DEVELOPMENT OF A LOW COST IRON REMOVAL PLANT FOR HAND TUBEWELL

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BY

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ABSTRACT

The rural water supply in Bangladesh is based on hand pump tubewells installed to collect water from shallow aquifers. But the use of tubewell water for domestic purposes is declining due to the presence of high concentration of iron in the ground water of some rural areas. In these iron problem areas people are inclined to use water from unprotected sources which indirectly affect the health of the rural community. So to make an effort to solve these problems, several iron problem areas were surveyed and some households were interviewed about their opinions regarding water quality and the reasons for non-usage of tubewell water in iron problem areas. The rural people of those areas also told about different water sources which they use for various domestic purposes. It was observed that the main reasons for the non-usage of tubewell water in an iron problem area were aesthetics and staining clothes and utensils.

In a locality where iron concentration of tubewell water was above 20.0 mg/l, an iron removal plant with a gravity flow aerator, a coarse media flocculator, a plain sedimentation tank and a coarse media filtration chamber was constructed and its performance was observed. The iron removal efficiency was good enough, but the yield as well as filter run was neither satisfactory nor acceptable to the rural people. Then the design

of the plant was modified, e.g. tubesettlers were placed in the sedimentation chamber instead of a plain sedimentation chamber, an additional narrow plain sedimentation chamber was built after the filtration chamber. The performance of the modified plant was found quite satisfactory to the rural people both in removing iron from water and increasing yield as well as filter run. In this plant the iron removal efficiency was found to be 99.3%, the yield was 14.4 litres/min which was about 75.6% higher than the yield of the previous plant.

Maintenance problem, the most important problem of all the Iron Removal Plants constructed so far, was also removed by increasing the filter run to 22 days--- an increase of about 55.0% compared to the filter run of the previous plant. The cleaning procedure which is very simple and easy to do is also accepted to the consumers.

After the construction of the plant, the households using the effluent water were also interviewed and it was observed that the water quality, plant yield and cleaning frequency are acceptable to the people.

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NOTATIONS

C_t	Concentration at time t=t
C_o	Concentration at time t=0
K_g	Proportionality factor
k_g	Gas transfer co-efficient
ρ_s	Density of the particle
ρ_w	Density of water
A_c	X-sectional area of the particle
V_s	Settling velocity of the particle
C_D	Newton's drag co-efficient
μ	Dynamic viscosity
R	Reynolds number
Q	Flow rate
G	Average velocity gradient
a	X-sectional area of the flocculator
S	Slope factor
td	Detention time
Gtd	Camp number
B	Width of the sedimentation chamber

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CHAPTER 1

INTRODUCTION

1.1 General

A primary requisite for good health is an adequate supply of water that is of satisfactory sanitary quality. It is also important that the water be attractive and palatable to induce its use; otherwise, consumers may decide to use water of doubtful quality from a nearby unprotected stream, well or spring. In the urban areas, where a municipal water supply passes near a property, the owner of the property should be urged to connect to it because such supplies are usually under competent supervision. But when a municipal water supply is not available, specially in the rural areas, the tubewell water is the safest water source for drinking, personal hygiene and other domestic purposes. DPHE, Bangladesh and other organizations install most of the tubewells used in the rural areas. Ahmed [1] has observed that the greater the use of tubewell water for all domestic purposes the less is the incidence of diarrhoeal attack. But the physical quality of water is an important factor for the acceptance of it to the rural people. Bacteriological quality carries little importance to the rural people, they prefer water which tastes good and is odorless and which does not change the color of food or does not stain clothes.

Ground water drawn from tubewells contain iron in larger concentrations in many places of Bangladesh. An investigation made by Ahmed, Hossain, Khan and Badruzzaman [2] shows that in some places like Rajshahi, Jessore, Khulna, Kushtia, Rangpur, Kurigram, Pabna, Sirajganj, Tangail, Chittagong and several regions of Dhaka the concentration of iron varies from 1 to 5 mg/l and in some places it has been found as high as 25 mg/l.

1.2 Statement of the Problem

Groundwater of our country usually has a high iron content and in some areas (Art. 1.1) deposits go far beyond the tolerance of local people. The presence of iron in water is objectionable primarily because the precipitates of these metals alter the appearance of water turning it turbid yellow-brown to black. In addition the deposition of these precipitates stains clothes and teeth. Although discoloration from precipitates is the most serious problem associated with water supplies having excess iron, foul tastes and odors can be produced by the growth of iron bacteria. These filamentous bacteria, using reduced iron as an energy source, precipitate it, causing pipe incrustations. Decay of accumulated bacterial slimes creates offensive tastes and odors.

Iron content water imparts a taste to water which is described as metallic, astringent or medicinal. Finally, the precipitates of these metals may lead to difficulty with water treatment processes such as ion change. Iron interfere with laundering operations. It imparts a taste to water which is detectable at very low concentrations. Iron-bearing waters are often called ferruginous water. They have a bitter taste and, in combination with the tanin, impart an inky color to tea infusions. They also impart a brown-colored deposit on vegetables during washing and cooking.

Water bearing iron also generally favors the growth of several groups of bacteria including **Crenothrix, Leptothrix** etc. 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 or elevated storage tanks. The rapid growth of these bacteria lessen the flow rates in or to a pipe line. In addition, if they break loose, the large masses will clog nozzles, lines and valves. The bacteria as they decay impart a particularly bad taste and odor to the water making it objectionable to drink or use for sanitary purposes.

The problem of iron removal as it is faced by municipalities and industrial supplies is easily handled, because they have large aeration equipments and can use coagulation methods for precipitation and filtration. The main problem exists in removing iron from rural water supplies e.g. hand tubewells etc, as the rural people have neither any equipment for aeration nor any chemical for coagulation or flocculation. Hence an iron removal plant for handpump tubewell should have to be designed so that it can remove iron from ground water without extra cost of aeration or the addition of chemicals for coagulation.

1.3 Rationale of the Study

In the context of Bangladesh, plenty of ditches, ponds, tanks and rivers are available everywhere. But rural people can't use water from those unprotected water sources for drinking purpose. Since water from these sources is highly turbid, algae enriched and contaminated by microorganisms, people is dependent on hand pump tubewells installed to collect water from shallow aquifers.

In some of the areas of Bangladesh ground water carries a high concentration of iron. Due to aesthetic problem people are not interested in using tubewell water which carries iron. They are inclined to use water from unprotected sources which cause different water-borne diseases. In a survey conducted by UNICEF and World Health Organization (WHO) in Bangladesh in 1976, it was found that the attack rate of diarrhoeal diseases in iron problem areas was 53 percent higher than in non-iron problem areas [1]. In this way tubewell water consumption decreases drastically and the rural people suffer from different water-borne diseases. As a result the main purpose of sinking hand pump tubewells in the rural areas is not achieved. To increase the tubewell water consumption many iron removal plants have been designed and installed in the rural areas of Bangladesh by different organizations. According to Ahmed [1] about 200-300 community type iron removal plants have been constructed in the rural areas. All these plants can remove about 70-80 percent of iron effectively [1]. But the main problem of all these plants is maintenance problem. The rural people are not interested in cleaning the plants and within only a few days the plants become abandoned. As a result many plants have been out of order and resulted in failure.

Recently Ahmed [3] has designed an iron removal plant on the basis of laboratory model study. But it needs detailed field investigation study with some alternative arrangements. This model plant consists of four chambers, e.g. one flocculation chamber, one sedimentation chamber and two filtration chambers.

1.4 Objectives of the Research

Following are the specific objectives of the proposed research:

a) To observe the performance of different components of the model plant (e.g. Gravity flow aerator, coarse media flocculator, sedimentation tank, coarse media filtration chamber).

b) To observe the overall iron removal efficiency of the plant and its possible improvements.

c) To observe the operation and maintenance performance of the plant (e.g. the daily yield, the length of run between cleaning, the people's interest in maintaining the plant, people's acceptance of the plant).

CHAPTER 2
LITERATURE REVIEW

2.1 General

The presence of iron in groundwater is now considered to be a major problem throughout the world and produces numerous adverse effects. These problems are severe in the context of Bangladesh as groundwater is a vital source for the safe drinking water supply to its rural population. At present, in the rural areas, hand pump tubewells are regarded as the only means for collecting groundwater for drinking and other domestic purposes because of numerous socio-economical and technical reasons. Though at present, one tubewell for 104 people has been installed, a recent survey unfortunately reveals that only 32% of the rural population use tubewell water for drinking and a few use it for other domestic purposes [1]. High concentration of iron in groundwater which causes various problems is the main reason for this low consumption.

2.2 Occurrence of Iron

The presence of iron in groundwater is generaly attributed to the solution of rocks and minerals, chiefly oxides, sulfides, carbonates, and silicates containing these metals. Iron occurs in the silicate minerals of igneous rocks. Pyroxenes, amphiboles, and some micas generally contain iron. It also occurs in the form of various oxides, such as magnetite (Fe_3O_4), hematite (Fe_2O_3), and limonite ($2Fe_2O_3.3H_2O$). The sulfide and carbonate minerals are also important sources of iron. These include pyrite (FeS_2) and siderite ($FeCO_3$). Ferrous iron (Fe^{++}) is a soluble, invisible form that may exist in well waters or anaerobic reservoir waters. When exposed to air, this reduced form slowly transforms to insoluble visible, oxidized ferric iron (Fe^{+++}).

Many groundwaters are low in dissolved oxygen and are supersaturated with carbon dioxide, owing to weathering of carbonate rocks or to increased carbon dioxide concentration in the soil gas. 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 [4].

$$Fe^{+2} + 2CO_2 + 2H_2O \text{ ---> } Fe(HCO_3)_2 + 2H^+$$

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, which are subsequently exposed to air; and as a product of pipe corrosion producing red water. Most soils, including gravel, shale and sandstone rock, contain iron. Decomposing organic matter in water removes the dissolved oxygen usually present in water; then the water dissolves mineral oxides, changing them to soluble compounds. Ferrous iron may be found in the lower levels of deep reservoirs, flooding soils, or rock containing iron on its compounds, hence it is best to draw water from a higher level, but below the upper portion, which supports microscopic growth like algae.

2.3 Iron Problem Areas of Bangladesh

Ground water collected through handpump tubewells in Bangladesh carries a high concentration of iron and in many locations the concentration is much higher than the accepetable limit. Ahmed, Hossain, Khan and Badruzzaman [2] has prepared a map to show the distribution of iron in ground water of Bangladesh. The map has been presented in Fig 2.1. This map has been prepared compiling the available information about the ground water quality of the shallow aquifers. It has been observed that iron content of ground water in most of the places of Bangladesh is greater than 1.00 mg/l and in many locations the iron content of ground water is more than 5 mg/l [2]. Fig. 2.1 also indicates that ground water of about 65% of the area of Bangladesh has average iron content more than 2 mg/l.

