATING COSTS.

Sl No	Components	Unit	Farid pur	Gopalganj	Manikganj	Tangail	Bandarban	Khagrachhari
			1	2	3	4	5	6
1	Production well	No	3	3	2	4	6	4
2	Treatment plant	Nos	1	1	1	1	1	1
3	Daily water production	M ³	2385	900	1614	4227	1450	1100
4	Daily pumping hour	Hour	8.5	12.0	10.0	13.4	16.0	15.0
5	Electric bill/month	Tk(Lk)	1.10	0.34	0.26	1.08	1.6	0.50
6	Staff cost/month	Tk(Lk)	0.73	0.38	0.21	1.67	0.25	0.48
7	Misc cost/month	Tk(Lk)	0.30	0.01	0.07	0.24	1.00	0.07
8	Total operating cost	Tk(Lk)	2.13	0.73	0.54	2.99	2.85	1.05
9	Unit production cost	Tk/m ³	2.98	2.70	1.12	2.36	6.55	3.21

Sl. No	Components	Unit	Chandpur	Laxmipur	Noakhali	Rangpur	Gaibandha	Kurigram
			7	8	9	10	11	12
1	Production well	No	4	2	5	7	3	2
2	Treatment plant	Nos	3	1	1	1	2	2
3	Daily water production	M ³	3677	1900	537	3199	3087	2222
4	Daily pumping hour	Hour	12.0	12.0	8.00	7.00	22.0	9.00
5	Electric bill/month	Tk(Lk)	2.50	0.50	0.45	0.89	1.25	0.48
6	Staff cost/month	Tk(Lk)	1.31	0.40	0.12	1.00	0.32	0.16
7	Misc cost/month	Tk(Lk)	1.40	0.10	0.15	0.09	0.30	0.12
8	Total operating cost	Tk(Lk)	5.21	1.00	0.72	1.98	1.87	0.76
9	Unit production cost	Tk/m ³	4.71	1.75	4.35	2.06	2.02	1.14

Sl. No	Components	Unit	Serajganj	Sunamganj	Sylhet	Hobiganj	Jessore	Satkhira
			13	14	15	16	17	18
1	Production well	No	1	2	9	4	13	6
2	Treatment plant	Nos	1	1	1	1	3	1
3	Daily water production	M ³	1400	1900	6300	2240	9555	1501
4	Daily pumping hour	Hour	19.0	8.00	11.0	12.0	8.00	14.0
5	Electric bill/month	Tk(Lk)	0.19	0.47	2.73	0.61	2.25	0.30
6	Staff cost/month	Tk(Lk)	0.36	0.26	1.33	0.35	1.80	0.28
7	Misc cost/month	Tk(Lk)	0.05	0.08	0.43	0.25	0.17	0.04
8	Total operating cost	Tk(Lk)	0.60	0.81	4.49	1.21	4.22	0.62
9	Unit production cost	Tk/m ³	1.31	1.42	2.38	1.80	1.47	1.38

Sl. No	Components	Unit	Barishal	Pirozpur	Bagerhat	Rangana	Total 22-towns
			19	20	21	22	
1	Production well	No	18	1	1	2	100
2	Treatment plant	Nos	1	1	1	2	29
3	Daily water production	M ³	14680	1536	2275	4540	72225
4	Daily pumping hour	Hour	18.0	16.0	14.0	16.00	280.9
5	Electric bill/month	Tk(Lk)	3.75	0.32	0.52	2.8	24.89
6	Staff cost/month	Tk(Lk)	2.25	0.58	0.65	0.08	14.97
7	Misc cost/month	Tk(Lk)	0.25	1.47	0.51	0.28	7.38
8	Total operating cost	Tk(Lk)	6.25	2.37	1.68	3.16	47.24
9	Unit production cost	Tk/m ³	1.42	5.16	2.46	2.32	2.55

**COSTS (INVESTMENT; OPERATING & MAINTENANCE) OF IRON REMOVAL PLANTS
INSTALLED IN URBAN WATER SUPPLY SYSTEM AS WELL AS THE PLANT USING
SUB SURFACE AERATION TECHNOLOGY.**

- A. DPHE installed iron removal plants in urban water supply system. These have capacity to handle large volume of water (usually 200m³/h flow rate capacity). These are costly and can not be compared with the plant in the pilot project. However effort has been taken to find out the unit cost of production. The cost includes both investment or capital cost and operation & maintenance cost (O&M cost).

a. Investment Cost.

(Capacity: 200 cubic meter per hour; Iron conc. > 5 ppm).

Type of work	Life	Cost, Tk (Laks)	Remark
Civil works	50 years	80.00	depreciated value not considered.
M/E	10 years	15.00	
Piping etc.	20 years	20.00	
TOTAL:		115.00	

b. O&M cost.

The unit O&M cost per cubic meter of water has been calculated by the DPHE using treatment plant in 22-town in iron problem area and is found Tk. 2.55. Considering an average pumping period of 8 hours in a day, the O&M cost per year becomes Tk. 2.55/m³)X(200m³/hr)X(8 hrs/day)X(365days /year) = Tk 14.89 laks/ year.

B. The production cost of the pilot plant.

a. Investment Cost. (Capacity: 25 cubic meter per hour; Iron conc. 12.00 ppm).

- Civil construction
 - i. Iron removal unit(treatment pant) : Tk 2.00 laks
 - ii. Underground reservoir etc : Tk. 1.00 laks
 - iii. Pump house : Tk. 0.35 laks

Tk.3.35 Laks.
- Tube well and the airlift pump; other pumps & accessories:
 - i. Air compressor: : Tk. 125000.00
 - ii. Discharge head : Tk. 8000.00
 - iii. MS column pipes (9 pc; Tk. 5400.00/ pc) : Tk. 48600.00
 - iv. ¾" dia GI airline pipes(27.5m X Tk. 115.00) : Tk. 3162.50.
 - v. Rubber tube(¾" dia) : Tk. 1500.00
 - vi. Pump & fittings for secondary lifting (20 HP; 2900 RPM) : Tk. 45000.00
 - vii. Sludge pump(1 HP) : Tk. 8000.00

Tk. 2,39,262.00

Total investment cost : Tk 574262.00 = 5.74 laks.

b. O&M cost:

- Electricity (Tk. 2.5/ kw -h)
 - [(7.46 kw+14.92)X8X 365=65349.60 kw -h)] : Tk. 163374.00
 - (Staff cost(1-pump operator) , Tk. 500.00/month. : Tk. 6000.00
 - Others, Tk. 500.00/month. : Tk. 6000.00
 - Regeneration of flocculation chamber, once a year. : Tk. 4848.00
- :Tk. 180222.00**

Total O&M cost :Tk. 1.80 laks.

APPENDIX V-C.

Calculation of the present value of the unit cost of effluent water using conventional method adopted in large urban water supply system, the capacity of the plant being 200 cubic meter per hour. (Iron conc. > 5 ppm).

Year	Investment Cost (AV).	Operational Cost (AV).	Total Cost	Discount Factor at 15%.	Discounted Total Cost at 15%.
1	115.00	0.00	115.00	1.00	115.00
2		14.89	14.89	0.87	12.95
3		14.89	14.89	0.76	11.32
4		14.89	14.89	0.66	9.83
5		14.89	14.89	0.57	8.49
6		14.89	14.89	0.50	7.45
7		14.89	14.89	0.43	6.40
8		14.89	14.89	0.38	5.66
9		14.89	14.89	0.33	4.91
10	15.00	14.89	14.89	29.89	8.37
11		14.89	14.49	0.25	3.72
12		14.89	14.89	0.21	3.13
13		14.89	14.89	0.19	2.83
14		14.89	14.89	0.16	2.38
15		14.89	14.89	0.14	2.08
16		14.89	14.89	0.12	1.79
17		14.89	14.89	0.11	1.64
18		14.89	14.89	0.09	1.34
19		14.89	14.89	0.08	1.19
20		14.89	14.89	0.07	1.04
Total:					211.67

The total discounted cost with 15% discounted rate 211.67 laks for 20 years. Hence the cost of unit volume (01m³) of treated water becomes

$$(\text{Tk. } 211.67 / 20 \text{ years}) \times (1 \text{ year} / 365 \text{ days}) \times (1 \text{ day} / 8 \text{ h}) \times (1 \text{ h} / 200 \text{ m}^3) = \text{Tk. } 1.81.$$

Calculation of the present value of the unit cost of effluent water using subsurface aeration technology, the capacity of the plant being 25 cubic meter per hour (Iron conc. = 12 ppm).

Year	Investment Cost(AV).	Operational Cost (AV).	Total Cost	Discount Factor at 15%.	Discounted Total Cost at 15%.
1	5.75	0.00	5.75	1.00	5.75
2		1.80	1.80	0.87	1.57
3		1.80	1.80	0.76	1.37
4		1.80	1.80	0.66	1.19
5		2.08	2.08	0.57	1.19
6		1.80	1.80	0.5	0.90
7		1.80	1.80	0.43	0.77
8		1.80	1.80	0.38	0.68
9		1.80	1.80	0.33	0.59
10	2.39	1.80	4.19	0.28	1.17
11		1.80	1.80	0.25	0.45
12		1.80	1.80	0.21	0.38
13		1.80	1.80	0.19	0.34
14		1.80	1.80	0.16	0.29
15		2.08	2.08	0.14	0.29
16		1.80	1.80	0.12	0.22
17		1.80	1.80	0.11	0.20
18		1.80	1.80	0.09	0.16
19		1.80	1.80	0.08	0.14
20		1.80	1.80	0.07	0.13
Total:					17.65

The total discounted cost with 15% discounted rate 17.65 laks for 20 years. Hence the cost of unit volume (01m^3) of treated water becomes
 (Tk. $17.65/20$ years) $\times$ (1 year/ 365 days) $\times$ (1 day/8 h) $\times$ (1 h/25 m^3) = Tk. 1.20.

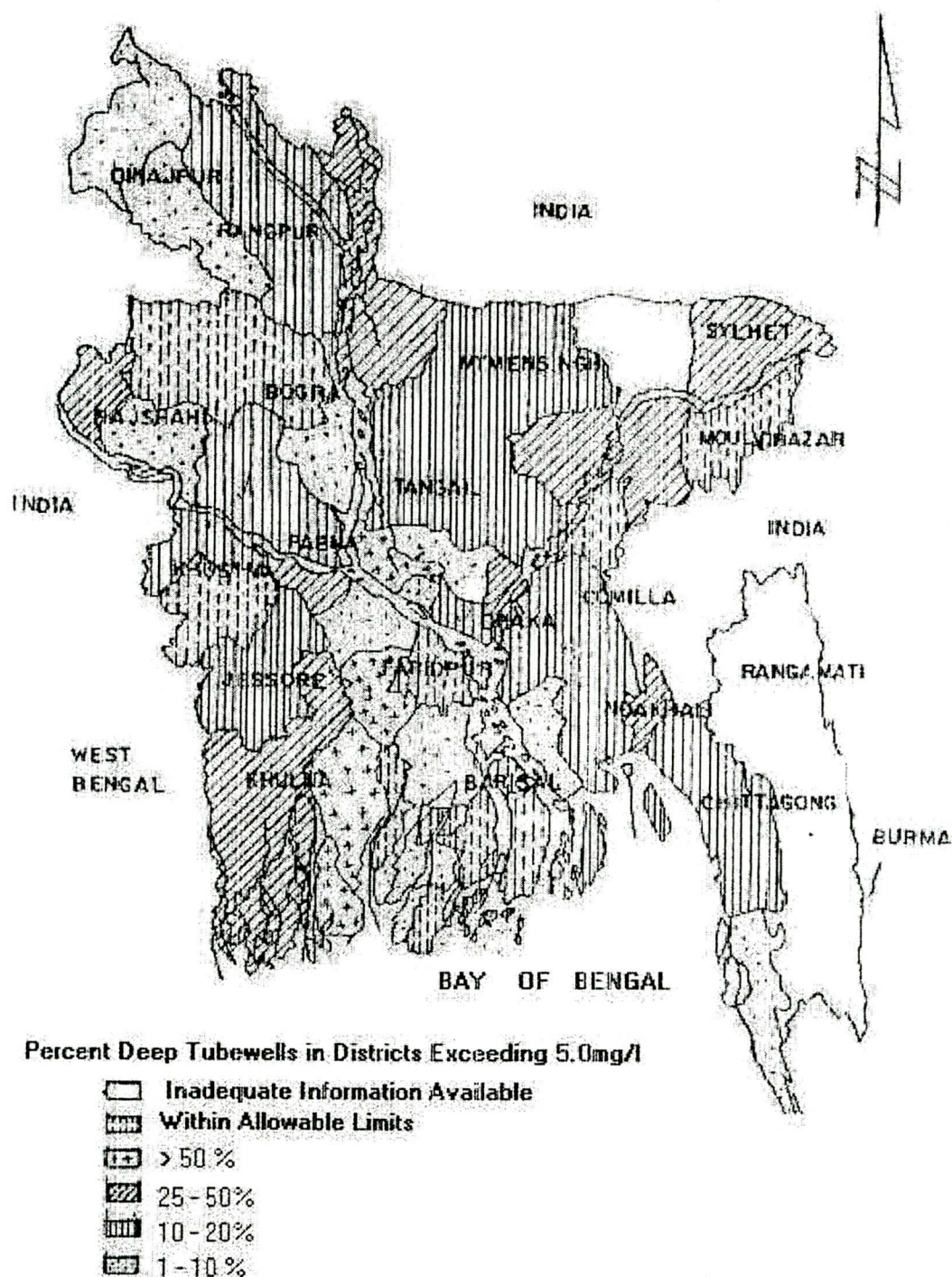


PLATE 01: Iron content in deep tube well water of Bangladesh
(Iron>5.0 mg/L) [After Hossain, D., Huda, M.K., 1997]

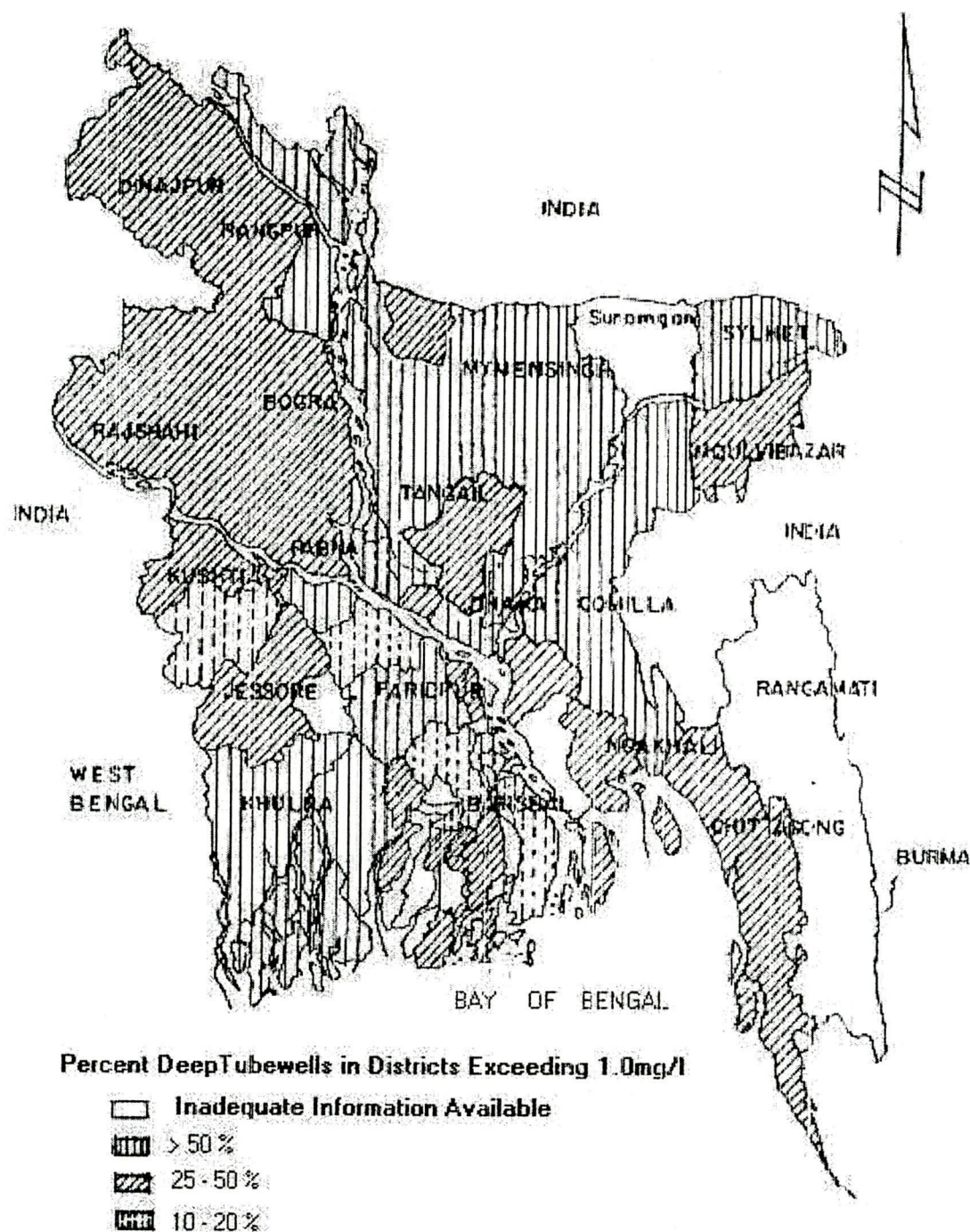


PLATE 02: Iron content in deep tube well water of Bangladesh.
 (Iron > 1.0 mg/L) [After Hossain, D., Huda, M.K., 1997]

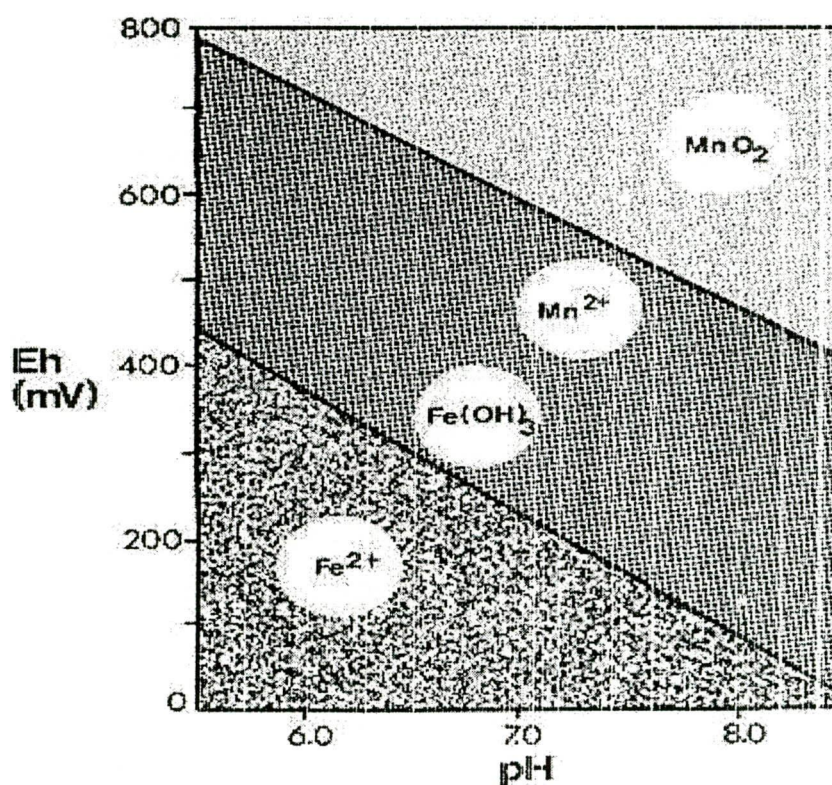


PLATE 03: Transition between oxidised and reduced states of Iron & Manganese [After Hallberg, R.O., Martinell, R., 1976]

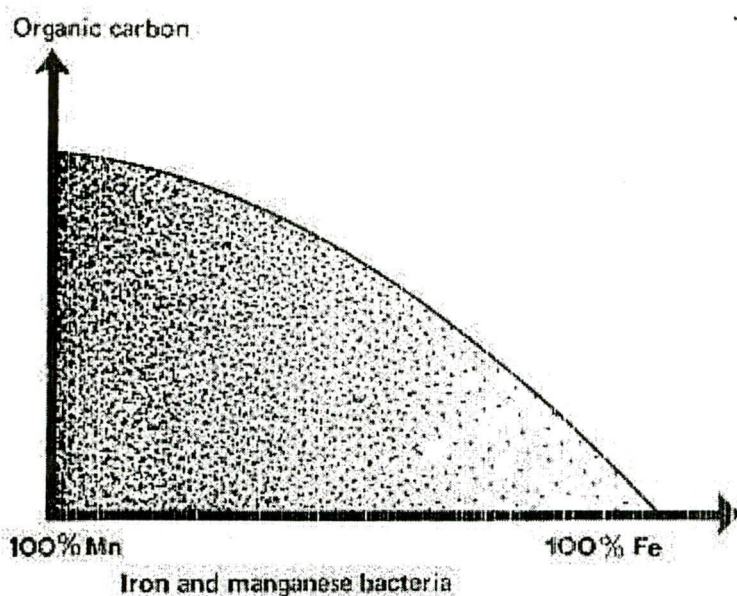
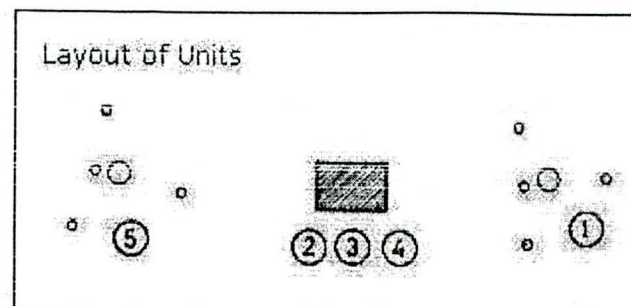


PLATE 04: The effect of Iron and Manganese bacteria in nature [After Hallberg, R.O., Martinell, R., 1976]

- ①-⑤ Supply of Wells and aeration
- ② Aerator, the OXYGENERATOR
- ③ Degassing Tank
- ④ Pump for aerated water



LAYOUT OF VYREDOX PLANT

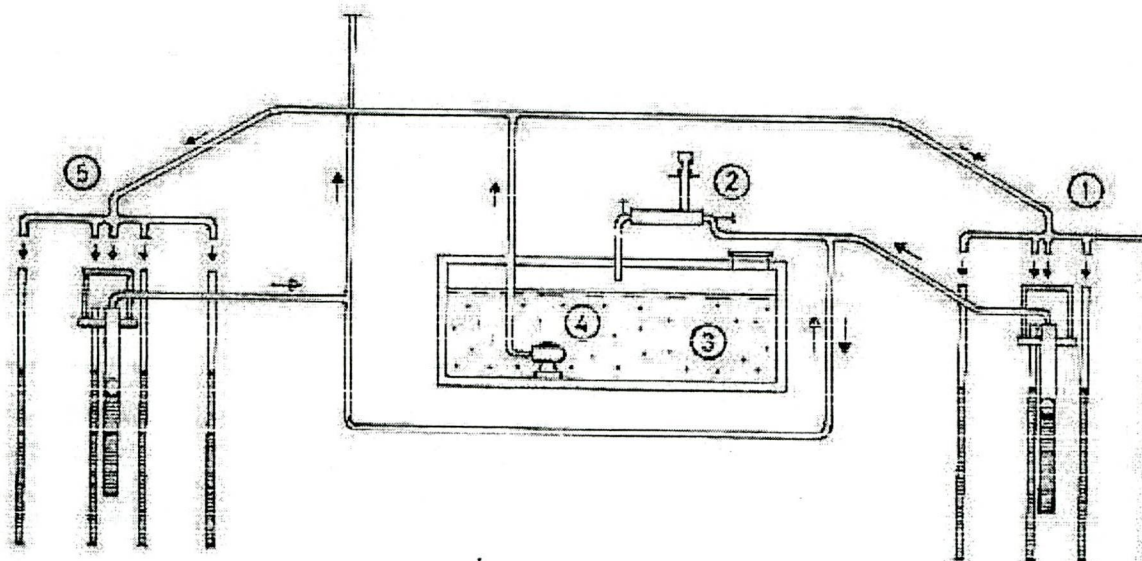


PLATE 05: Vyredox plant with two supply wells complete with aeration wells and oxygenator house
 [After Hallberg, R.O., Martinell, R., 1976]

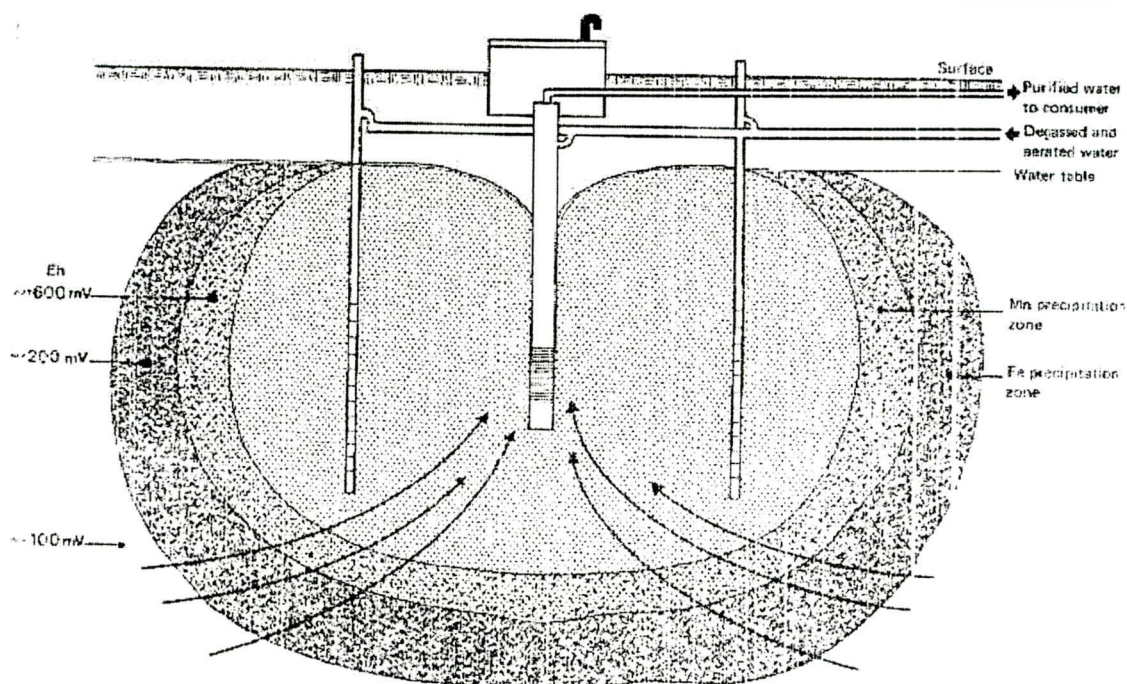


PLATE 06 : Schematic view of the precipitation of Fe & Mn around the Viredox well in the acquifer [After Hajjberg, R.O., Martinell,R., 1976]