The WHO (1983) suggested a guide line value of 0.3 mg/l for iron in drinking water. The limit can hardly be maintained in rural water supply in Bangladesh. For this reason, Department of

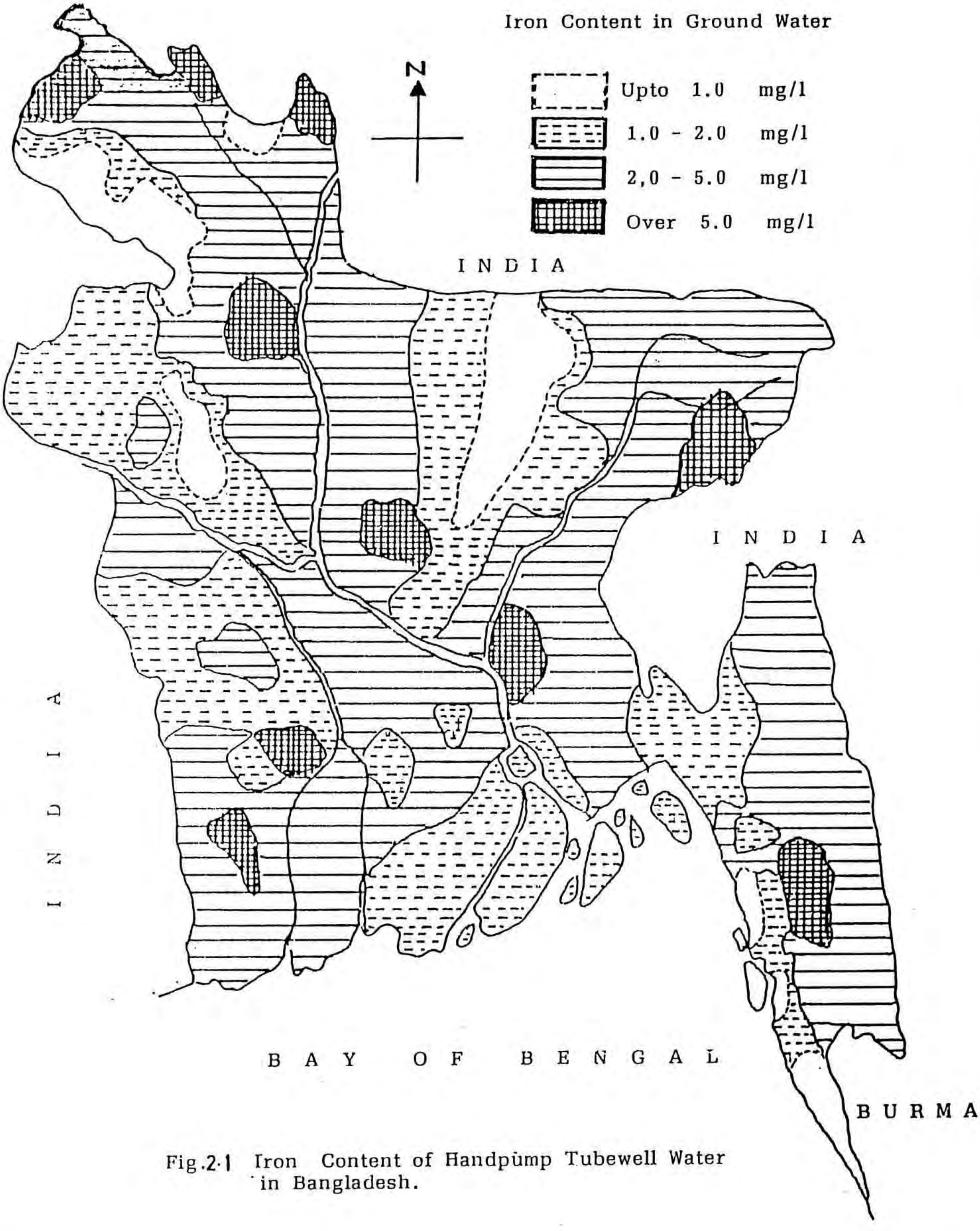


Fig.2·1 Iron Content of Handpump Tubewell Water in Bangladesh.

Environment Pollution Control (DEPC), Bangladesh, recommended a desirable limit of 1 mg/l of iron in drinking water. But in the case of hand pump tubewells in rural areas, the maximum tolerable limit was set at 5 mg/l in the absence of a better source. This local standard is being followed in rural water supply in Bangladesh.

Based on the distribution of iron bearing aquifers, allowable limits in Bangladesh and people's acceptability, the country may be divided into three iron problem areas.

Area Type - I : Iron problem free zones;

Iron content of handpump tubewell water in these zones is less than 1 mg/l. Rural people accept it as excellent water and installation of IRP is not required.

Area Type -II : Moderate iron problem zones;

Iron content of hand pump tubewell water is between 1 and 5 mg/l. People consider this water as good, medium or bad depending on the concentration of iron. Installation of IRP in these zones is optional.

Area type -III : Acute iron problem zones ;

Iron content of tubewell water is higher than 5 mg/l. In some places iron content has been found as high as 25 mg/l. Installation of IRP is absolutely essential to increase tubewell water consumption.

2.4 History of the Practice of Iron Removal

According to American Water Works Asssociation [5] 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. The earliest plants employed aeration and filtration, sometimes supplemented by the addition of lime, to treat groundwaters. The same method of treatment predominates today. By 1941 there were a reported 598 iron removal plants in the United States. The great majority served small communities and the total pumpage was only 220 mgd or as average of 370,000 gpd per plant. By 1958, approximately 1340 water treatment plants, roughly 14 percent of the total in the United States, included processes for the removal of iron [5].

2.4.1 Previous Techniques for Iron Removal

According to Ahmed [6] iron removal at the household level was attempted in some places of India and Bangladesh with four earthen pitchers placed one above the other. Raw water from the top pitcher dripped through a hole and passed 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 was very slow and unsuitable for all domestic uses.

In some places a force and lift pump was used to spray the water onto a filter bed enclosed in a brick chamber and then allowed to pass through a gravel under-drainage system [6]. The filtrate was tapped slightly above the bottom. Efficient removal of iron was possible, but such type of a plant involved a high initial cost and the maintenance of a force pump, and frequent cleaning of the large filter bed was not easy. In other places, a 200 l steel barrel, partially filled with filter materials, was placed below the discharge mouth of the hand pump by raising it to a higher elevated position from the ground [6]. 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 which would be acceptable to rural people. The design and performance of three iron removal plants developed during the last two decades are described in the following articles briefly.

2.4.2 Iron Removal Plant Developed in India

According to Dixit and Pathak [7] in 1970 an Iron Removal Plant for domestic purposes was made in India by C-PHERI (now called as NEERI) . After the initial laboratory experiments it was tested on a field scale at Howrah for nearby three months. Water containing 1 to 6 mg/l of Iron and 142 to 427 mg/l of free CO_2 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 Fig. 2.2. It has a capacity of 40 gallons per hour 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, 30 cm depth. The third chamber contains 30 cm of coarse sand, supported over a 5 cm 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 cokebed gets sufficiently aerated and CO_2 is released. Process of dripping through the second chamber provides further aeration to the already aerated water to reduce the dissolved CO_2 still more.

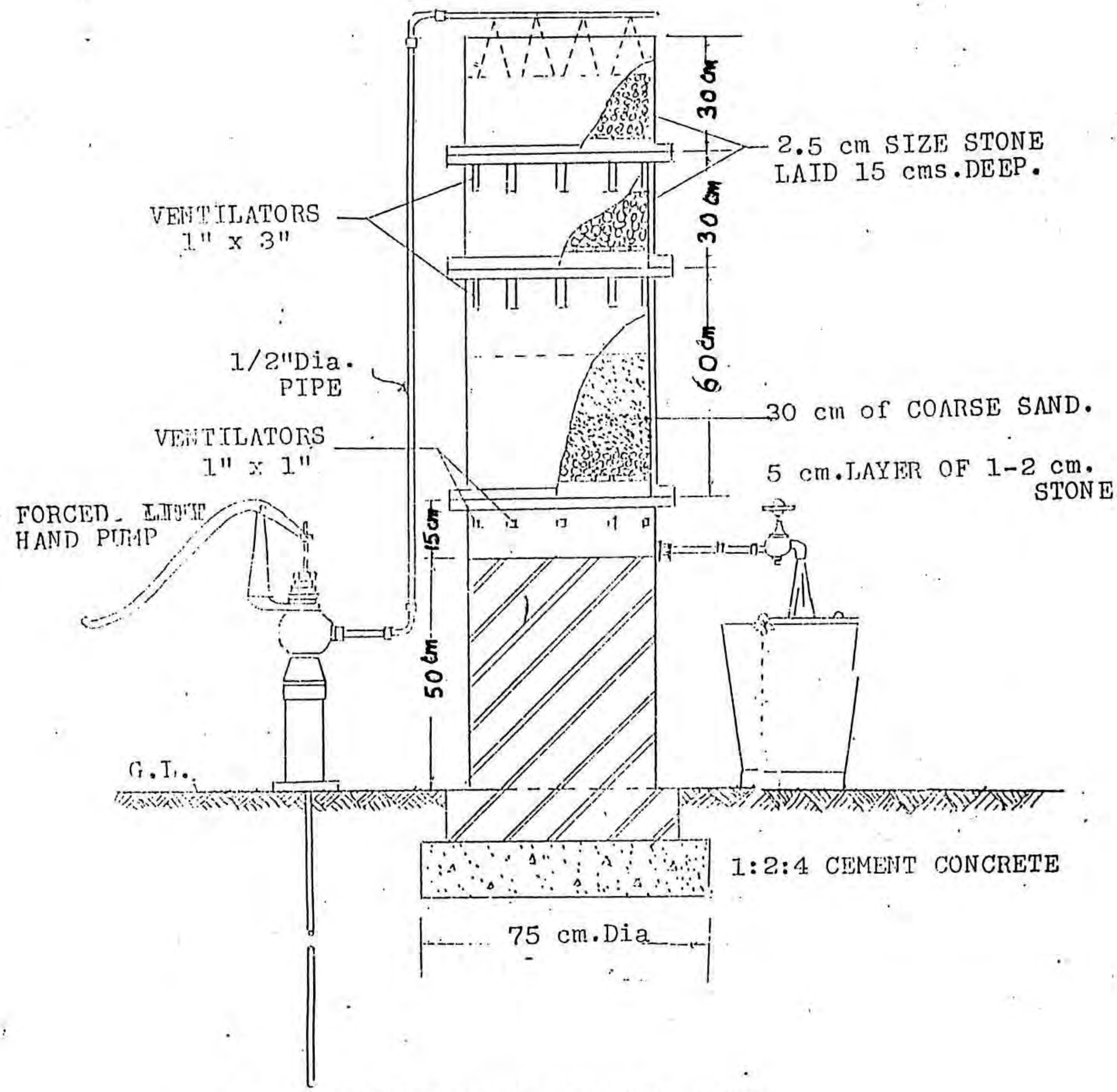


FIG 2.2 C-PHERI IRON REMOVAL UNIT

(CAPACITY - 40 GPH)

After initial laboratory experiments the field tests were carried out on tubewells at Howrah. The tubewells used for these studies are located at Onkarmal Jettia Road and College Ghat Road, Howrah, West Bengal.

Performance of the Plant:

Sampling of raw and treated water was done at the start and every 60 minutes thereafter. Iron content was measured by orthophenonthroline method. The analysis of raw water and treated water of the tubewells at Onkarmal Jettia Road and College Ghat Road are given in Table 2.1 [7].

Table 2.1 Analysis of Raw water and Treated Water of Tubewells

Parameters	Tubewell at Onkarmal Jettia road		Tubewell at College ghat Road	
	Raw water	Treated water	Raw water	Treated water
Period of sampling	21.2.70-3.3.70	240 min after the start of the plant	12.3.70-16.4.70	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

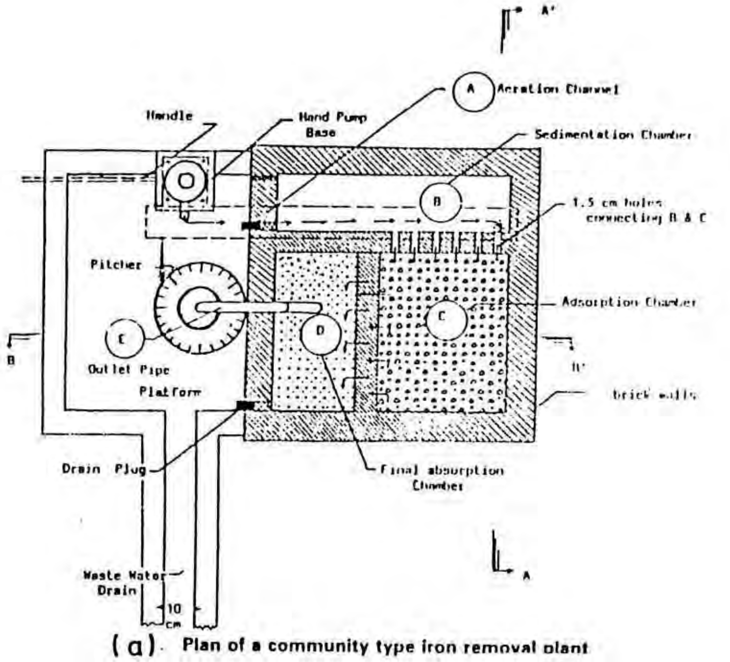
2.4.3 Iron Removal Plant Developed in Bangladesh

Design and Principle of the Plant

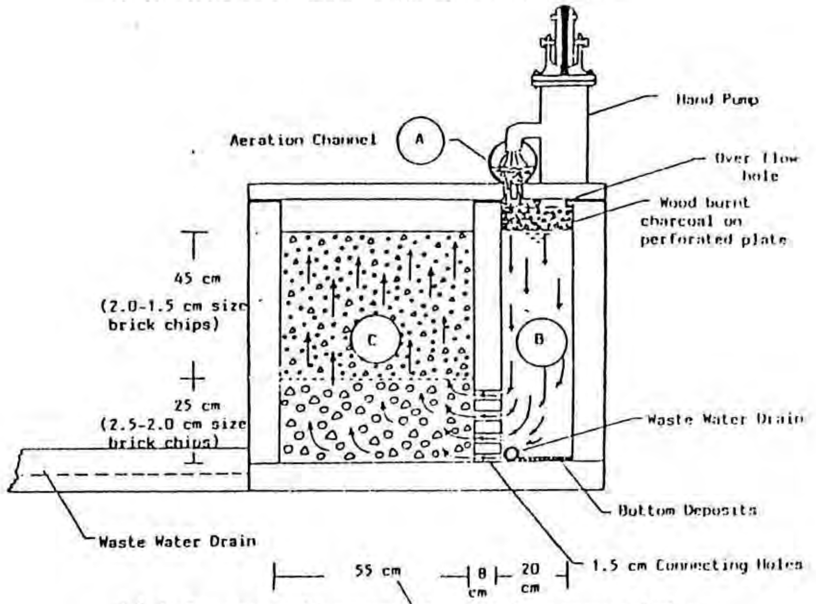
Ahmed and Smith [6] developed an Iron Removal Plant which consists of four major units, e.g. aeration channel, sedimentation, and two brick-chip adsorption chambers. The plan and sectional elevations have been shown in Fig. 2.3a, 2.3b and 2.3c.