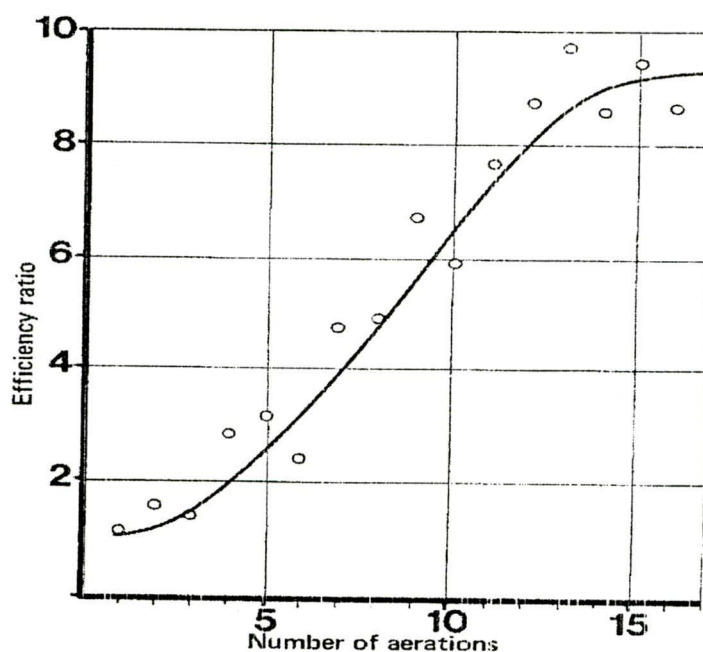


PLATE 07 : The efficiency ratio of a viredox plant is increased with the number of aeration. After a certain number of aerations the ratio curve flatens and stabises. [After Hallberg, R.O., Mart:nel,R., 1976]

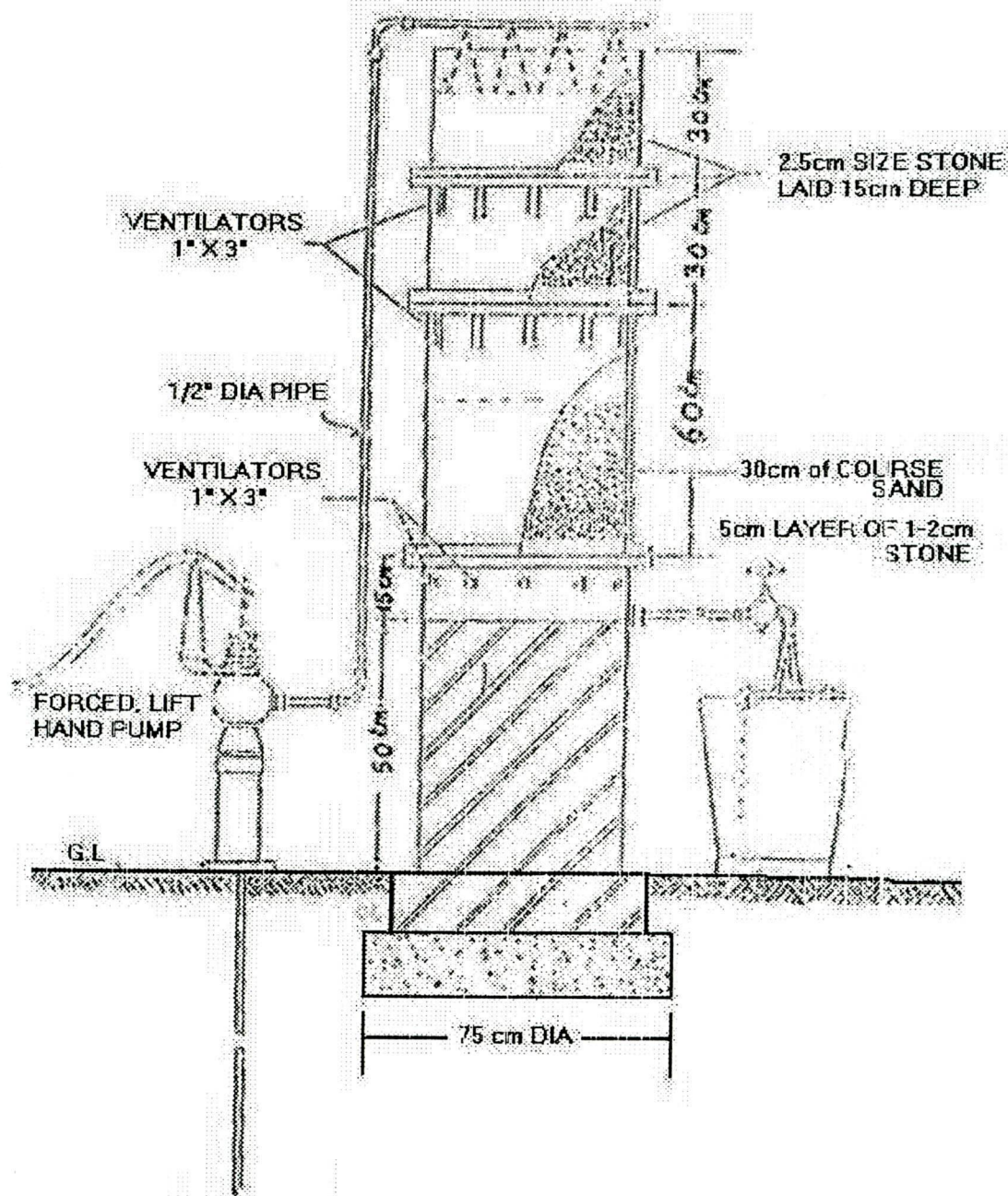
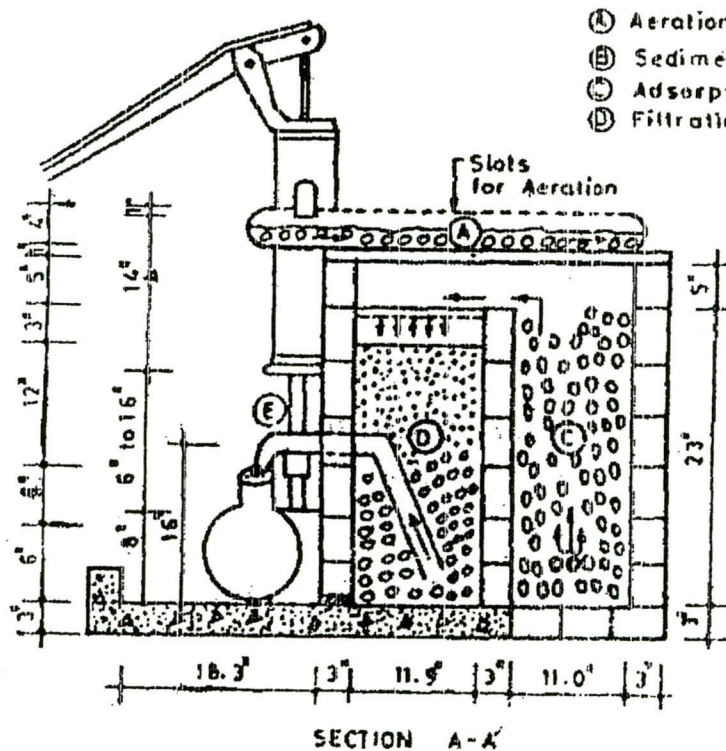
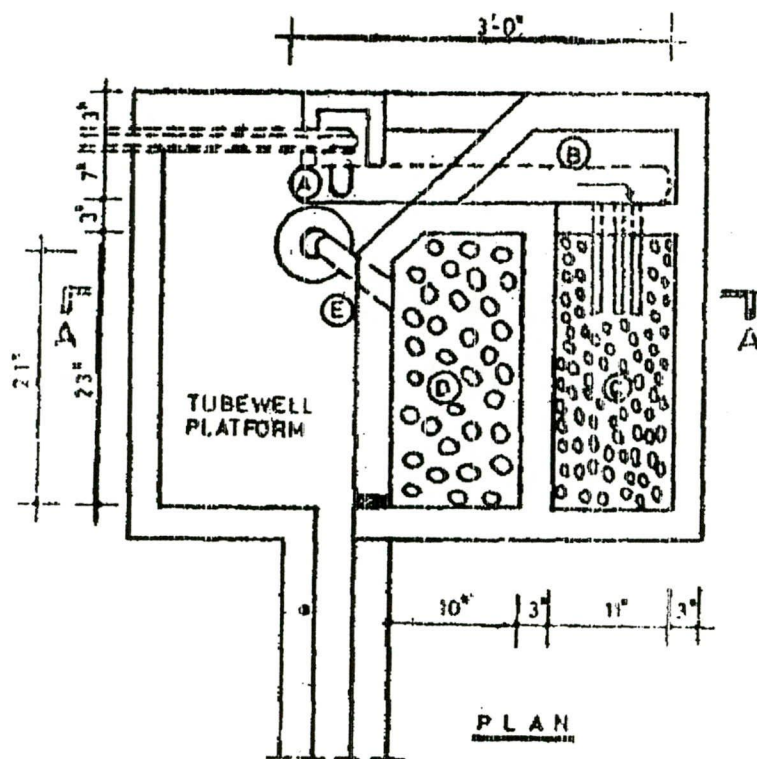


PLATE 08: C-PHERI IRON REMOVAL UNIT [Capacity 10 GMT]

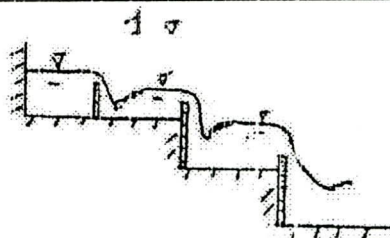
[After Dixit, R.C., Pathak, B.N., 1971]



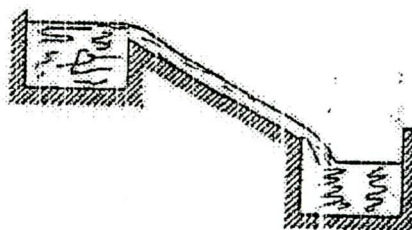
- (A) Aeration Chamber
- (B) Sedimentation Chamber
- (C) Adsorption Chamber
- (D) Filtration Chamber

PLATE 09: IRP developed in Bangladesh

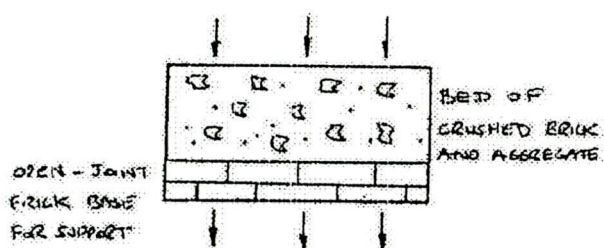
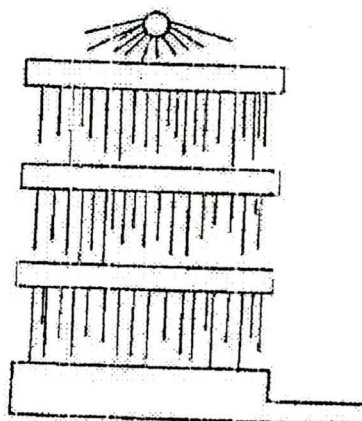
Cascades: water is allowed to fall down a series of steps turbulence and hydraulic jump formation assist aeration.



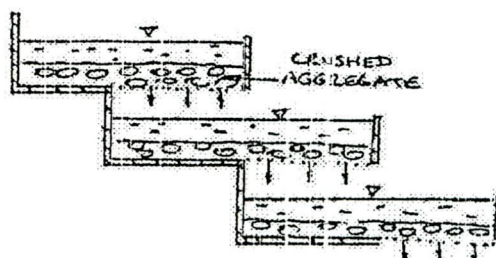
Inclined aprons: water flows supercritically down a steeply inclined apron. Turbulence can be increased by fitting studs and plates.



Tray aerators: water falls through a series of four to six trays which are perforated with small holes. The Indian Ministry of Health recommends 5-12 mm diameter holes at 25-75 mm centres. A total area of 0.015 to 0.045 m² per m³ water flowing per hour should be provided.



CONTACT BED (MADRAS, INDIA)



CASCADE/CONTACT BED

PLATE 10: Various types of gravity aerators

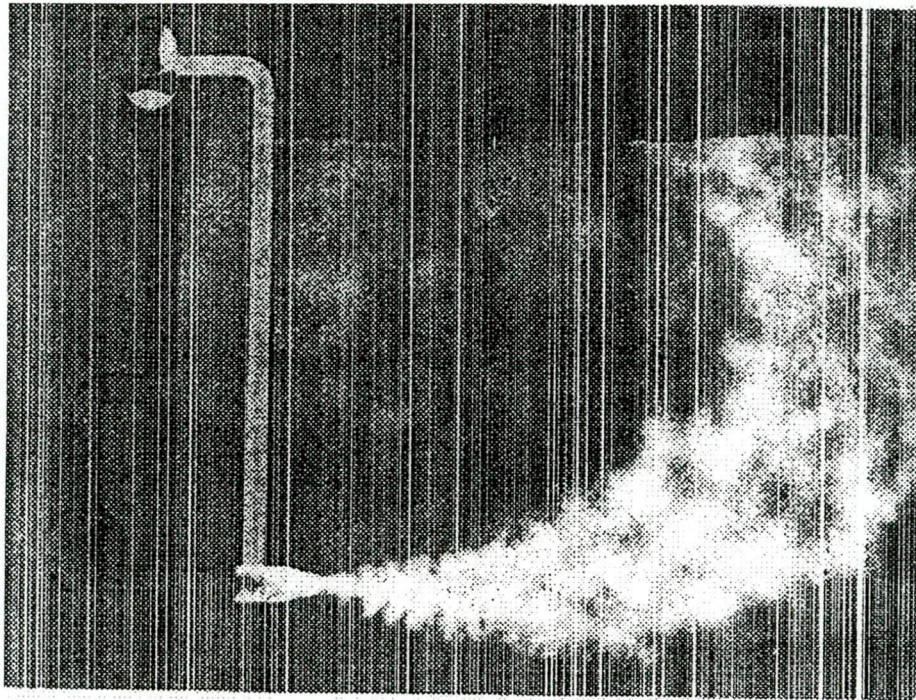


PLATE 11 : Air diffusers for aeration of water

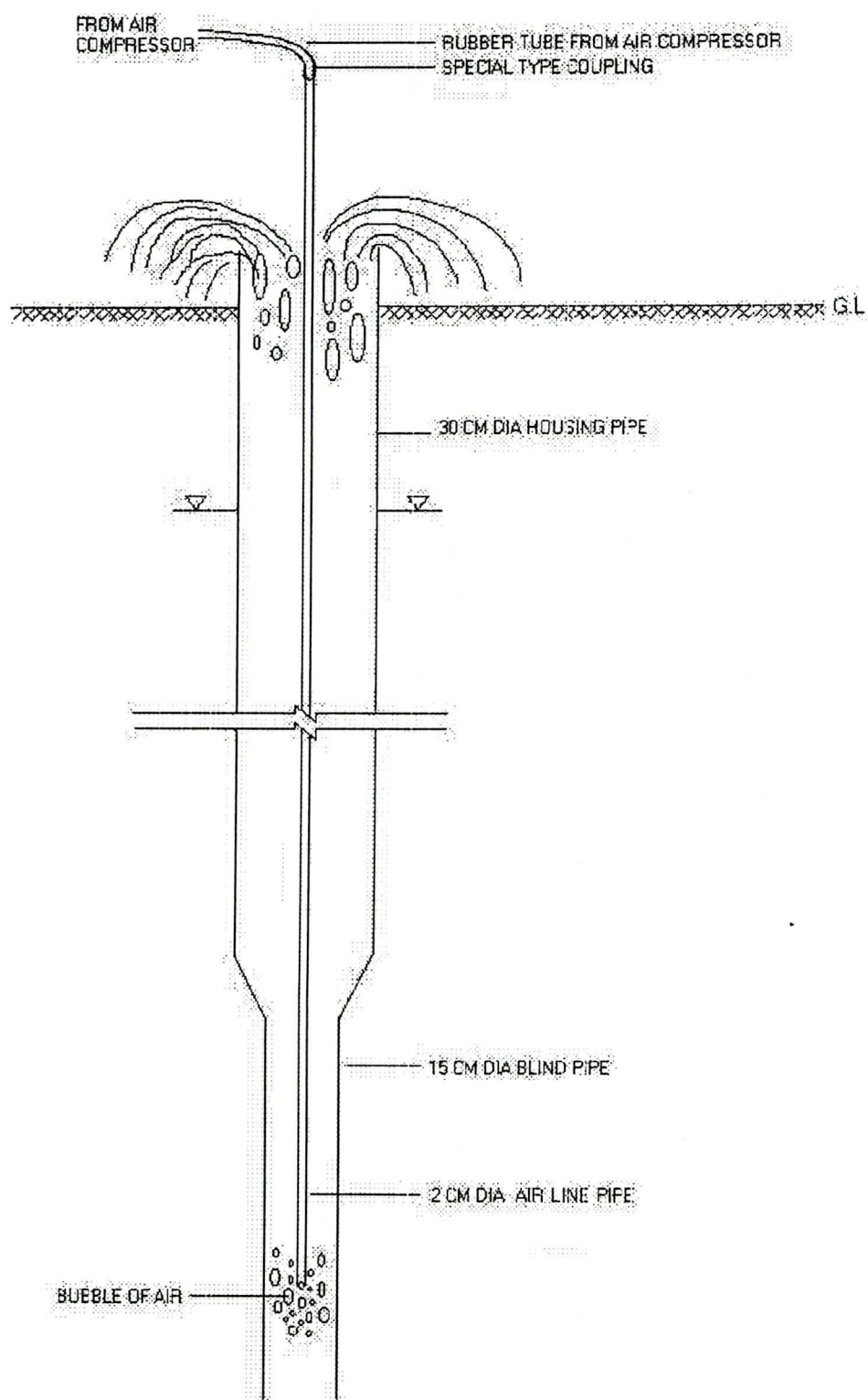


PLATE 12: SCHEMATIC VIEW OF CLEANING A TUBE WELL BY COMPRESSED AIR

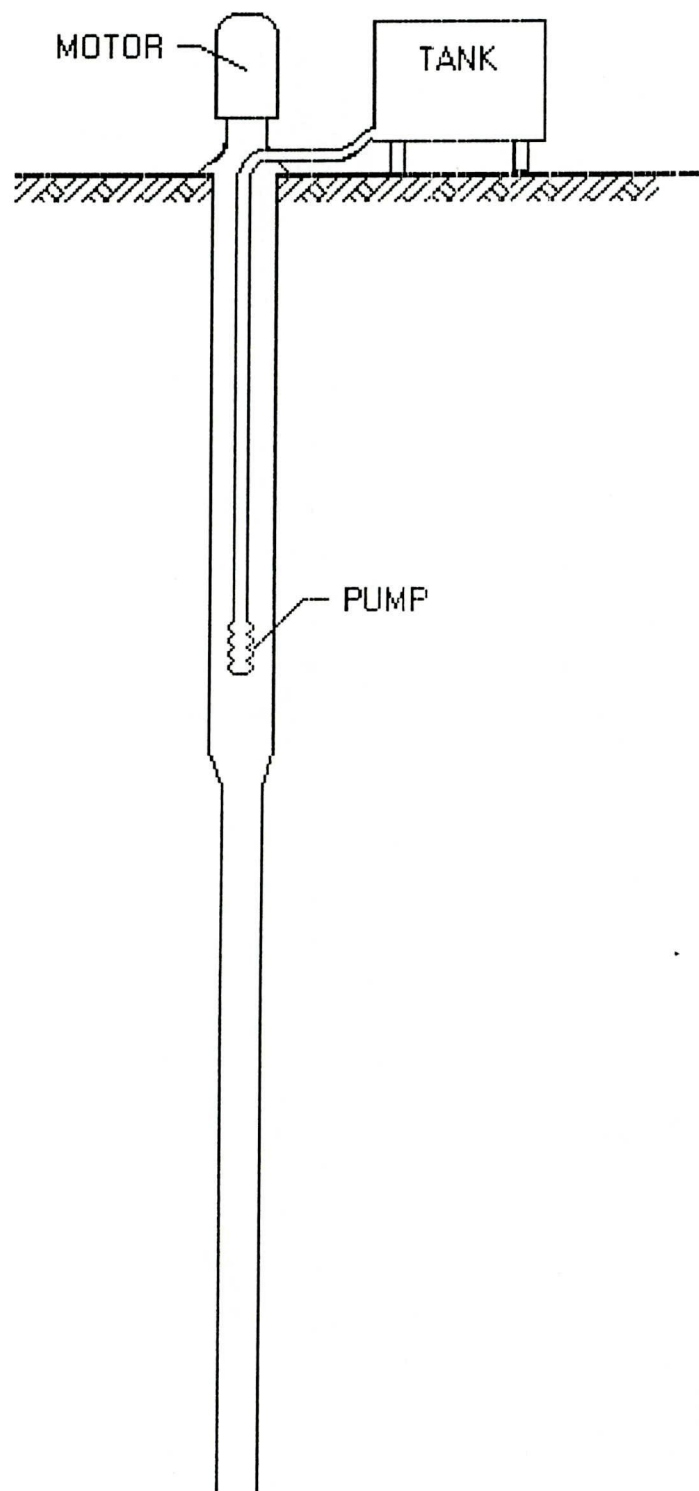


PLATE 13 : RAWHIDING METHOD OF TUBE WELL REGENERATION
[Source: DPHE, Bbangladesh]

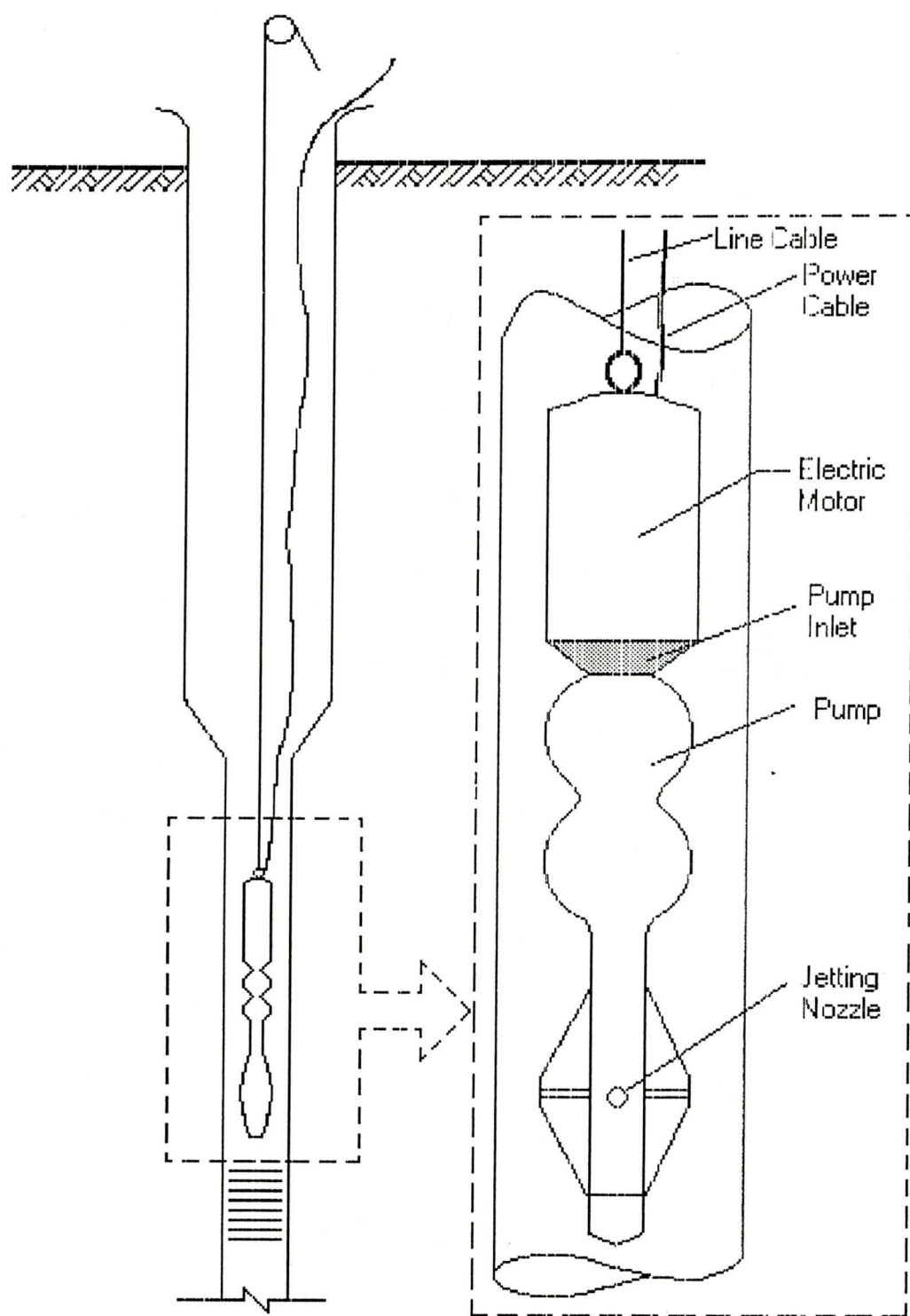
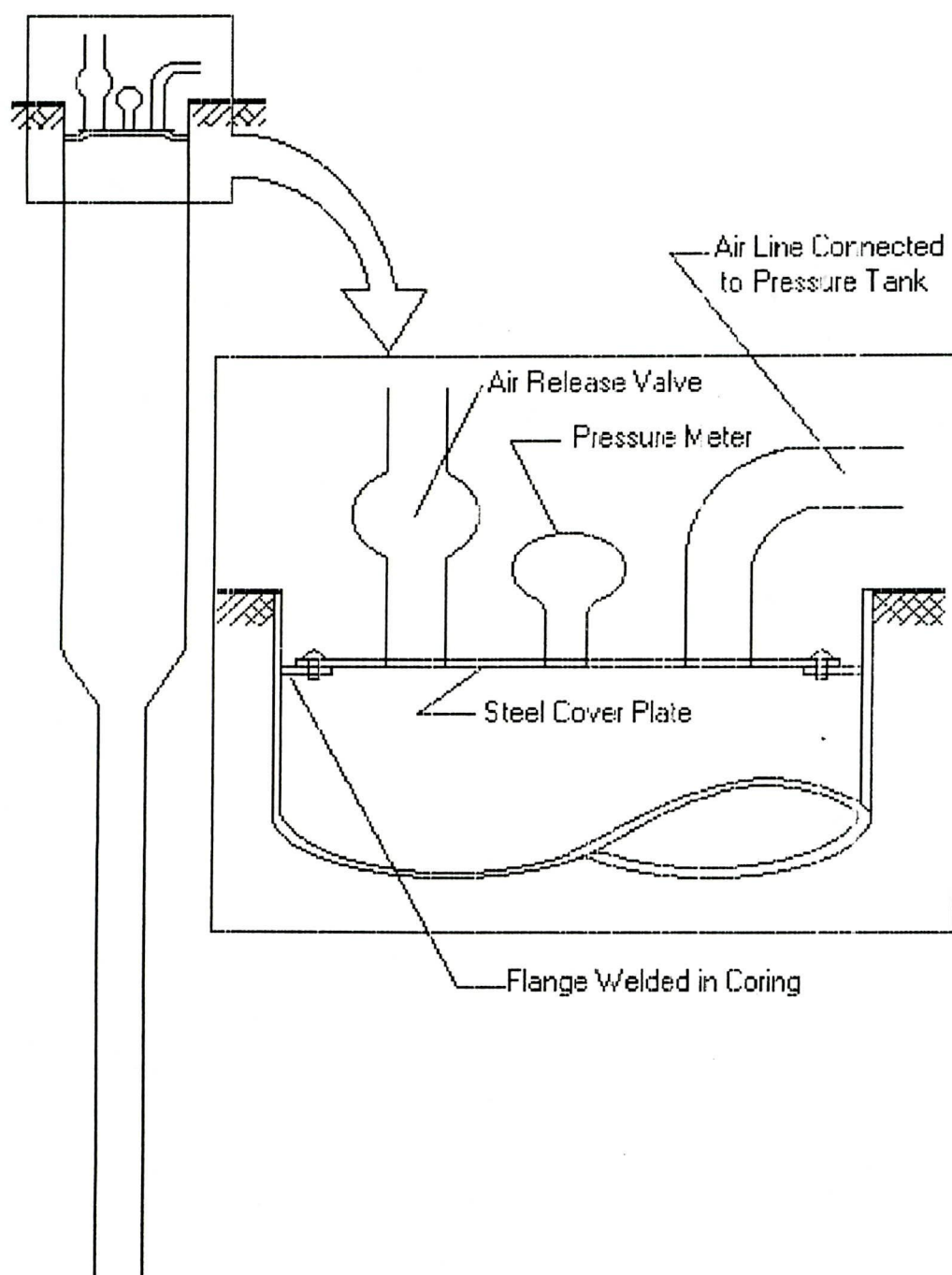
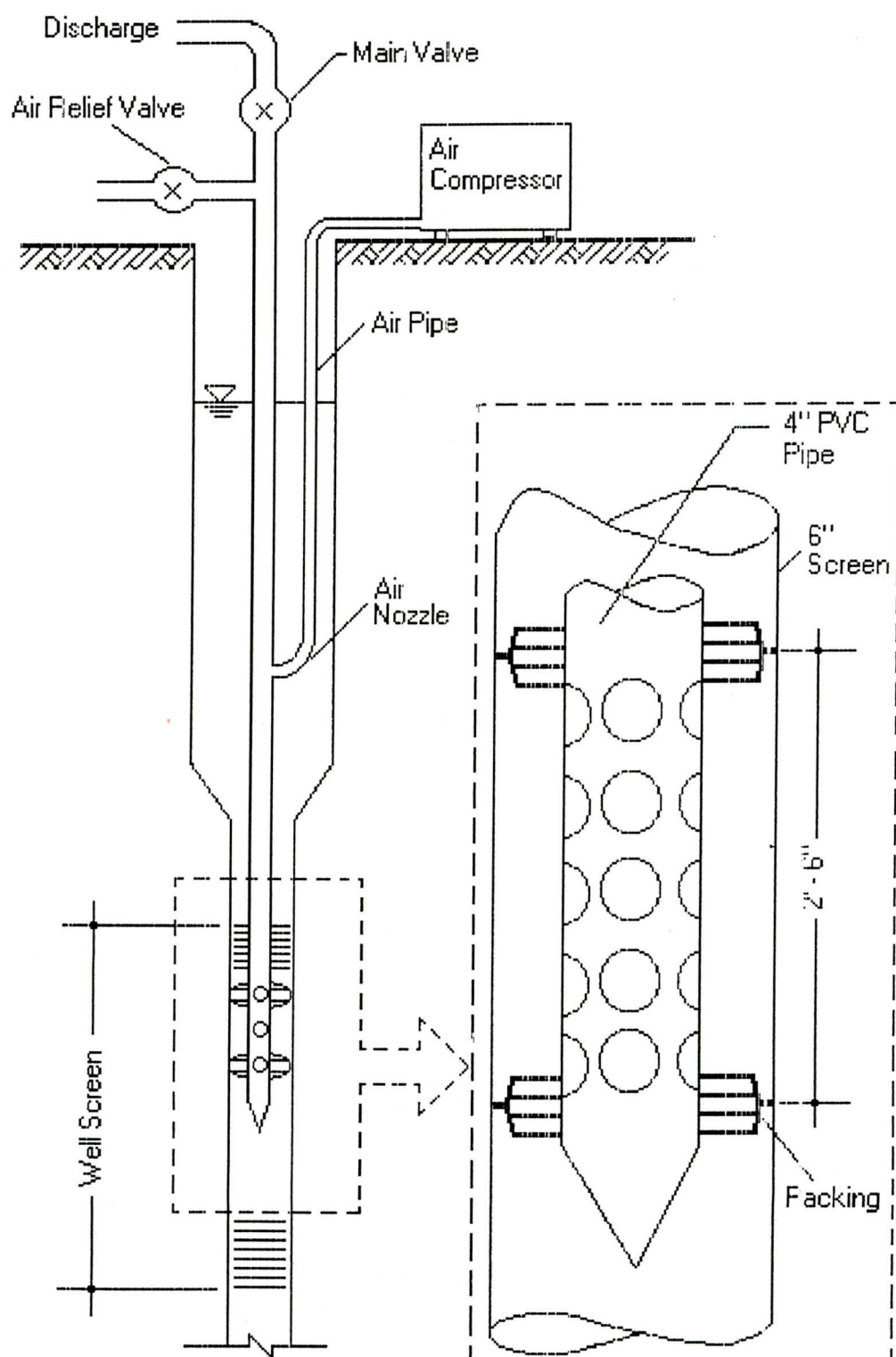