The aeration channel, A, is made of 135 cm long, 10 cm diameter polyvinyl chloride (PVC) pipe, which is capped at the two ends but is provided with an inlet opening near the left end and an outlet opening near the right end of the pipe. The pipe top is finely slotted (8-10 slots, 5 cm long) allowing air to enter the pipe. One third of the depth of the pipe is filled with 1.5-2.0 cm size brick chips. Water discharged through the spout directly enters the PVC pipe and flows horizontally over the brick chips. The water is sufficiently aerated due to the increased contact surface with air. The aerated water then drips into the sedimentation chamber, via a thin layer of charcoal, through the slotted outlet opening of the pipe and a small hole in the cover of the sedimentation chamber located below the outlet opening.

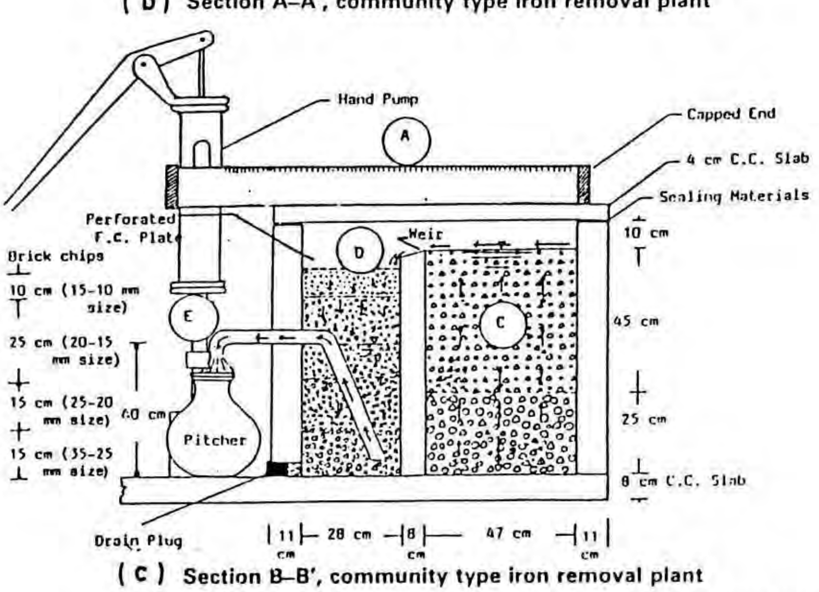
The sedimentation chamber, B, is a rectangular brick chamber and it provides a minimum detention time of 8 mins for the previously aerated water, during which some portion of the already precipitated iron flocs settle at the bottom of the chamber.



(a) Plan of a community type iron removal plant



(b) Section A–A', community type iron removal plant



(c) Section B–B', community type iron removal plant

FIG. 2.3 IRON REMOVAL PLANT DEVELOPED IN BANGLADESH

Water from the sedimentation chamber then enters the adjacent chamber, adsorption chamber.

The adsorption chamber, C, is a rectangular brick chamber filled with well graded, 1.5-2.5 cm brick chips in two layers. During the upward flow of water, the small iron flocs adhere to the surface of the brick chips, initially due to surface attraction. Water from the adsorption chamber flows over a weir and enters into the final adsorption chamber, D.

The final adsorption chamber, D, is filled with graded brick chips arranged in layers. A perforated ferrocement plate helps in distributing the incoming water uniformly over the bed. Treated water flows out from the lower portion of the chamber, through a 38 mm diameter PVC pipe (E).

Performance of the Plant

The plants have been found to be effective in removing iron from tubewell water. The normal capacity of a No. 6 hand pump tubewell is 20 l/min, but the yield capacity of the iron removal plant is 9 to 13 l/min. In 1983-85 period, in the light of previous performance, some design modifications were made, e.g. putting the aeration channel, A, under a ferrocement cover slab, using a perforated PVC separator between the different layers of coarse media in chambers C and D and providing a 25 mm gate valve at the end of the effluent pipe, E. The estimated cost of construction of each plant is about £50 (in 1983-85). The plants have been found to be very effective in removing soluble iron from tubewell waters to an iron concentration often less than 1 mg/l. A summary of inspection reports of some operating iron removal plants is presented in Table 2.2 [8].

Table 2.2 Summary of Iron Removal Data Obtained During Inspection of Iron Removal Plants Operating in Villages in Bangladesh [8].

Area	No. of plants monitored	Iron (mg/l)		Average number of beneficiaries
		Raw	Treated	
Sialkool	17	11	0.4	175
Sialkool	20	15	0.5	175
K. Haripur	20	15	1.1	200
K. Haripur	23	14	0.7	200
Sreemongal	35	15	0.5	250
Sreemongal	35	15	0.4	250
Sindurkhan	15	13	0.7	200
Sindurkhan	15	13	0.6	225

2.4.4 Iron Removal Plant developed by UNICEF, Dhaka

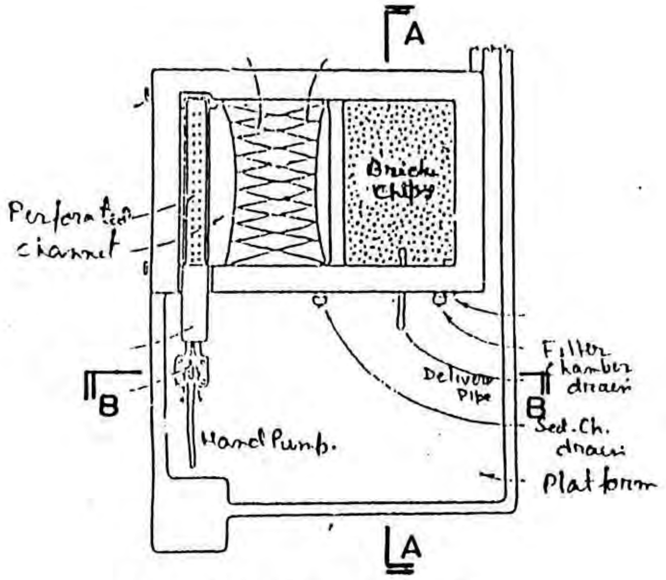
In 1986-87 UNICEF developed an Iron Removal Plant which was further improved [9]. The plan and sectional elevations are shown in Fig. 2.4a, 2.4b and 2.4c.

Design and Principle of the Plant

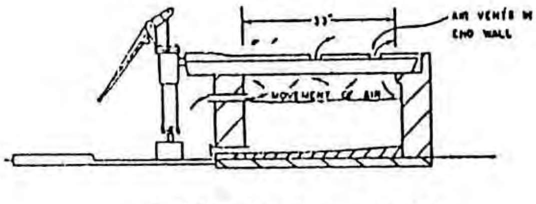
The plant consists of three units, e.g. perforated ferrocement channel, sedimentation chamber and brick chip filter. Water passes from the handpump into a ferrocement channel. Then water drops through the perforated base of the channel into the sedimentation tank and is aerated. Aeration causes soluble iron to precipitate out of solution, and form flocs of ferric oxide. Some iron flocs are removed as water flows across the sedimentation tank, by sedimentation or by adhesion to the walls. Water then passes over a dividing wall and down through the filter where the rest of the iron flocs are removed.

Performance of the Plant

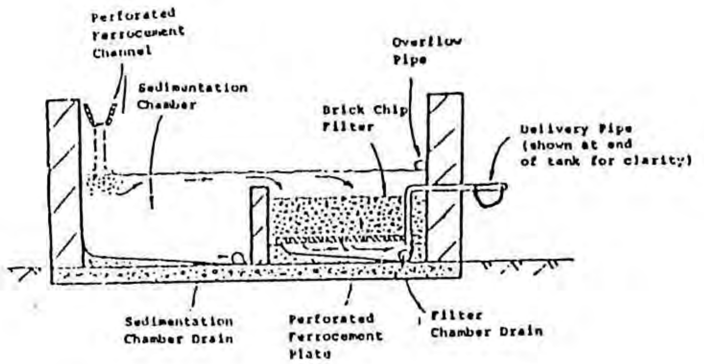
The improved iron removal plants have been found to be effective in iron removal and the filter run was also satisfactory. The performance results of five iron removal plants have been shown in Table 2.3.



a) PLAN OF THE IRP



b) SECTION B-B



c) SECTION A – A

FIG. 2·4 IRON REMOVAL PLANT DEVELOPED BY UNICEF, DHAKA.

Table 2.3 Performance of the Improved Iron Removal Plants (IRP) by UNICEF [9]

IRPs	Iron content (ppm)		Percentage removal of iron	Average filter run (days)	Approximate no. of beneficiaries
	Raw water	Average treated water			
Site 1	23	2.3	90%	11	60
Site 2	16	1.8	89%	13	60
Site 3	10	2.6	74%	18	150
Site 4	23	2.2	90%	20	80
Site 5	23	3.9	83%	9	200
Averages:	19	2.6	85%	14.2	110

Recently a study on the improved iron removal plants has been made in which 89.2% of the IRPs have been visited at least once during the period of April - June, 1990 by DPHE Officials [10]. This study shows that the iron removal is satisfactory. With an average cleaning interval of 12 days (with minimum of 5 days) the iron concentration has been reduced to 1.5 ppm (avg.) from 15 ppm (avg.). With the same interval of cleaning it has been observed that the higher the concentration in raw water the higher the concentration in treated water but it has not exceeded 2.5 ppm. The survey of beneficiaries shows that 19% use water for all purposes and 42% only for drinking and cooking and 42% like to assist in maintenance.

The recent survey statistics, performance and maintenance of the improved iron removal plants and community participation are listed in Tab 2.4, 2.5, 2.6 & 2.7.