PLATE 14 : WATER JETTING METHOD OF TUBE WELL REGENERATION
 [Source: DPHE, Bangladesh]



**PLATE 15: 'PRESSURIZING WITH AIR' METHOD OF TUBE WELL
REGENERATION [Source: DPHE, Bangladesh]**



**PLATE 16 : 'SECTION WISE CLEANNG' METHOD OF TUBE WELL
REGENERATION [Source: DPHE, Bangladesh]**

AIR LIFT PUMP FOR DEEP TUBE WELL

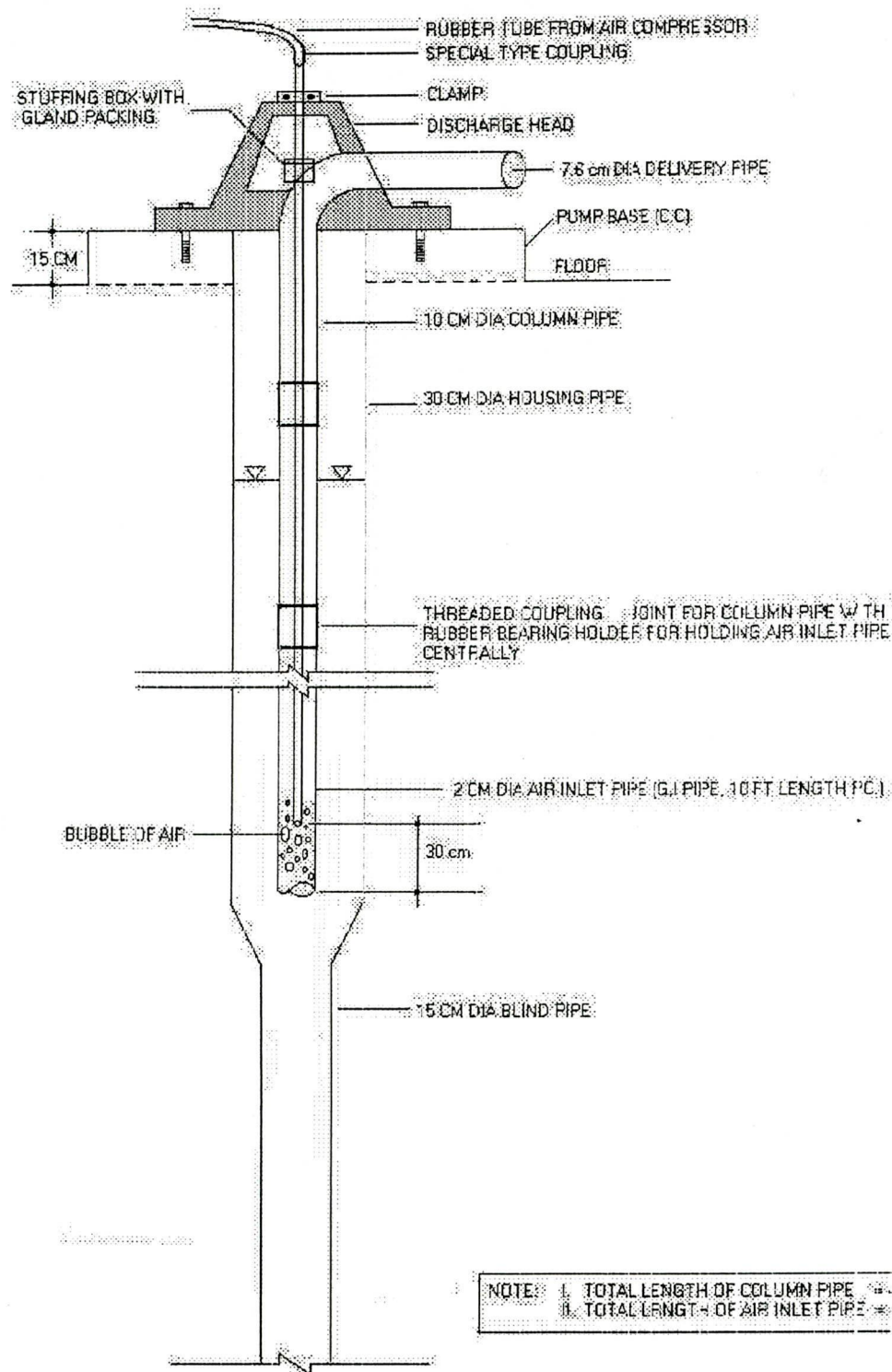


PLATE 17: DEVELOPED AIR LIFT PUMP FOR DEEP TUBE WELL

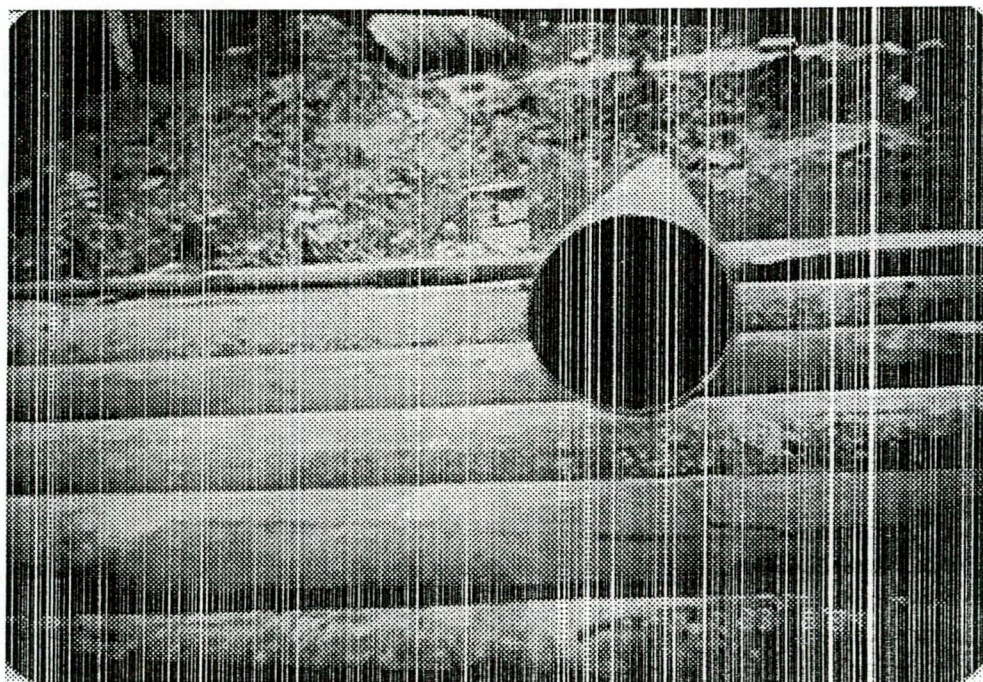


PLATE 18: Iron layer is seen deposited on both sides of the M.S. column pipe as well as on the wall of air line pipes.

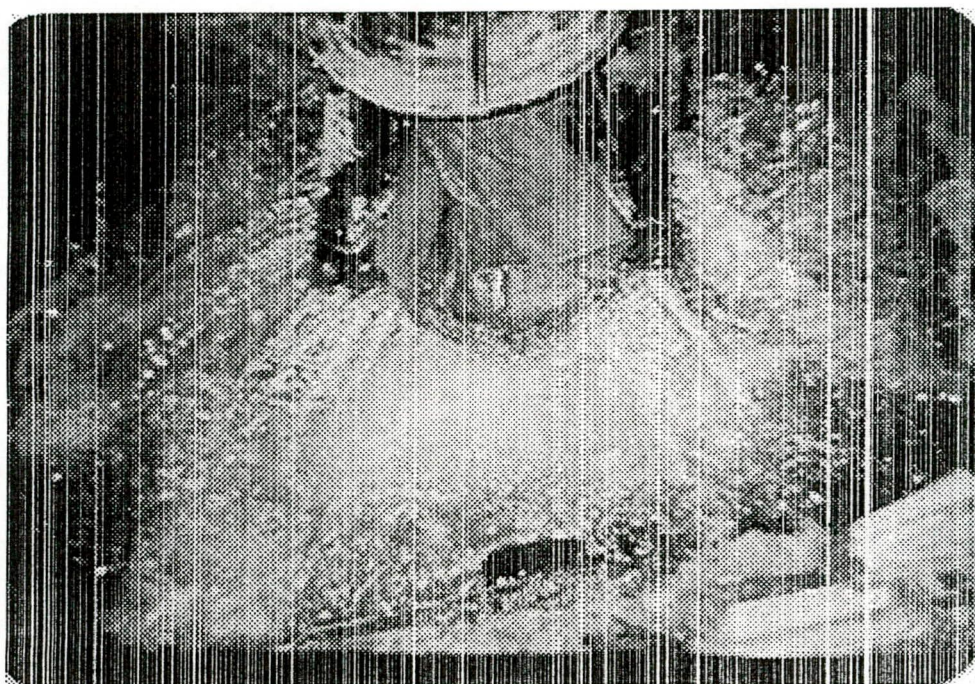


PLATE 19 : Water is seen coming out of the deep tube well housing pipe when air is being injected below in side the column pipe.

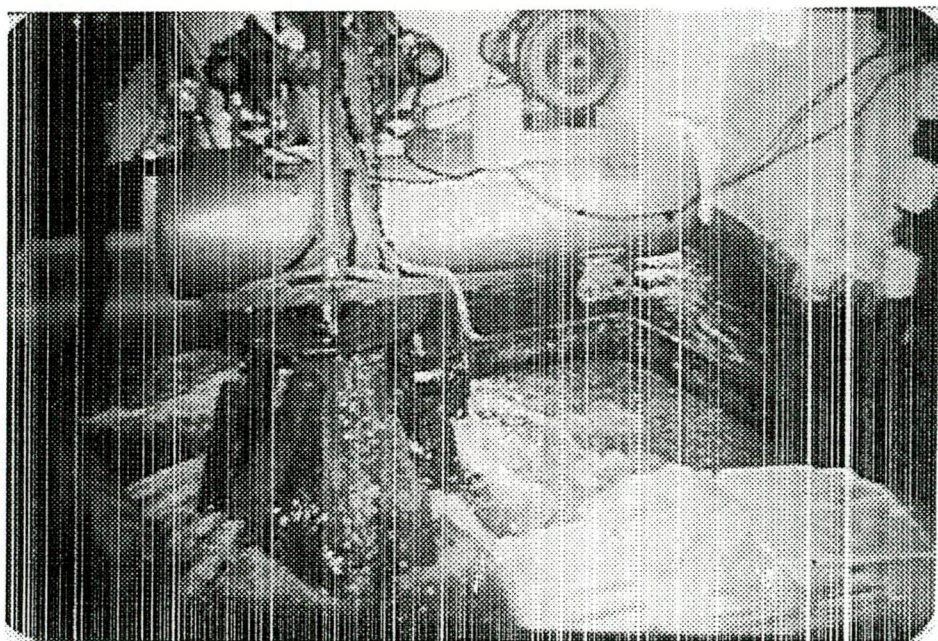


PLATE 20 : Another view of water flow from the deep tube well when compressed air is injected into the tube well for cleaning incoming water of iron.



PLATE 21: G.I. air-line pipes are being installed with the help of chain pulley.

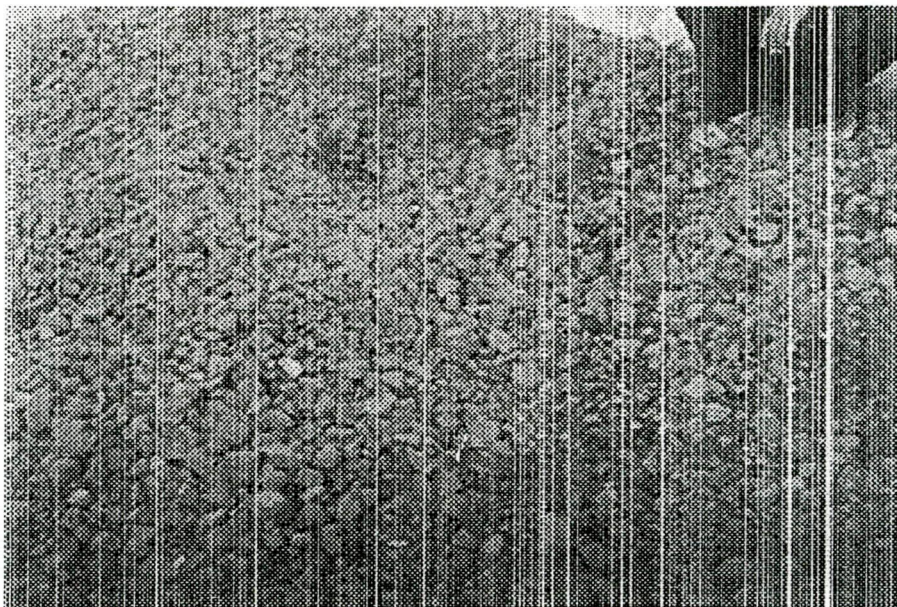


PLATE 22 : The course media flocculators with full of iron sludge when lifted out from the flocculation chamber.

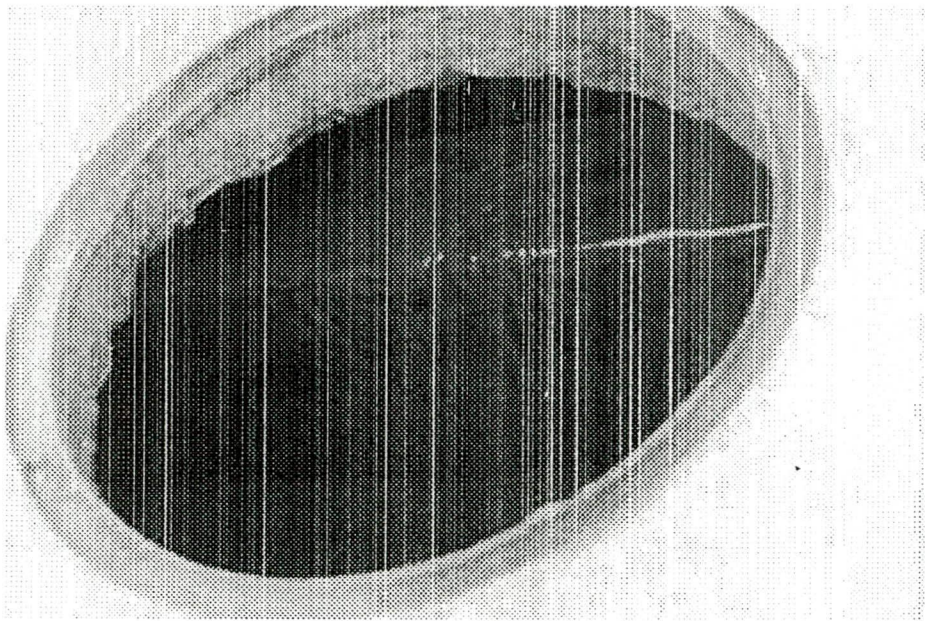


PLATE 23 : Water flows over the end wall of sedimentation chamber.

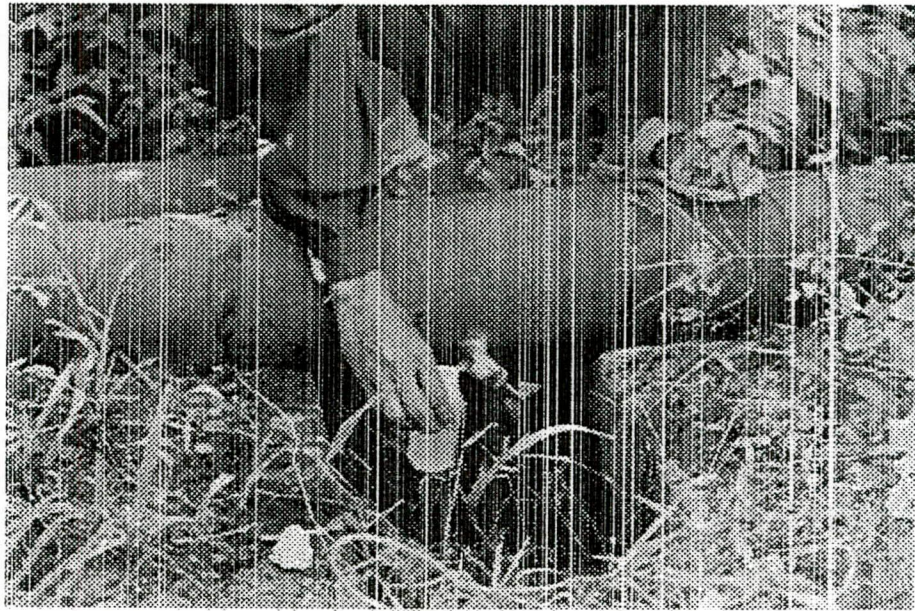


PLATE 24: Water sample is being collected at the inlet of the underground reservoir.

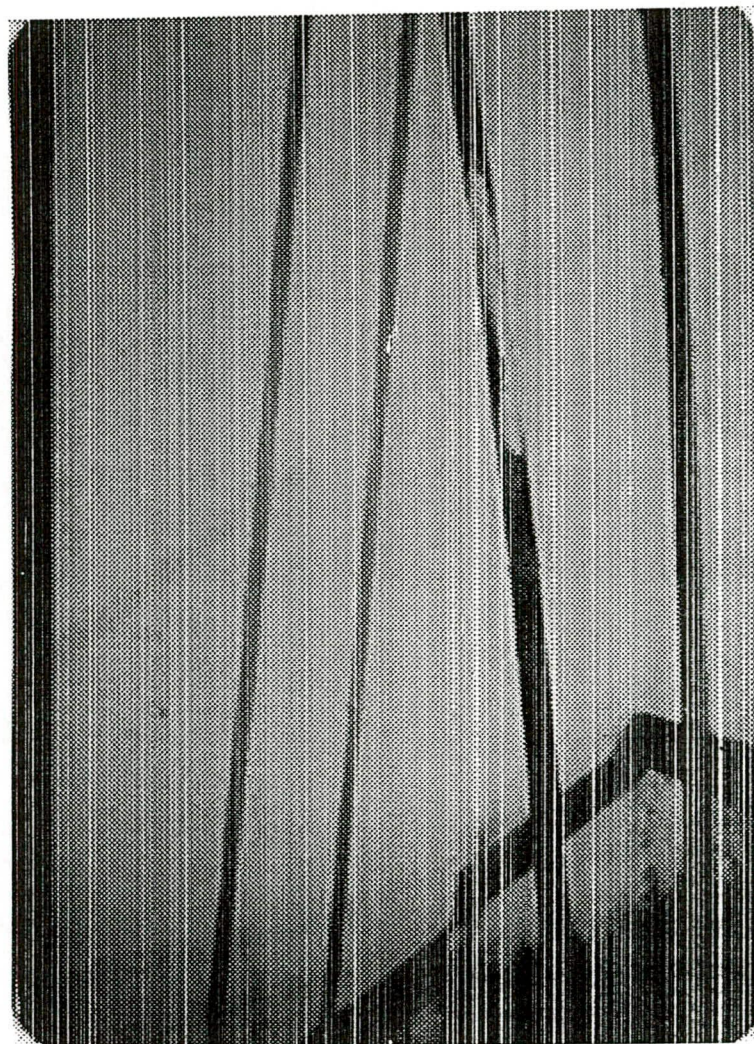


PLATE 25 : Iron layer is seen deposited around the airline pipe.

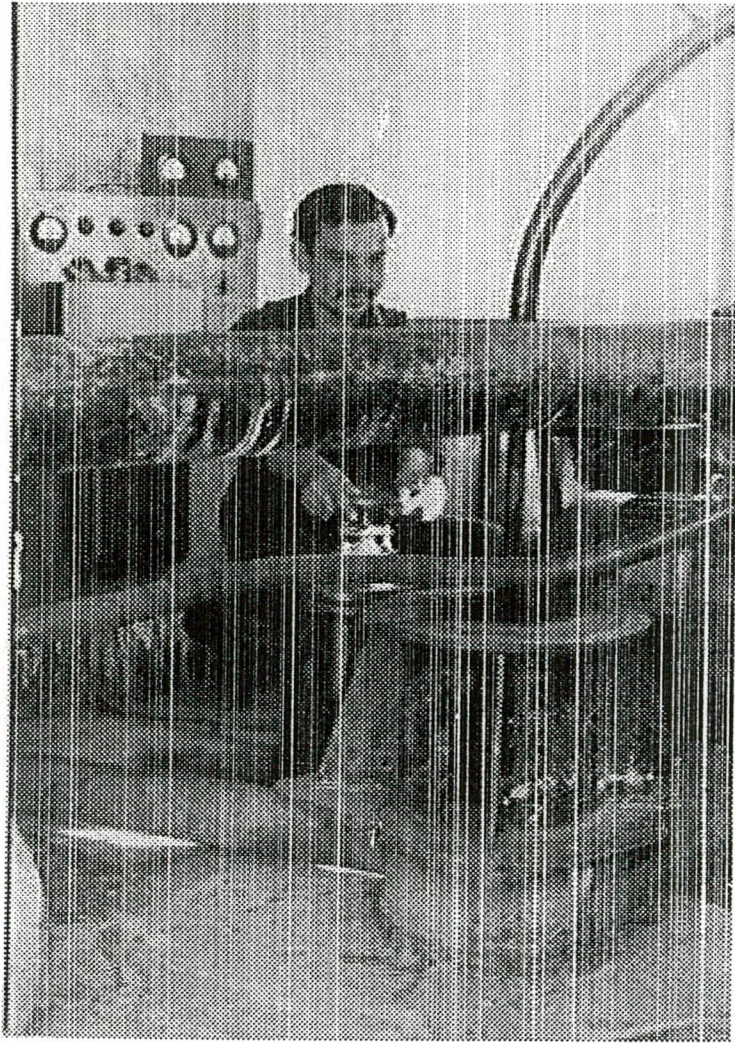


PLATE 26: The water discharge may be regulated to some extent by the gate valve fitted with the delivery pipe.