Tab 2.4 Survey Statistics of the Improved Iron Removal Plants developed by UNICEF [10]

Name of District	No. of IRP		
	Installed	Surveyed	
		In use	Abandoned
Pabna (Total)	54	48	6
(%)	(100.0)	(88.9)	(11.1)
Sirajgong (Total)	114	92	22
(%)	(100.0)	(80.7)	(19.3)
Sylhet (Total)	1	-	1
(%)	(100.0)	-	(100.0)
Tangail (Total)	19	18	1
(%)	(100.0)	(94.7)	(5.3)
Grand Total	188	158	30
(%)	(100.0)	(84.0)	(16.0)

Tab 2.5 Survey of the UNICEF Improved Iron Removal Plants not in use [10]

Name of District	Number of IRP not in use	Number of IRP not in use because of					
		breakage and non-availability of spare IRP parts	lack of interest/ motivation	easy access of insects	break down of tube well	not a felt need	damaged during flood
Pabna							
Total	6	1	1	0	1	3	0
(%)	(100.0)	(16.7)	(16.7)	(0.0)	(16.7)	(50.0)	(0.0)
Sirajgong							
Total	22	10	4	2	1	4	1
(%)	(100.0)	(45.0)	(18.2)	(9.1)	(4.5)	(18.2)	(4.5)
Sylhet							
Total	1	0	1	0	0	0	0
(%)	(100.0)	(0.0)	(100.0)	(0.0)	(0.0)	(0.0)	(0.0)
Grand							
Total	29	11	6	2	2	7	1
(%)	(100.0)	(37.9)	(20.7)	(7.0)	(7.0)	(24.1)	(3.5)

Tab 2.6 Performance and Maintenance of the Improved Iron Removal Plants developed by UNICEF [10]

Name of District	Number of IRP in use and surveyed	Iron concentration ppm: Raw water (avg)	Iron concentration ppm: Treated water (avg)	Interval of cleaning days (avg)	Number of units with clean: Interior	Perforated channel	Settling chamber	Brick chips	Net	Over flow pipe	No. of IRPs with water level above partition wall: <3 inch	>=3 inch
Pabna												
Total	48	14.2	1.4	15	38	47	30	32	-	43	44	4
(%)	100.0				79.2	97.9	62.5	66.7	-	89.6	91.7	8.3
Sirajgong												
Total	92	15.54	1.48	12	72	91	47	60	-	87	87	5
(%)	100.0				78.3	98.9	51.1	65.2	-	94.6	94.6	5.4
Tangail												
Total	18	13.38	1.26	8	-	17	17	18	4	15	13	5
(%)	100.0				-	94.4	94.4	100.0	22.2	83.3	72.2	27.8
Grand												
Total	158	15.0	1.4	12	110	155	94	110	5	145	144	14
(%)	100.0				69.6	98.1	59.5	69.6	3.2	91.8	91.1	8.9

Tab 2.7 Use of Effluent Water of the Improved Iron Removal Plants for Different Purposes (Community Participation) [10]

Name of District	Number of households near IRP visited	No. of households use water for: All purpose	All purpose except bathing	Only drinking	Drinking and Cooking	No. of households believe that IRP water is better	Number of households want to: assist in maintenance	pay for maintenance
Pabna								
Total	48	9	18	1	20	48	13	7
(%)	(100.0)	(18.8)	(37.5)	(2.0)	(41.7)	(100.0)	(27.1)	(14.5)
Sirajgong								
Total	92	26	21	2	42	92	40	8
(%)	(100.0)	(28.3)	(22.8)	(2.3)	(45.7)	(100.0)	(43.5)	(8.7)
Tangail								
Total	18	0	0	2	15	17	14	17
(%)	(100.0)	(0.0)	(0.0)	(11.1)	(83.3)	(94.4)	(77.8)	(94.4)
Grand								
Total	158	35	39	5	77	157	67	32
(%)	(100.0)	(18.9)	(21.1)	(2.7)	(41.6)	(99.4)	(42.4)	(20.3)

2.4.5 Some Other Research Works on Iron Removal

Wong [11] 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 greensand filtration. These three processes have been described in Art. 2.8.1, 2.8.2 & 2.8.3.

Equina [12] has made a study on the Pretreatment of water containing iron and manganese using a horizontal-flow filter with crushed stone as the filter media. A regression analysis was made to determine the factor(s) affecting the filter performance. The length of the filter run was found to be the most important factor for the removal of iron from groundwater. At the filtration rate of 0.40 cu.m./sq.m./h, iron with the average concentration of 1.24 mg/l could be removed by 47%.

Czekalla, Mevius and Hanert [13] has shown that iron and manganese can be removed by microorganisms in rapid sand filters. They have shown that rapid sand filtration is the most widely used treatment method employed for reduced North German groundwater containing iron and manganese. The filters of 21 (in the main groundwater) treatment plants were examined by analyzing the backwashing material and the microbial settlement on the surface of the filter sand, using scanning electron microscopy, in particular with the aid of in situ time ongrowth experiments, which show the formation of the oxides. Following the formation of oxides from "statu nascendi", it was seen that metal ion oxidation only took place in direct contact with biological structures. The highest oxidation rates were achieved using a process called EPS iron oxidation (oxidation at Extracellular Polymeric Slime substances).

According to AWWA [5] iron and manganese are found in undesirable concentrations in more than one fourth of the municipal wells in the United States. Seekonk [14] installed a system to remove these metals from three of its municipal wells. Raw water from one of the wells contained 6.2 mg Mn/l. After treatment, the manganese concentration was below the Massachusetts standard of 0.05 mg/l.

Ogedengbe, Olasupo and Adeniji [15] have shown that powdered palm kernel shells have good adsorption capabilities (surface area = 2276 sq.m./gm), and can remove taste, color, turbidity, acidity and iron from well waters, thus rendering them palatable. A simple household filter using powdered activated palm kernel shells has been constructed and tested.

Zirschky and Carlson [16] have shown that overland flow, an effective wastewater treatment process, can also be used for potable water treatment. Many groundwaters contain excessive amounts of ferrous iron that result in a water of poor aesthetic quality. The natural reaeration 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.

Frankel [17] has developed an appropriate technology type of water filter for supplying drinking water to rural communities in Southeast Asia. The filter consists of two stages --- the first stage is made up of coconut fibers and the second stage uses burnt rice husks. In this type of filter coliform removal as well as iron removal can be achieved. A typical design of a filter plant, whose total construction cost amounts to less than US$2 per capita, is shown for a community of 800 persons. It is believed that the quality of effluent from this treatment process is reasonably good for most villages where investment in more expensive water treatment plants simply cannot be afforded.

Kibret [18] has shown that dry filter is one of the alternatives that can be applied for iron removal and the process uses the self purification capacities of iron bacteria. Investigations made on the pilot plants showed that iron removal process by dry filtration depends on the hydraulic load, filter depth, size of filter material, the development of the micro-organisms, and iron concentration in the raw water. Dry filter does not only remove iron but it also removes manganese, ammonia, carbon dioxide and provides sufficient oxygen supply to the treated water. The results obtained from the test plants were not below the standard limits except from the full scale production plant. However, complete removal of iron by dry filter is feasible provided the best possible favorable combinations of the factors on which iron removal depends are found.

In order to find effective processes for purifying polluted source water in Harbin City, Wang, Tian and Yin [19] tested various processes consisting of ozonation, sand filtration and/or GAC filtration and adsorption, i.e. ozonation, ozonation-sand filtration, ozonation-biological activated carbon, ozonation-sand filtration-biological activated carbon and biological activated carbon in a pilot plant of 8 cu.m./d capacity. In addition, a small plant of 500 l/d capacity was used to conduct comparative studies between two processes - ozonation and ozonation biological activated carbon as well as two types of carbon. The results have shown that, of the processes tested, both the processes ozonation-biological activated carbon and ozonation-sand filtration-biological activated carbon are most effective in removing various pollutants, including turbidity, color, iron, manganese, organic substances measured in COD, BOD and chromatograms, ammonium, nitrite and nitrate.

Bajracharya [20] has made a study which investigates the possibility of iron removal by a simple low cost filtration technique, using coarse sand of effective size 3 mm and proposes a simple filtering unit that can be constructed in conjunction with handpumps in iron prone areas. An attempt has also been made to determine the possibility of backwashing under low heads. The efficiency of the unit with different loading concentration has also been determined.

2.5 Chemistry of Iron

Iron (II) (Fe^{2+}) is chemically a reduced and soluble form which exists in a reducing environment (absence of dissolved oxygen and low pH). These conditions exist in groundwater and anaerobic reservoir water. When it is pumped from underground or an anaerobic hypolimnion, CO_2 and H_2S are released, raising the pH. In addition, water become exposed to air creating an oxidizing environment. The reduced iron starts transforming to its stable, oxidized, insoluble form of iron (III) (Fe^{3+}). The rate of oxidation of iron depends upon the type and concentration of the oxidizing agent, pH, alkalinity, organic content, presence of catalysts.

2.5.1 Solubility of Iron

The solution of iron-bearing minerals is often attributed to the action of carbondioxide in groundwaters. Most of the carbondioxide 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 (organic substances, hydrogen sulfide) capable of reducing the higher oxides of iron to the ferrous, Fe(II) states. Similar conditions are believed to be responsible for the solution of iron from the sediments of stratified lakes.

In natural ground water, soluble iron exists mainly in the bivalent state. Some trivalent ferric iron may also exist in solution especially in aquifers where low pH values are encountered. 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. According to Ghosh, O'Connor and Engelbrecht [21], 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 equilibria 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, however, the precipitation of basic carbonates, e.g. $[Fe(OH)_2.FeCO_3]$, with somewhat different solubility characteristics is probable, especially in the pH range of 8 to 11 [22]. 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 [21]. 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.

2.5.2 Effect of alkalinity on Iron Solubility

A rough comparison of the solubility of ferrous carbonate in water having the same hydrogen ion concentration, 10^{-7} M, but differing alkalinities, 50 and 500 mg/l $CaCO_3$ equivalent, can be obtained from the equilibrium expressions for the solution of ferrous carbonate and for the formation of carbonate ion [5].

$$FeCo_3(s) \longleftrightarrow Fe^{++} + CO_3^{--}$$

$$K_{FeCO3} = Fe^{++} + CO_3^{--} \qquad (2.1)$$

$$HCO_3^{-} \longleftrightarrow H^{+} + CO_3^{--}$$

$$K_2 = \frac{H^{+}CO_3^{--}}{HCO_3^{-}} \qquad (2.2)$$

Substituting Eq. (2.2) in Eq. (2.1) for CO_3^{--}, we obtain

$$Fe^{++} = \frac{K_{FeCO3}}{K_2}\,\frac{H^{+}}{HCO_3^{-}} = \frac{H^{+}}{HCO_3^{-}} \qquad (2.3)$$

Since most of the alkalinity is in the form of bicarbonate ion, the concentrations of bicarbonate are 10^{-3} M and 10^{-2}M, respectively.

Therefore when $HCO_3^- = 10^{-3}M$, $H^+ = 10^{-7}M$

$Fe^{++} = 10^{-4}M = 5.5$ mg/l Fe

and when $HCO_3^- = 10^{-2}M$, $H^+ = 10^{-7}M$

$Fe^{++} = 10^{-5}M = 0.55$ mg/l Fe

Equation (2.3) states that 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.

2.6 Chemical Oxidation

2.6.1 Oxidizing Agents:

There are many oxidizing agents, e.g. chlorine, chlorinedioxide, potassium permanganate etc.

Chlorine and chlorinedioxide

These gases are powerful oxidizing agents and can be used to oxidize iron. Normally only chlorine is found to be used since chlorine dioxide is expensive. The reactions with chlorine in the presence of calcium bicarbonate alkalinity are as follows:

$$2Fe(HCO_3)_2 + Cl_2 + Ca(HCO_3)_2 = 2Fe(OH)_3 + CaCl_2 + 6CO_2$$

According to Feachem, McGarry and Mara [23] 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 [23]. 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 dioxide (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:

$$3Fe(HCO_3)_2 + KMnO_4 + 7H_2O = MnO_2 + Fe(OH)_3 + KHCO_3 + 5H_2CO_3$$

The products of the reaction are manganese dioxide which precipitates to the surface of the filter media, ferric hydroxide which is also insoluble, potassium bicarbonate, and carbonic acid, which are soluble and remain in the effluent. The carbonic acid can be broken down into carbondioxide and water.

2.6.2 Kinetics of Iron Oxidation and Precipitation

Rate of Iron Oxidation

Various investigators have studied the rate of iron oxidation. All have concluded that the rate of ferrous iron oxidation is of the first order with respect to the ferrous iron concentration and the partial pressure of oxygen. In addition, the oxidation rate has been found to be strongly dependent on pH [21]. 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 [24]. In case of water having low pH, the pH value is increased by stripping carbondioxide or adding lime. Alternately, 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.

Rate of Iron Precipitation

When ground waters supersaturated with respect to ferrous carbonate are aerated, the pH increases because of the loss of carbondioxide, thereby further increasing the degree of supersaturation. As a result, the precipitate formed may be expected to contain both ferrous carbonate and ferric hydroxide. The rate of precipitation of iron would therefore be determined by the rate of oxidation of ferrous iron plus the rate of ferrous carbonate precipitation.