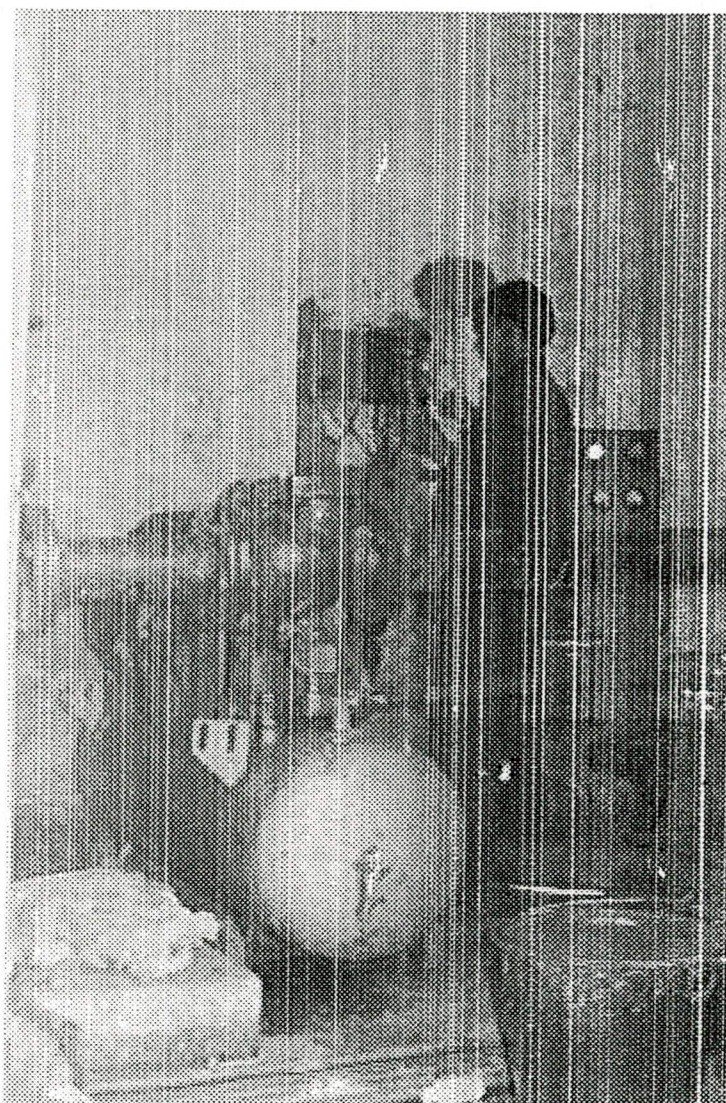


PLATE 27: The air compressor is seen inside the pump house.

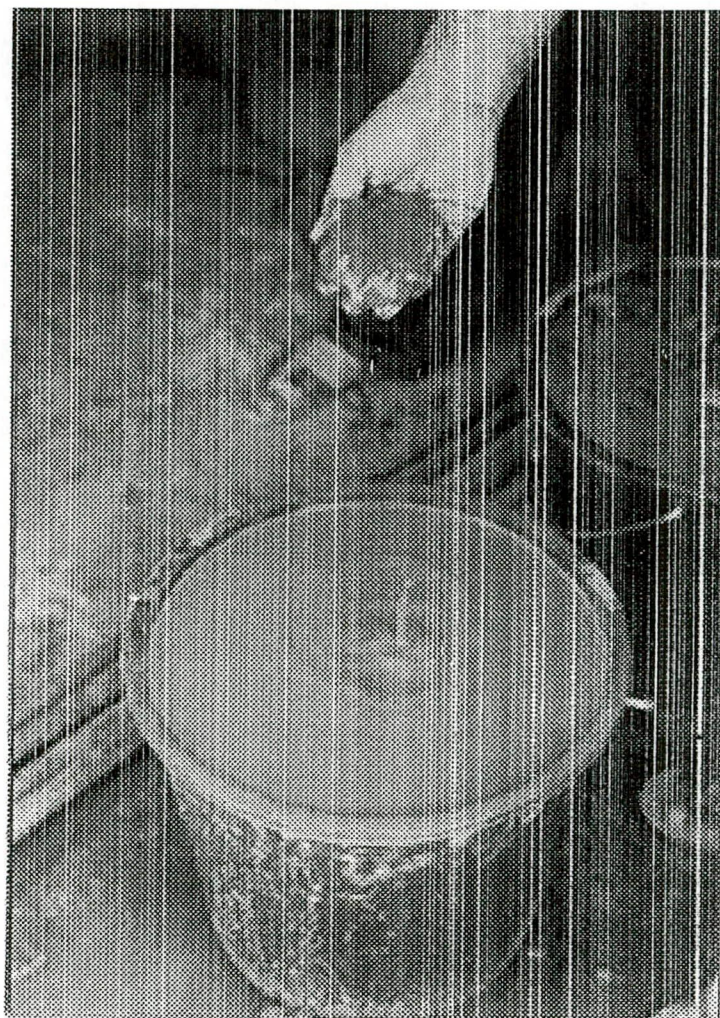


PLATE 28: The Iron sludge is seen deposited inside the interstices of the coarse media flocculator.



PLATE 29: The delivery pipe of the deep tube well to the inlet of the flocculator chamber. The aerated water sample is collected at this point.

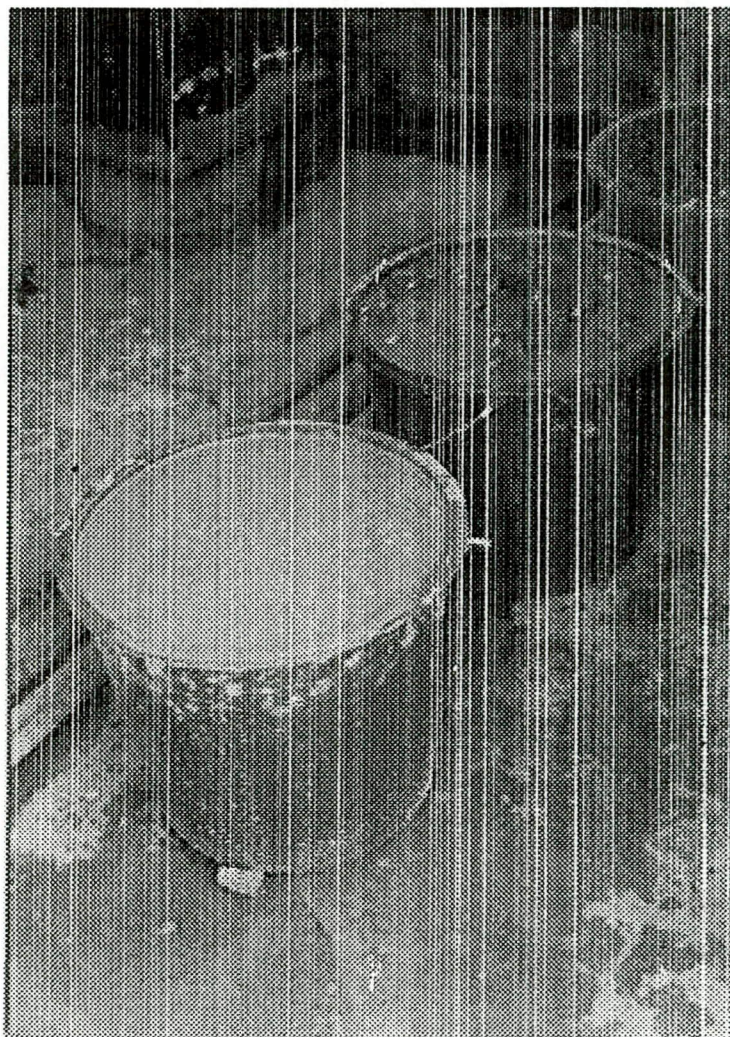


PLATE 30: Iron sludge volume is measured by volumetric method with the help of plastic buckets.

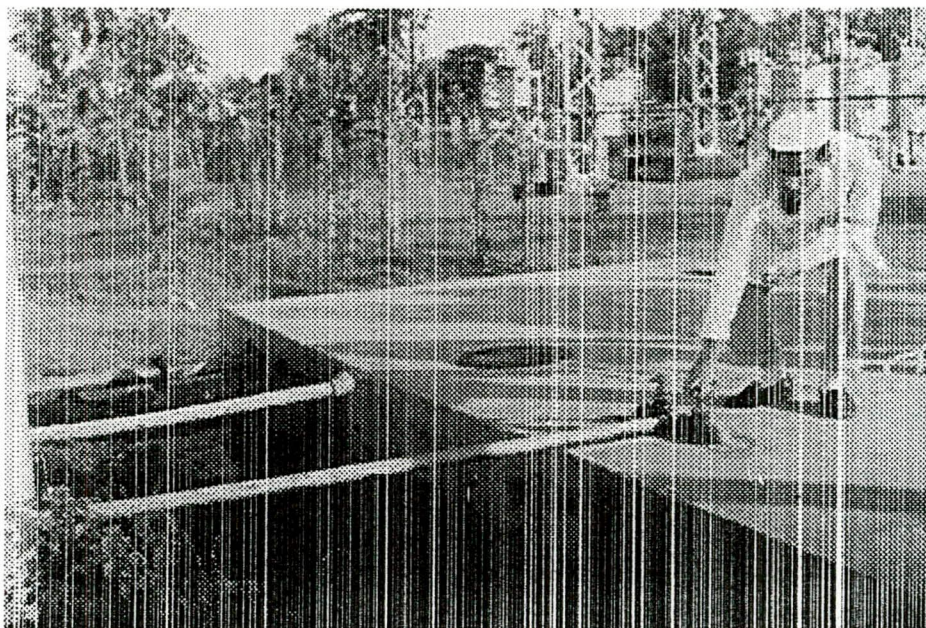
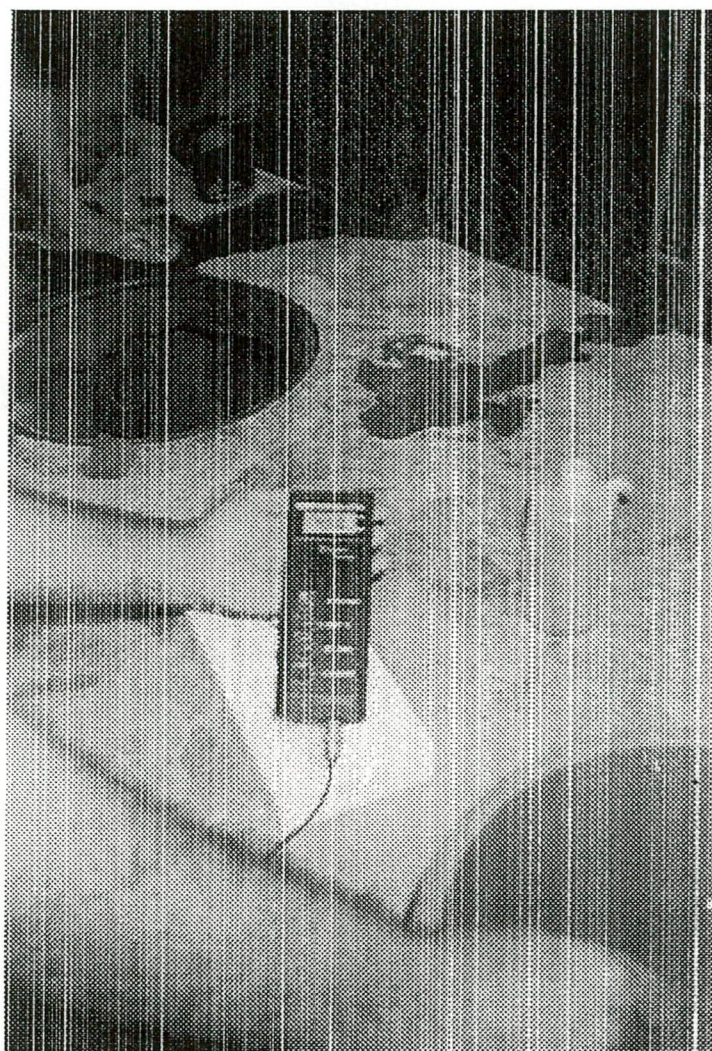


PLATE 31 : THE SUCTION PIPE OG THE SLUDGE PUMP



PLATE 32: pH of water sample is being measured at site with the help of pH meter and buffer solution



**PLATE 33 : DESOLVED OXYGEN (DO) CONTENT OF THE WATER SAMPLES IS
BEING MEASURED WITH THE HELP OF A DO METER AND A
THERMOMETER**

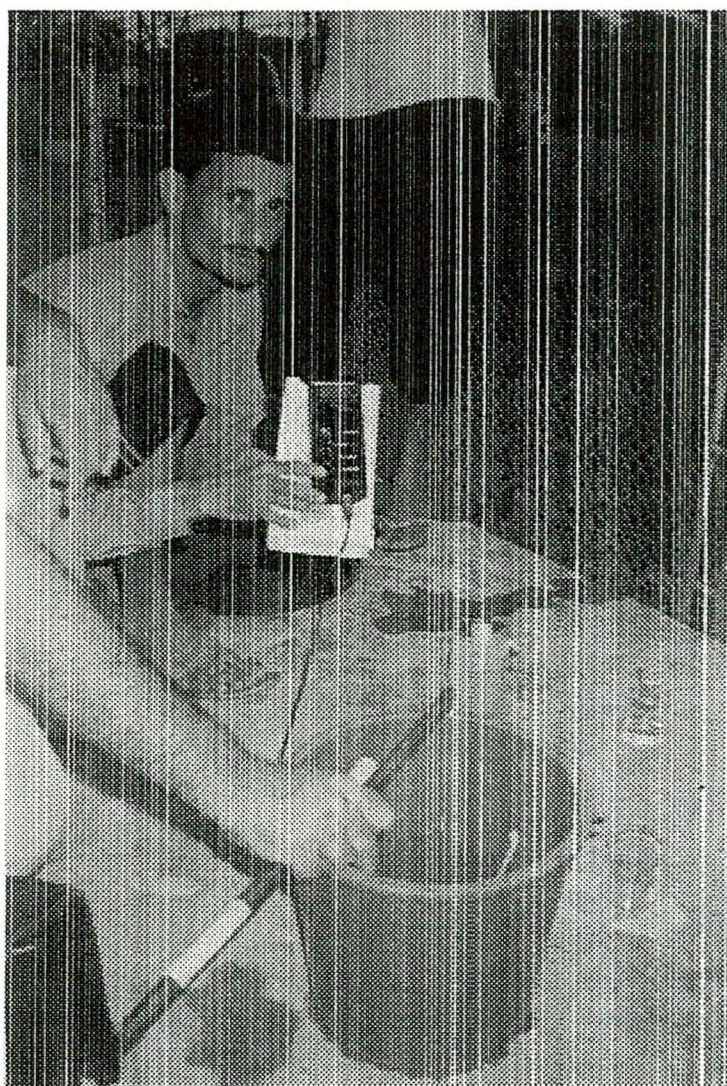


PLATE 34 : ANOTHER VIEW OF TAKING MEASUREMENT OF DO CONTENT OF THE WATER SAMPLES AT SITE WITH THE HELP OF A DO METER AND A THERMOMETER