Equilibrium pH

Ground waters, although entirely devoid of dissolved oxygen as pumped from the ground, are supersaturated with CO_2. As a result, aeration increases the pH. In waters having low alkalinities 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.

2.7 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, the other may be called organic iron which is colored with humic acids that chelate the iron. Organic iron may be present in colored well waters as well as colored surface waters. Organic iron is also known as chelated iron. The first thing to do when examining a water that contains iron is to find out whether it is ordinary iron (inorganic) or the organic variety. Then according to the variety of iron the method of removal of iron should be selected.

2.7.1 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 CO_2 present can be determined from the pH and alkalinity. If there is a large amount of dissolved carbondioxide present in the well water it would be wise to aerate it first. In this way the free carbondioxide will be liberated and the pH will be slightly elevated.

The great majority of iron removal plants employ aeration, flocculation, sedimentation and filtration. In many instances oxidizing agents such as chlorine, chlorine dioxide, potassium permanganate etc. are added following aeration to aid in oxidation. Where the pH is too low for rapid oxidation, lime is added.

i) Aeration

Aeration is the treatment process whereby water is brought into intimate contact with air for the purpose of (a) increasing dissolved O_2, (b) reducing dissolved CO_2 and (c) removing various organic compounds responsible for taste and odor. In other words, it 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 supersaturation,
- the water temperature,
- the interfacial area of a gas contact and water exposure.

The most common gas transfer equation is represented as [24],

$$Ct = Co + (Cs - Co)\,[1 - \exp(- Kg\ t)]$$

where,

Ct and Co = concentration at time t = t and t= 0 respectively,

Cs = the saturation concentration at a given temperature,

Kg = proportionality factor, a function of A/C, the area of interface per unit volume of liquid.

Therefore, $Ct = Co + (Cs - Co)\,[1 - \exp(-kg\ A/C\ t)]$

where kg = gas transfer coefficient. For the adsorption of oxygen in centimeter per hour, following value has been reported [25], $kg \doteq 32.3 \times 1.018^{(T-20)}$. This value can be both higher and lower in different circumstances.

The above equation indicates that oxygen transfer can be optimized by controlling four major parameters:

i) Generating the largest practicable area, A, of interface between a given volume of water, C, and air.

ii) Inducing a long exposure time, t.

iii) Preventing the buildup of thick interfacial films to keep transfer coefficient, kg, high.

iv) Ventilating the aerator to maximize oxygen transfer.

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

$$Fe(HCO_3)_2 \xrightarrow{\text{aeration}} Fe(OH)_2 + 2CO_2$$

further aeration:

$$4Fe(OH)_2 + O_2 + 2H_2O \xrightarrow{\text{aeration}} 4Fe(OH)_3$$

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 [26]. 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 1 hour retention has been necessary [26]. 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. For rural plants there are four methods of aeration - spray aerators, cascades, inclined aprons and tray aerators.

Spray Aerators

According to Walker [26] when water is already under a pressure head of 7 m or more, as when discharged from boreholes, it can be sprayed into basins through nozzles of special design. The basin should be large enough to catch wind blown spray. Upto 75% of carbon dioxide can be removed in a spray aerator.

Cascades

Water is allowed to fall as a thin sheet over one or more concrete steps. It is stated that a single cascade with a 400 mm supply can aerate 9000 m^3 of water a day with 50% - 60% carbondioxide removal [26].

Inclined aprons

Water passes down as inclined channel fitted with studs or plates so that the flow is turbulent with a zigzag movement. 25% - 50% of carbondioxide may be removed here [26].

Tray Aerators

In these type of aerators water falls through a series of trays perforated with small holes. According to Walker [26] the area of the trays required varies between 0.015 and 0.045 m^2 per cubic meter of water passing through each hour. Tray aerators are often built in stacks of four to six trays giving a total height of 1.2-3m. It gives 30% - 60% removal of CO_2 [26].

All the aerators discussed above can increase the dissolved oxygen in water to a desired extent. Among these spray aerators dissolve maximum amount of oxygen into water.

ii) Flocculation

Flocculation is the process of gentle and continuous stirring of water for the purpose of forming flocs through the aggregation of tiny particles present in water. It is thus the method of forming flocs that can be readily removed by settling or filtration. The efficiency of the flocculation process is largely determined by the number of collisions between the particles per unit of time.

There are two types of flocculators in use, e.g. (i) mechanical flocculators and (ii) hydraulic flocculators. Mechanical flocculators are not feasible as these require extra power. In hydraulic flocculators, the flow of water is so influenced by small hydraulic structures that a stirring action results.

Typical examples of hydraulic flocculators are "gravel bed" flocculators. The particles come into contact with the gravels during converging flow and large flocs are formed.

The velocity gradient that is introduced into the bed is a function of (i) the size of the gravel (ii) rate of flow.

iii) Sedimentation

Sedimentation is the process of separation of suspended heavier particles from water by gravity settling. The basic theory of sedimentation assumes the presence of discrete particles. When such a particle is placed in a liquid of lower density, it will accelerate until a limiting terminal velocity is reached, then:

gravitational force = frictional drag force

Now, gravitational force, $F = (\rho_s - \rho_w) gV$

frictional force, $F_r = C_D A_c \rho_w V_s^2 / 2$

where, ρ_s = Density of the particle

ρ_w = Density of water

V = Volume of particle

A_c = X-sectional area of particle

V_s = Settling velocity of particle

C_D = Newton's drag coefficient

d = Diameter of the particle

Equating the above two equations,

$$v_s = \sqrt{\frac{2gV(\rho_s - \rho_w)}{C_D \rho_w A_c}}$$

For spherical particles, $V = pie*d^3/6$, $A_c = pie*d^2/4$

which makes the equation, $v_s = \sqrt{\frac{4}{3}\frac{g}{C_D}\frac{\rho_s - \rho_w}{\rho_w} d}$

The relationship between C_D and Reynolds number, R, shows that

for $R < 1$, $C_D = 24/R$

for $1 < R < 10^4$, $C_D = 24/R + 3/R^{0.5} + 0.34$

for $10^4 < R < 10^5$, $C_D = 0.4$ (turbulent zone)

In the case of water treatment the size and settling velocity is such that the Reynolds number hardly exceeds 1.

Therefore, putting $C_D = 24/R$, the equation for settling velocity becomes, $v_s = \frac{g}{18}\frac{\rho_s - \rho_w}{\mu} d^2$, which is Stoke's Law.

Ideal Sedimentation Basin

Considering a discrete particle with settling velocity v_0 which just enter the sludge zone at the end of the tank, shown in Fig. 2.5a.

$v_0 = h_0/t_0$

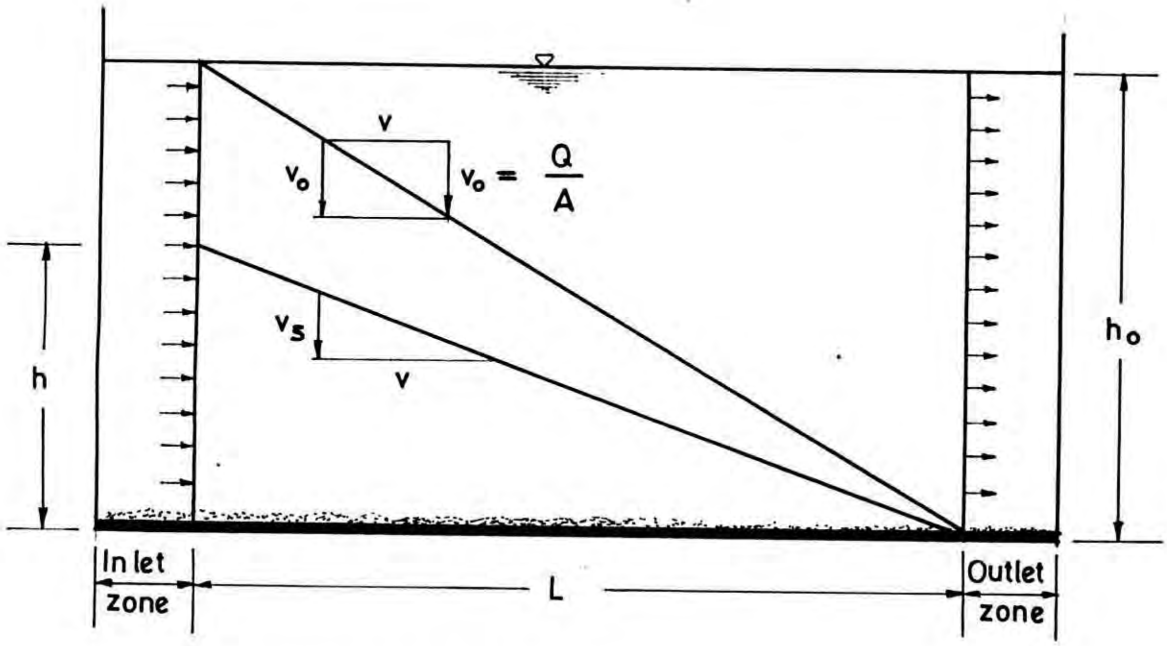


FIG. 2 5a DIAGRAM OF AN IDEAL SEDIMENTATION BASIN

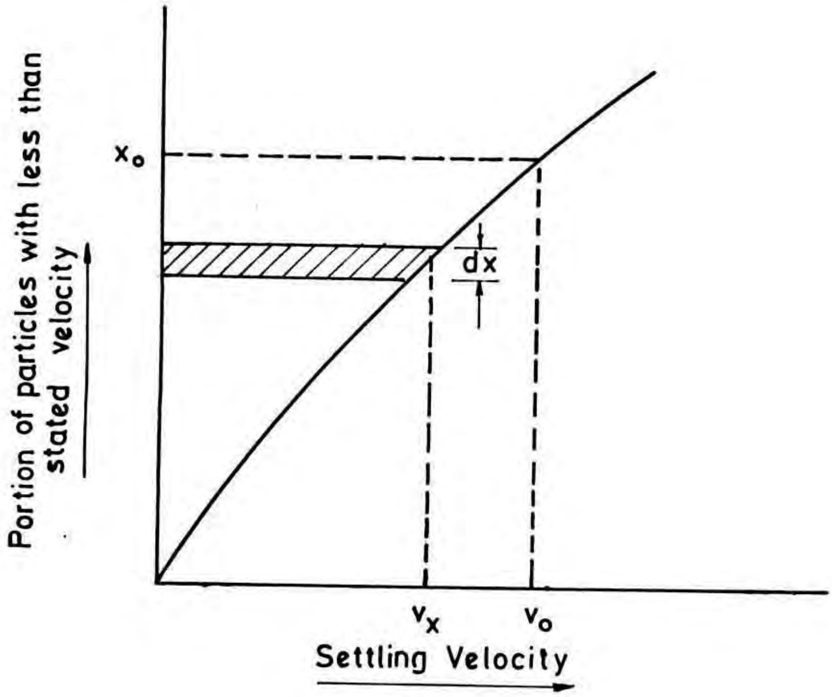


FIG. 2·5b SETTLING CHARACTERISTIC CURVE OF DISCRETE PARTICLES

$$t_o = \frac{\text{Volume of the tank (V)}}{\text{Flow per unit time (Q)}} = \frac{V}{Q}$$

$v_o = h_o Q/V = h_o Q/Ah_o = Q/A =$ Over flow rate

The tank will remove all the particles having settling velocity v_o or larger, which is independent of depth of the tank, dependent only on flow (Q) and the area of the tank in plan (A). From this concept, sedimentation basin should be constructed as shallow as possible to optimize the removal efficiency. Tube settlers or tank with false bottom are alternatives to shallow basins for higher efficiency in removing suspended solids.

The tank shown in Fig 2.5a will also remove the particles with settling velocity $v_s < v_o$ if the particles enter the tank at height h or lower, so that

$$h/h_o = v_s/v_o$$

Let Fig 2.5b represents the settling characteristic curve of a discrete particle suspension. The fraction of the particles from portion dx with v_x that will be removed is given by:

$$X = v_x/v_o * dx$$

The fraction of the total particles between 0 to X_o with $v_x < v_o$ that will be removed is

$$X = \int_0^{X_o} \frac{V_x}{V_o}\, dx$$

The particle removed with $v_x > v_0$ will be $= 1 - X_0$

The total particles removed from the suspension is

$$= (1 - X_0) + \frac{1}{V_0}\int_0^{X_0} V_x \, dx$$

iv) Filtration

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

Three types of filtration are in use, e.g.

i) Slow sand filtration (SSF)

ii) Rapid sand filtration (RSF) &

iii) Roughing filtration

In SSF, high quality of treated water is found, since bacteria is almost completely removed. Its installation is limited by operational problem, for example it can be operated satisfactorily with raw water of very low turbidity (20 NTU)[1].

RSF is quicker than SSF. Its efficiency in the removal of bacteria is less than that in SSF. Back washing is the main problem in RSF. Water of any turbidity can be used.

Roughing filtration uses much larger media than either SSF or RSF. The rate of filtration depends on (a) type of filter (b) the nature of the turbidity, and (c) desired degree of turbidity removal. Roughing filters are effective in removing suspended solids. The raw water of turbidity 20 to 150 NTU [1] is used to prevent too frequent clogging and to ensure continuous operation for an extended period of time.

According to Huisman, Sundaresan, Netto and Lanoix [27] a short comparison between Slow Sand Filter, Rapid Sand Filter and Roughing Filter can be made as follows:

Slow Sand Filter

Rate of filtration= 0.1-0.3 m/hour (2-7 $m^3/m^2/day$)

Medium size = 0.15-0.35 mm

Bed thickness = 1.0-1.2 m

Suspended matters are retained in the upper 0.5-2.0 cm of filter bed.

Rapid Sand Filter

Rate of filtration= 5-15 m/hour (120-360 $m^3/m^2/day$)

Medium size = 0.4- 1.2 mm

Roughing filter

The depth is divided into three layers; grain sizes of each layer are as follows:

1st layer= 10-15 mm

2nd layer= 7-10 mm

3rd layer= 4- 7 mm

Rate of filtration= 0.5-4 m/hour; but the rate may be upto 20 m/hour.

Another possibility is the use of **Horizontal filters.** The depth is normally taken from 1 to 2 m. The filter is divided into three zones, each 5 m long. The gravel sizes of each zone are 20-30 mm, 15-20 mm and 10-15 mm respectively. The horizontal flowrate is 0.5-1.0 m/hour.

2.7.2 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 [26]. 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 [26] 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 from a gas chlorinator (it often requires 5 or more mg/l).

The use of sodium hypochlorite is not always as effective as gaseous chlorine since the hypochlorite is made from caustic soda and does not lower the pH. 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.

2.8 Iron Removal 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, detention, filtration (with supplementary chlorination and/or the addition of lime).

b) Oxidation by potassium permanganate, chlorine, or chlorine dioxide followed by filtration.

c) Calcined magnesite - diatomaceous earth filtration

ii) Ion exchange

a) Ion-exchange (zeolite) softening

b) The manganese - zeolite process

iii) Stabilization with polyphosphates.

The methods can be renamed and rearranged as:

i) a) Aeration - filtration method

b) Chlorination - filtration method

c) Potassium permanganate-manganese greensand filtration method

ii) a) Water softening method

b) Manganese zeolite process

iii) Stabilization method

2.8.1 Aeration-filtration Method

This method was studied and developed by Wong [11]. 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.

2.8.2 Chlorination Filtration Method

According to Wong [11], 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 [$Ca(OH)_2$] 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.

2.8.3 Potassium - Permanganate - Manganese Greensand Filtration Method

According to Wong [11], equipment for this process is similar to that for chlorination-filtration process but differs in the primary oxidizing agent and the filter media. 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 greensand is a mineral capable of exchanging electrons and thereby oxidizes iron to its insoluble and filterable states. The greensand has the ability to oxidize and to filter. Its oxidative capacity is limited and the bed must be regenerated with $KMnO_4$ after backwashing. This process has an advantage in that the greensand can act as a buffer. If the feed of $KMnO_4$ does not oxidize all the soluble iron, the greensand 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 greensand.

Major disadvantages of this process are high operational costs associated with chemical requirements and filter bed deterioration if the pH falls below 7.1 [11]. In some cases, chlorine is used in conjunction with $KMnO_4$ to reduce chemical costs.

2.8.4 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.

2.8.5 Manganese Zeolite Process

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

$$Z - MnO_2 + Fe^{2+} \text{ ------ } Z - Mn_2O_3 + Fe^{3+}$$

$$Z - Mn_2O_3 + KMnO_4 \text{ ----- } Z - MnO_2 \text{ (Regeneration)}$$

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 greensand.

2.8.6 Stabilization Methods

The alternative to iron removal is stabilization or dispersion. According to Clark, Viessman and Hammer [28] sodium hexametaphosphates 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 poliphosphate 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.

2.9 Preventive Treatment of Iron

Preventive measures may sometimes be used with reasonable success. Sodium hexametaphosphate 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.

CHAPTER 3
DESIGN AND CONSTRUCTION OF THE IRON REMOVAL PLANT

3.1 Introduction

Numerous iron removal plants had been constructed since 1874 in the world [5]. In Bangladesh, attempts were taken to remove soluble iron from groundwater sources. Organizations like DPHE, UNICEF etc. constructed many iron removal plants in the iron problem areas of Bangladesh. But due to the lack of proper maintenance facilities of these plants, a large number of plants were left abandoned [1]. Now the purpose of this study lies with the design of a low cost Iron Removal Plant associated with adequate maintenance facilities.

3.2 Design of the Plant

The plant primarily designed is a community type iron removal plant. The plant consists of

- an aeration chamber
- a flocculation chamber
- a simple sedimentation tank
- a filtration chamber

3.2.1 Aeration Chamber

Chemical oxidation was avoided because of high cost and complexity in use. To aerate raw water an intimate contact between water and air should be achieved and it can be obtained in a number of ways which have been discussed in Art. 2.7.1.

According to Walker [26] spray aerators can remove upto 75 percent of CO_2, cascades can remove about 50-60 percent of CO_2. But these are costly and require a large area which is not possible to arrange in a small iron removal plant for hand tubewell. Besides, stoichiometrically only 1 mg dissolved O_2 is required to oxidize 7 mg of iron which can be calculated from the following relationship [29]:

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

(56 mg) (8 mg)

i.e. 7 mg/l of Iron is oxidized by 1 mg/l of oxygen.

Since aeration is a function of contact time and interfacial area, both can be increased by the use of tray aerator.

Tray aerator helps in aeration by the following ways:

i) Large surface area of tray provides sufficient contact time between air and water.

ii) An weir at the top edge of the aerator causes water to cascade down and flow uniformly over the tray in a thin layer. Thus it enhances contact between air and water.

iii) Coarse gravels randomly placed over the tray produce finer dispersion of water and thus increase interfacial area and help in aeration.

iv) The tray can be provided with undulations which cause the flow to create thin films and increase the contact between air and water. Hence tray aerator was selected and designed for the plant.

Design of Aeration Tray

Ahmed [3] has prepared a design chart for aeration tray for field use in which it is found that,

Area of aerator, A= 777 Q in cm^2

Volume of gravel, V= 166 Q in cm^3

where, Q= in liter/min

At the construction site, the tubewell was found to have an average yield of 20 liters/min.

So, Area of the aerator, A= 777*20

= 15540 cm^2

In the flexible pipe which would connect the spout of the tubewell to the inlet of the plant, aeration is supposed to occur to some extent. So the surface area of the flexible pipe should be taken into consideration.

Surface area of the flexible pipe (8 cm dia, 75 cm length)

= 2*pie*r*l= 2*3.141*4*75= 1885 cm^2 = 2000 cm^2

Since during the withdrawl of raw water from the aquifer some amount of oxygen was found to get dissolved into water the area of aeration plate may be smaller than the design area. The dissolved oxygen concentration of raw water was found to be 3 mg/l. The required dissolved oxygen is approximately 8.5 mg/l. So around 36% of the requirements of dissolved oxygen is achieved during the withdrawl of raw water. So 36% of the design area may be omitted from consideration.

Hence the required area of the aerator becomes

= (15540-2000-.36*15540) cm^2

= 7945 cm^2

This area can be furnished with an aeration plate of size **91 cm * 88 cm.**

According to Ahmed's design chart [3]

Volume of the gravel (1.84cm dia), V= 166*20

= 3320 cm^3

Total number of gravels= 3320/(4/3*pie*$(1.84/2)^3$)= 1018 nos.

Total surface area of gravels= 1018*4*pie*$(1.84/2)^2$= 10826 cm^2

Considering around 25% of the surface area of each gravel to be embedded into the plate, effective surface area of the gravels becomes= 10826*.75= 8120 cm^2

For finer dispersion of flow several undulations may be constructed over the plate alongwith the randomly spread angular gravels. Three undulations may be constructed transversely over the plate. Assuming the height of the undulations to be 3 cm and average width to be 6 cm, total surface area of the undulations can be calculated as, 3*91*(3+6+3)= 3276 cm^2.

So total surface area provided with the randomly placed gravels

= (8120-3276) cm^2

= 4844 cm^2

Number of gravels required (using 2.5 cm dia gravel)

= $4844/(4*pie*(2.5/2)^2$

= 247 nos.

A large weir can be constructed at the top end of the aeration plate which would make finer dispersion of water particle and thus lessen the amount of gravel required. On this basis only 24 gravels may be embedded partially into the aeration plate, 6 gravels randomly in each channel formed by the undulations.

3.2.2 Flocculation Chamber

The precipitates formed by aeration are of very small size and not heavy enough to settle down due to gravity. A study by Sung and Forbes [30] shows that when ferrous iron solution with initial concentration on the order of 2-5 mg/l is oxygenated, the precipitate is roughly concentrated in the submicron size 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 of 102 lpd/m^2, a factor of 400 lower than that of a typical sedimentation basin. So to enhance the settling characteristics they proposed to promote coagulation/flocculation before settling.

The mechanical flocculators (discussed in Art. 2.7.1) were not used as they would require extra power. Baffle flocculators require large number of baffles which are so costly to construct. Rotating paddles or impellers need electricity which is not feasible in the rural community.

The hydraulic flocculator e.g. gravel-bed flocculator which consists 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 and due to sudden drop in velocity.

So a gravel-bed flocculator was decided to adopt before sedimentation and due to the unavailability of gravel in project area, locally available brick chips were used as coarse media.

Design of Coarse-media Flocculator

Ahmed [3] has derived two formulae for the design of a coarse-media flocculator which are shown as,

$$G = 8.38*(Q/a)*(S/d) \qquad \text{--------------(1)}$$

$$Gtd = 3.354*(S/d)*L \qquad \text{--------------(2)}$$

where, G= Average velocity gradient (sec^{-1})

Q= Flow rate (ml/sec)

a= X-sectional area of the flocculator (cm^2)

S= Slope factor= $6/\psi$

d= Dia of coarse media (cm)

td= Detention time (sec)

L= Length of the flocculator (cm)

Gtd= Camp number

Angular brick chips were supposed to be used as coarse media in the flocculator. According to Carman [31] the shape factor of angular brick chips is 7.7. Assuming a camp number of 550 and a x-section of 90 cm * 30 cm (this size of the flocculator was chosen to adjust with the size of the aeration tray), the size of the gravel can be determined with the eqns (1) and (2).

Camp number, Gtd= 550

Detention time of the flocculator, td= 2.2 min (Art. 4.7.3)

= 132 sec

So, G= 550/132= 4.166

From eqn. (1)

$$G= 8.38*(Q/a)*(S/d)$$

Here, Q= 20 liters/min

a= (90*30) cm^2

face velocity, Q/a= 0.1234 cm/sec

Due to clogging face velocity increases, so multiplying it by 1.3, the actual face velocity becomes= (.1234*1.3) cm/sec

= .161 cm/sec.

Now putting the values in eqn. (1),

$$4.166= 8.38*.161*7.7/d$$

or, $d= 2.5$ cm

Hence the range of coarse-media can be taken between 2.5 cm and 3.75 cm.

Putting the values in eqn. (2),

$$550= 3.354*7.7/2.5*L$$

or, $L= 53.24$ cm

Hence the length of the flocculator may be taken 55 cm.

3.2.3 Sedimentation Chamber

Two major classifications of sedimentation basin are:

i) Horizontal flow unit

ii) Upflow unit.