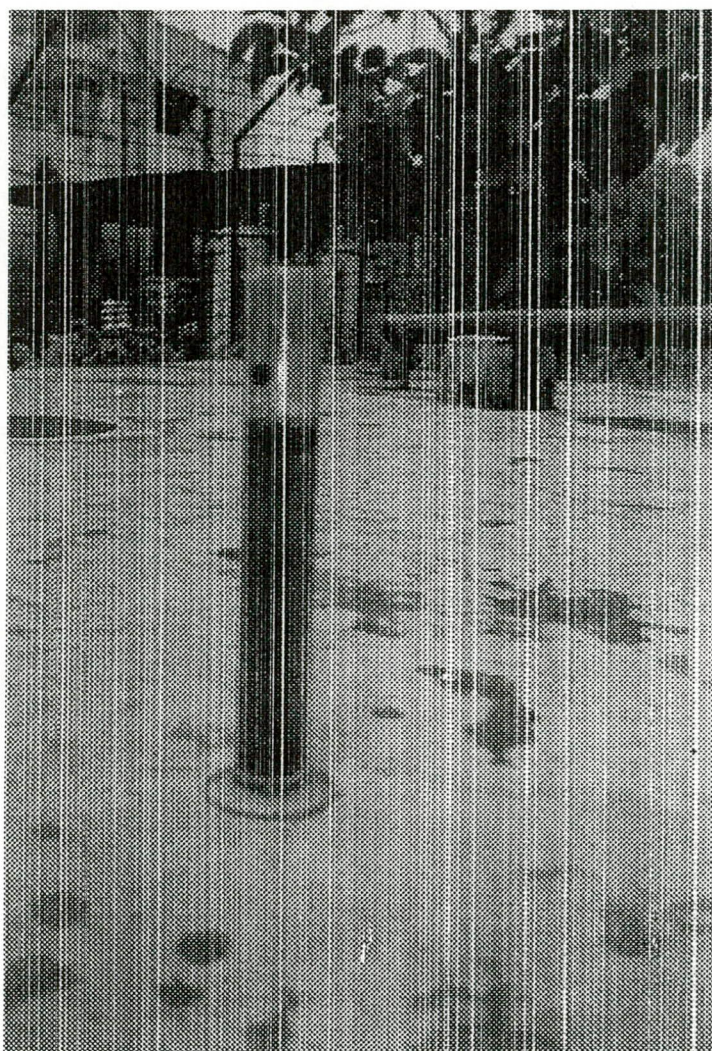


PLATE 35: Volume of Iron measurement in iron sludge from the voids of the coarse media flocculator by desolving it with HCL



PLATE 36 : Measurement of static water level as well as pumping water level with the help of AVO meter

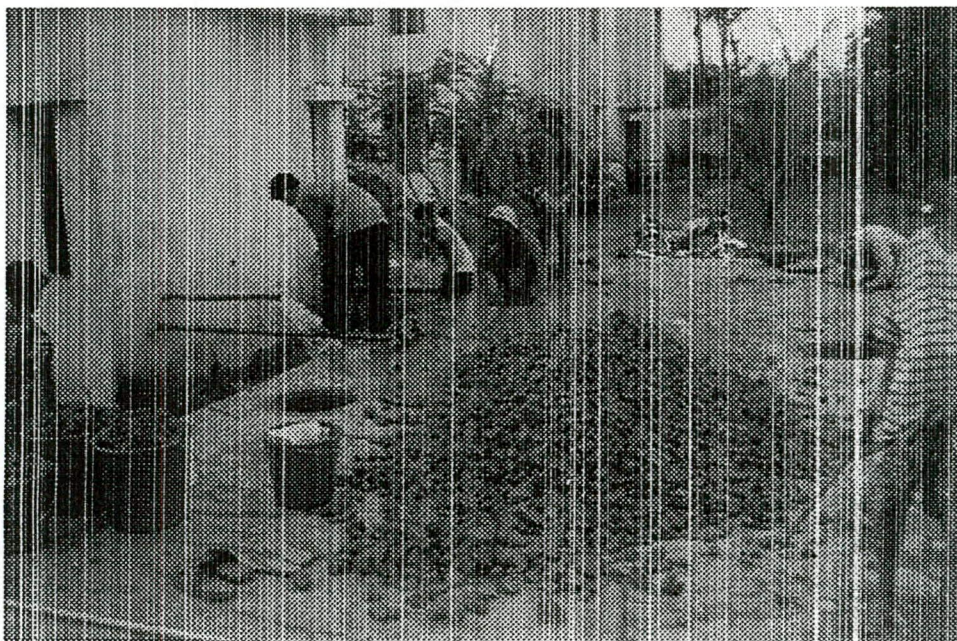


PLATE 37: Coarse media flocculator is being washed after being lifted from the flocculation chamber

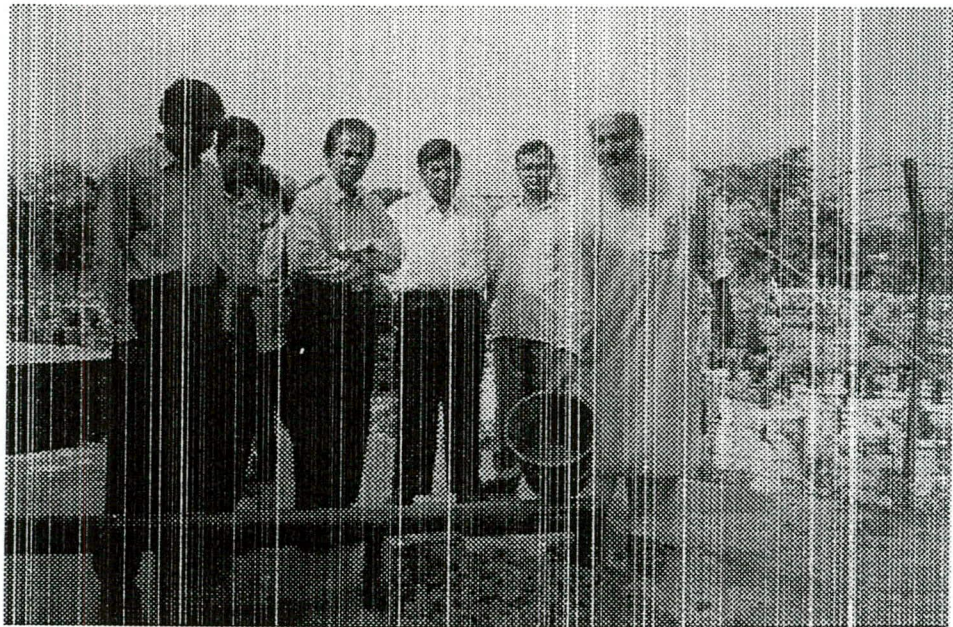


PLATE 38 : Iron sludge is being collected in a bucket from the voids of coarse media

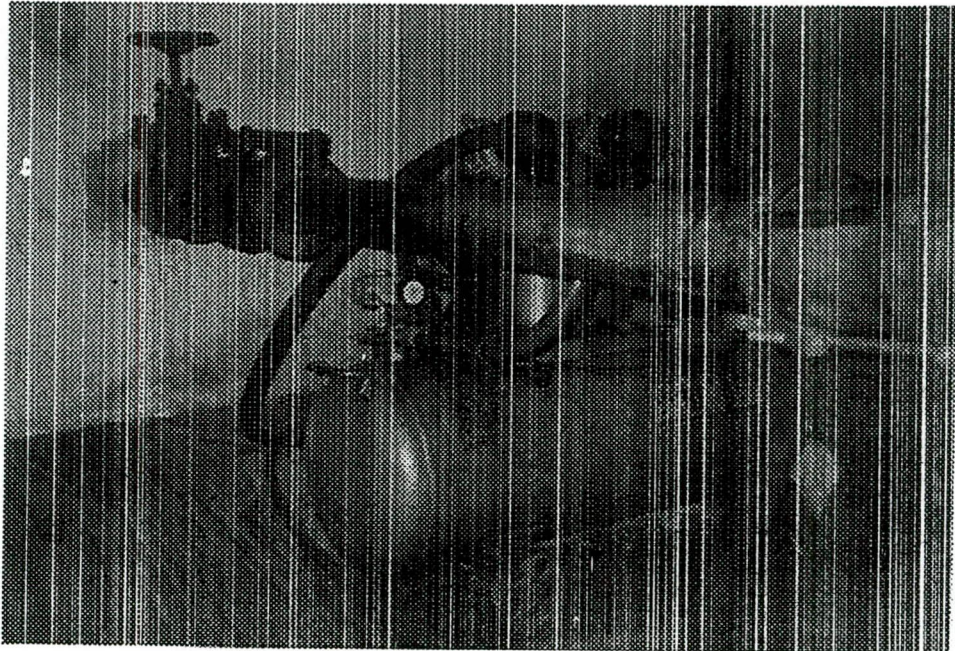


PLATE 39 : Air pressure is being measured with the help of pressure meter fitted with the air compressor of the airlift pump

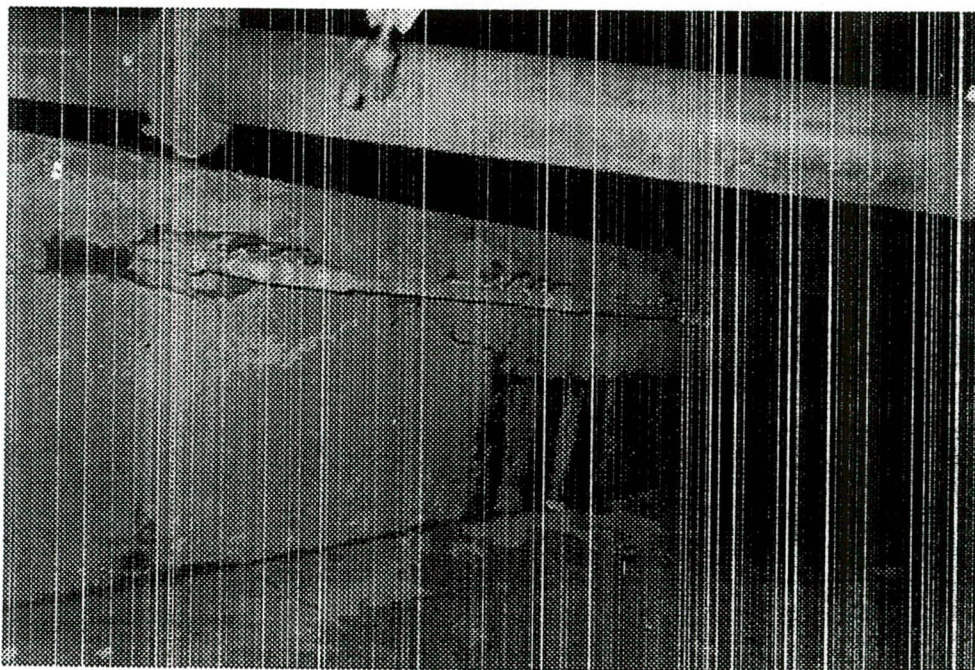


PLATE 40 : Air lines are seen fitted to the flocculation chamber. With the help of air surge developed at the air compressor, the flocculation chamber is regenerated. Thus taking out of coarse media from the chamber is not needed at the moment.

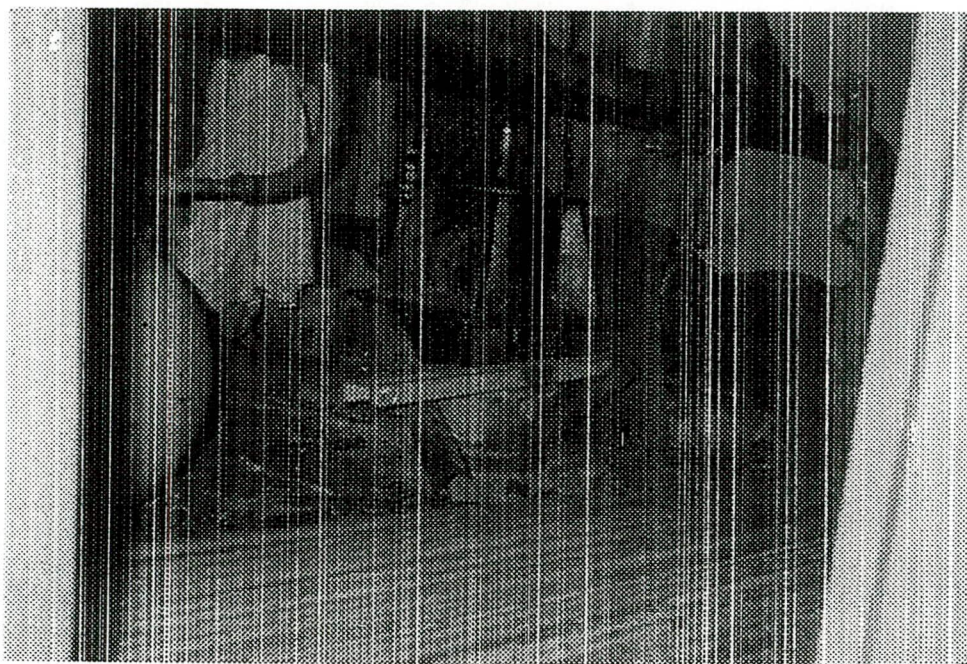


PLATE 41 : Modified setting of the discharge head. It was previously welded to the edge of housing pipe (CC Pump base was constructed as per site condition subsequently)

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