Since horizontal flow unit requires large area, so an upflow sedimentation unit was designed for plain sedimentation. The sedimentation chamber receives water from flocculation chamber in which large flocs are formed. These flocs settle down due to gravity in the sedimentation tank.

Design of Sedimentation Chamber

Overflow rate or settling velocity,

$$v_s = Q/(B*L) \text{ in } cm^3/cm^2/min$$

where, Q= Flow rate (cm^3/min)

B= Width of sedimentation chamber (cm)

L= Length of sedimentation basin (cm)

Ahmed [3] has shown that a range of overflow rate in between 1.25 and 1.50 $cm^3/cm^2/min$ may be selected for the design of a sedimentation tank.

Taking v_s= 1.50 $cm^3/cm^2/min$,

$$1.5 = Q/(B*L)$$

Here, Q= 20 liters/min

= 20000 cm^3/min

So, $1.5 = 20000/(B*L)$

or, $B*L = 13333.3 \ cm^2$

Around 40% removal of iron precipitates is expected to be done in the filtration chamber, So the remaining 60% removal is assumed to be done upto the sedimentation chamber.

So, B*L= 13333.3*0.60= 8000.0 cm^2

But at the bottom of the flocculation chamber settling of the iron precipitates occur to some extent. The surface area of the bottom of the flocculation chamber = 90*30 = 2700 cm^2

So, the required B*L= 8000.0 - 2700.0= 5300.0 cm^2

The settling of the iron precipitates occur to some extent at the bottom of the sedimentation chamber also. So the effective surface area of the sedimentation chamber becomes= 5300.0/2 = 2650.0 cm^2 = 2700 cm^2.

Hence the size of the sedimentation chamber may be taken=90 cm *30 cm.

A depth of 55 cm is taken to adjust with the depth of the adjacent chamber for flocculation.

3.2.4 Filtration Chamber

There are three types of filter, e.g.

- -- Slow sand filter (SSF)
- -- Rapid sand filter (RSF)
- -- Roughing filter

Though SSF is simple, its filtration rate is low. In the present case water to be filtered is ground water, so supreme bacteriological water improvement is not required which SSF can provide best. Moreover SSF clogs rapidly.

On the other hand the technical level of rapid sand filter stands in contrast to the simple plant to be constructed in the rural areas. So for convenience, "Roughing filtration" technique being very simple and effective and less costly was selected.

The factors which stand in favor of roughing filter are as follows:

-- It is simple in operation and cheaper in cost.

-- It uses gravel and uses much larger media than either SSF or RSF.

-- Filtration rate in roughing filter is relatively high because of large pore spaces in filter bed which is not likely to clog rapidly.

-- The solid materials retained by the filters are removed by flushing easily.

Design of the Roughing Filter

Since the flow is intermittent and the quantity of water pumped per journey is only a small fraction of the total capacity of the filter bed, according to Ahmed [3] the roughing filter bed may be designed considering the average rate of flow of 375 liters/hour.

Assuming a filtration rate of 1.40 m/hour, the required surface area = 375000/140= 2679 cm^2 = 2700 cm^2

So the size of the filter bed may be taken = 90 cm * 30 cm.
The size of the filter media may be assumed = 6 mm- 15 mm.
The height of each filter = 55 cm.

The plan and sectional elevations of the plant have been shown in Fig. 3.1, 3.2 and 3.3.

3.3 Construction of the Plant

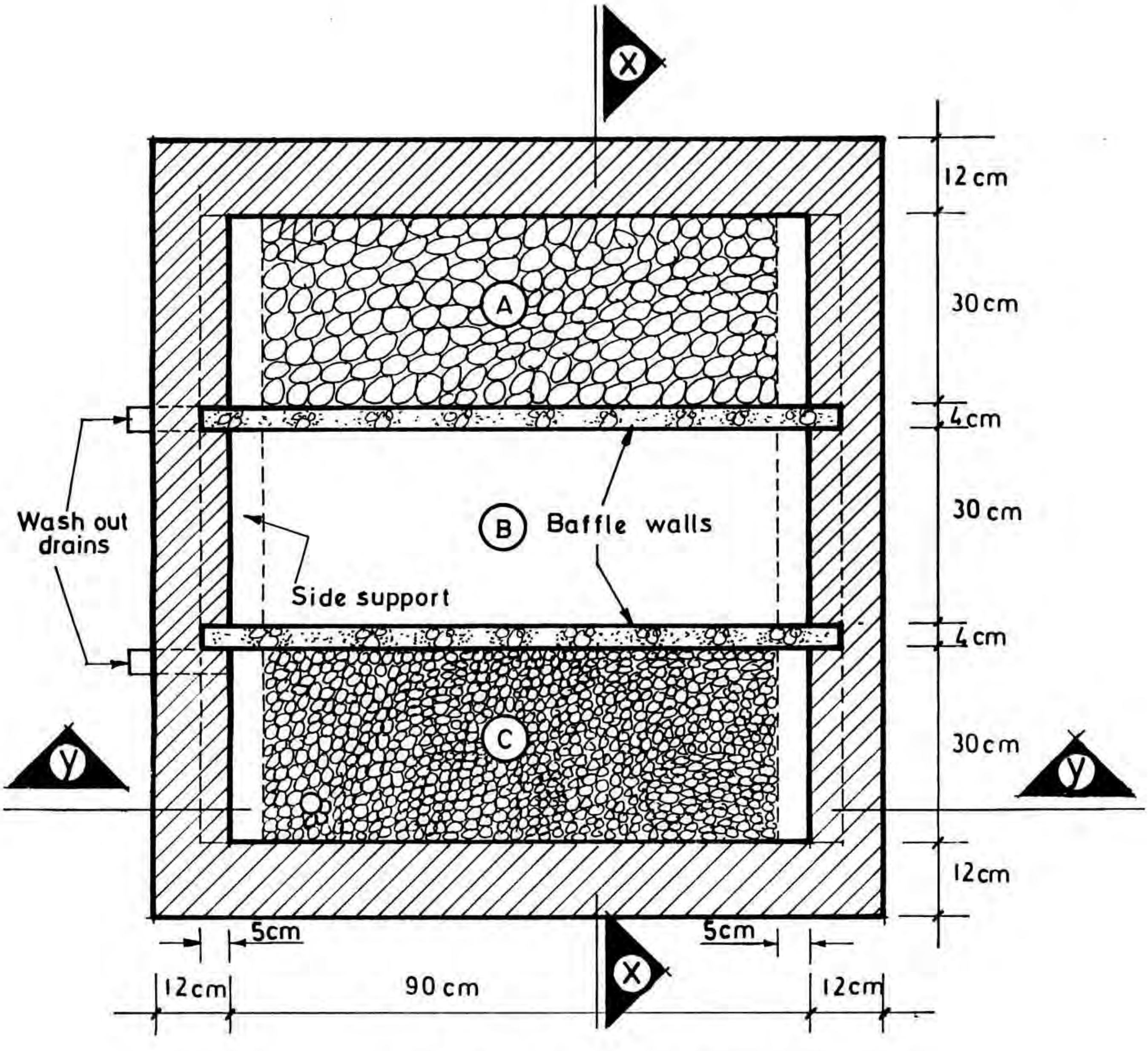
The plant consisted of many components. Some of the components were precast and the others were constructed at the plant site. The plan and elevations of the precast members have been shown in Fig. 3.4.

The precast members were:

- Aeration tray - 1 no.
- Baffle walls - 2 nos.
- Perforated plates - 3 nos.
- Cover slabs - 2 nos.

The cast in-situ members were:

- Main plant chamber - 1 no.
- Inlet pipe - 1 no.
- Outlet pipe - 1 no.



(A) FLOCCULATION CHAMBER

(B) PLAIN SEDIMENTATION CHAMBER

(C) FILTRATION CHAMBER

FIG. 3.1 PLAN OF THE IRON REMOVAL PLANT

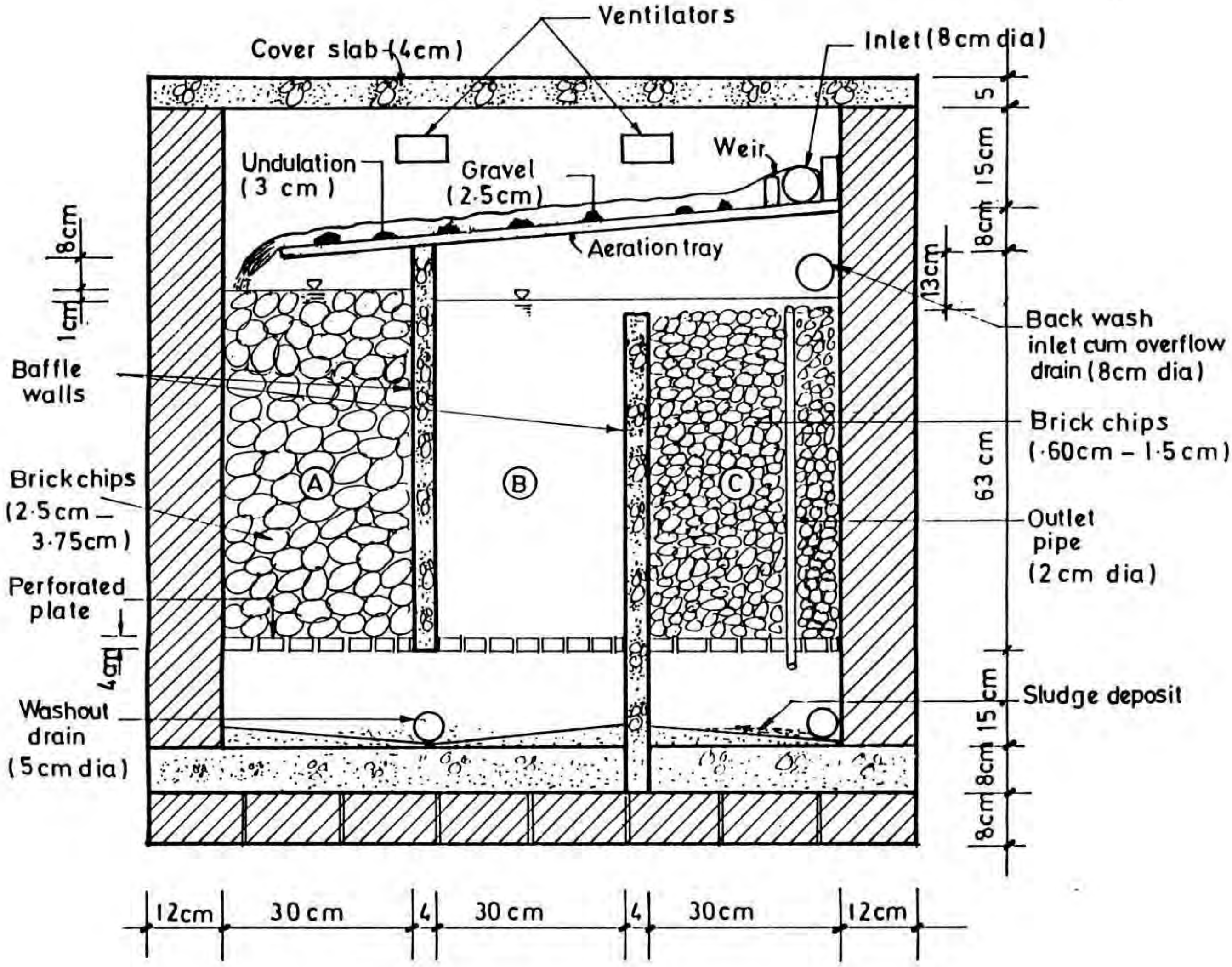


FIG. 3·2. LONGITUDINAL SECTION X–X OF THE PLANT

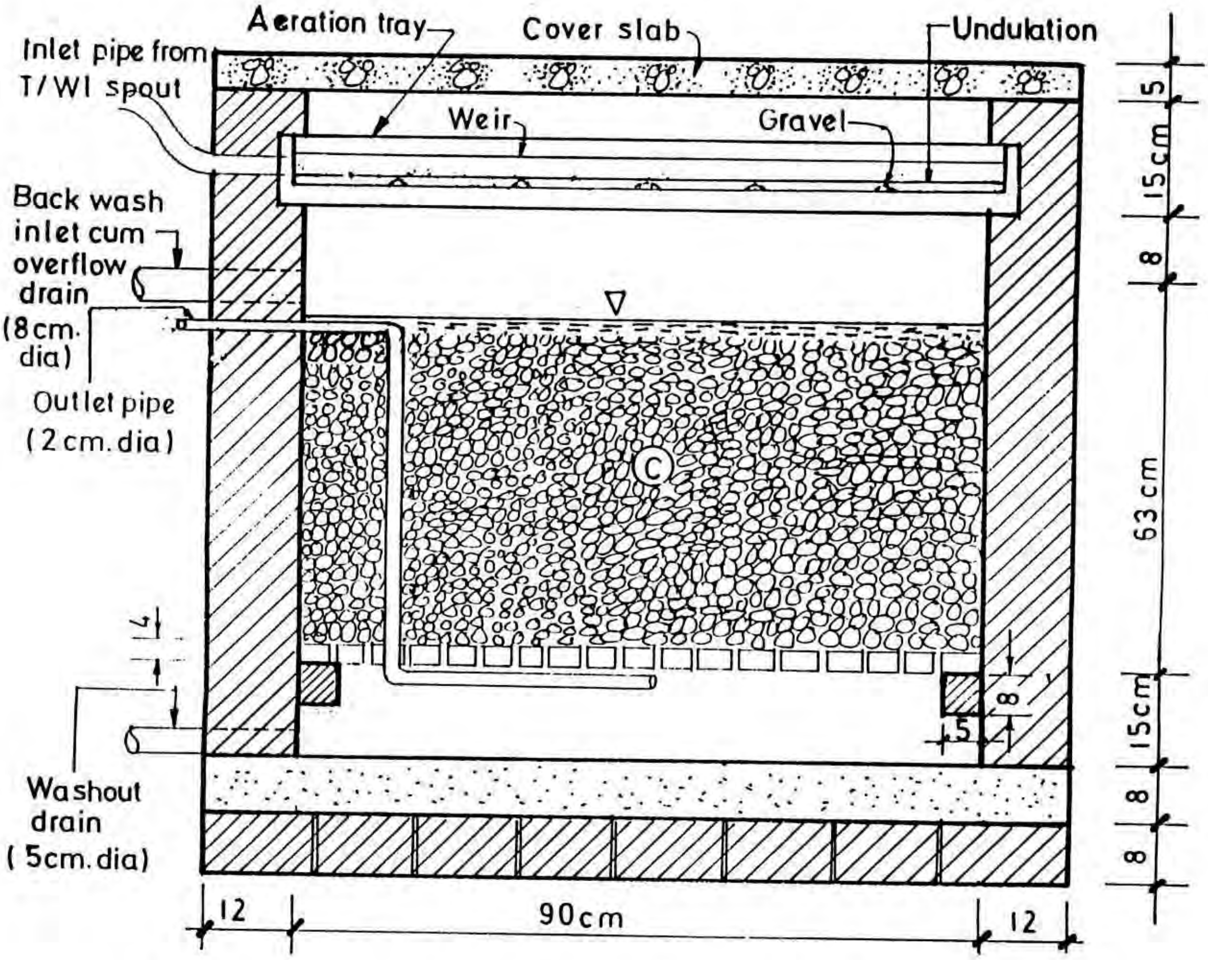


FIG. 3.3a TRANSVERSE SECTION Y – Y OF THE PLANT

FIG, 3.3b T/WL SPOUT AND THE FLEXIBLE PIPE CONNECTION

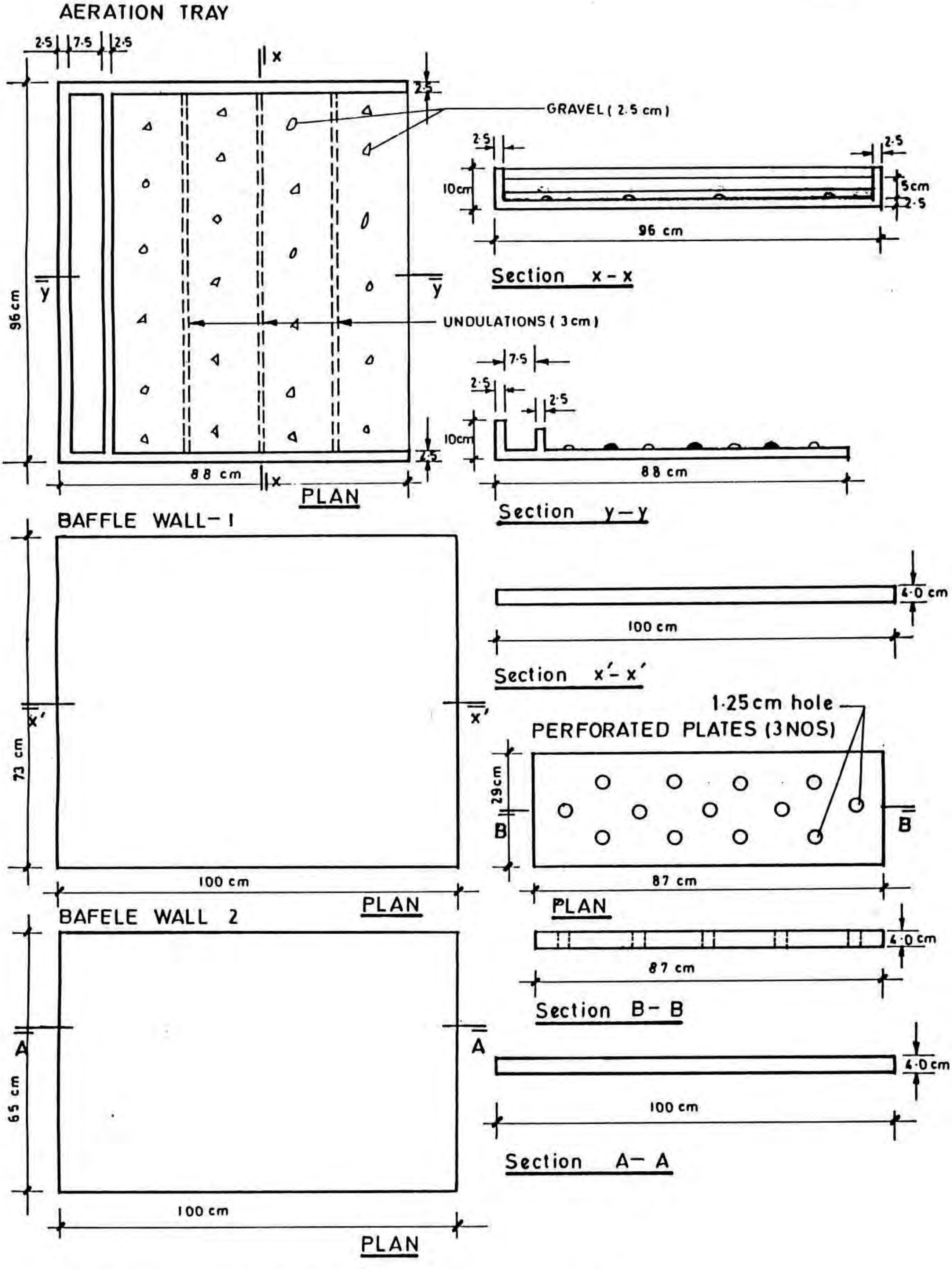


FIG. 3·4 PRECAST MEMBERS OF THE PLANT

- Drain wash pipe - 2 nos.
- Back wash cum over flow pipe - 1 no.
- Test pipe - 2 nos.

The wooden molds of all these components were constructed in the woodshop.

3.3.1 Aeration Tray

The aeration tray (2.5 cm thick) was cast in the laboratory with cement concrete (1:2:3) reinforced with wire mesh (16 gauge). Three undulations were constructed over the tray and 24 nos. of brick chips (2.5 cm) were embedded partially into the tray.

The purposes of the aeration tray were:

- to aerate the raw water coming from the tubewell.
- to form insoluble iron precipitates from soluble ferrous iron present in tubewell water.

3.3.2 Baffle Walls

Baffle walls (4 cm thick) were cast in the laboratory with cement concrete (1:2:3) reinforced with wiremesh (16 gauge).

The purpose of the baffle walls was:

- to create different chambers for flocculation, sedimentation and filtration.

Two baffle walls were used in the plant (Fig. 3.4).

3.3.3 Perforated Plates

Perforated plates (4 cm thick) were cast in the laboratory with cement concrete (1:2:3) reinforced with wire mesh (16 gauge). The plates were perforated with mechanical device.

The purposes of the perforated plates were:

- to create chambers at the bottom for scum deposit.
- to support the aggregates contained in the chambers.

Three perforated plates were constructed for the plant.

3.3.4 Cover Slabs

The cover slabs (4 cm thick) were precast in the laboratory with cement concrete (1:2:3) reinforced with wire mesh (16 gauge).

The purpose of cover slabs was:

- to cover the top of the whole plant as a prevention against any contamination from outside sources.

Two cover slabs were constructed each having a dimension of 114 cm * 61 cm.

3.3.5 Main Plant Chamber

The main plant chamber was made of brick masonry and supported on a brick soling (8 cm) having 8 cm cement concrete on the top.

3.3.6 Inlet Pipe

A flexible pipe of 8 cm dia. was used as an inlet and it was connected to the spout of the tubewell with a clip.

3.3.7 Outlet Pipe

2 cm dia. PVC pipe was used as outlet pipe. Three pipes were connected with two elbows to form the outlet pipe.

3.3.8. Drain Wash Pipe

Two PVC pipe of 5 cm dia. with cap were used as drain wash pipes. They were placed at the bottom to remove settled solids and scum from time to time. One of the drain pipes was placed at the mid-point of flocculation and sedimentation chamber, and the other at the far end of the filtration chamber.

3.3.9 Backwash Cum Overflow Pipe

A 8 cm dia PVC pipe was used for this purpose. When the plant became clogged with iron precipitates, the backwash cum overflow pipe was used for back washing. When the level of water rises up the allowable limit (the limit beyond which mixing of water of different chambers would take place), then the same pipe is used as overflow pipe. The center of this pipe was at a height of 74 cm from the bottom of the plant.

3.3.10 Test Pipes

Three plastic pipes of 1 cm dia. were used as test pipes for the purpose of collecting sample for test and analysis.

After the construction the plant showing different chambers has been presented in Plate No. 1 and 2.

Plate No. 1 Iron Removal Plant showing Different Chambers with Media

Plate No. 2 Iron Removal Plant showing the Aeration Chamber

CHAPTER 4
METHODOLOGY

4.1 General

The research includes visits to the iron problem areas, measurement of the existing iron concentration of tubewell water, selection of the site where the plant would be constructed, design and construction of the plant, sampling, laboratory test and detail analysis of the data. This chapter describes site survey, site selection, construction of the plant, working principle of the plant, sampling, laboratory test and analysis of data.

4.2 Survey of the project area

In consultation with the department of public health engineering several iron problem areas were selected and it was decided to visit those places with the help of the Sub-Assistant Engineer and two tubewell mechanics of the respective sites. The selected iron problem areas were visited and surveyed and the iron concentration of different hand pump tubewells were measured. Simultaneously the heights of the tubewells were also taken to adjust with the plant height. The primarily surveyed areas were the surrounding places of Dhamrai Bazar, Kalampur Bazar, Baratia, Dhulibhita and Sutipara.

4.3 Selection of the Tubewell Site

A construction site was selected from the primarily surveyed iron problem areas on the basis of iron concentration of tubewell water and the spout height of the tubewell. The sites where the iron concentration was above 3 mg/l and the spout height was above 63 cm were taken into consideration. The site distance was also another controlling factor in the site selection. The finally selected site was at the village of Baratia adjacent to Kalampur Bazar where the iron concentration of the tubewell water was 20 mg/l and the spout height was 80 cm.

4.4 Construction of the Plant

Some of the components of the plant were precast and the rest were constructed at the site. The precast members were carried to the construction site prior to the construction of the whole plant. After buying bricks, cement, sand and other accessories necessary for the construction of the plant, the construction work was begun. At first the foundation trench was excavated. Then a 8 cm brick soling was laid on the base over which a 8 cm concrete layer was provided to prevent seepage or any kind of leakage at the bottom of the plant. After three days of curing of the base the boundary wall was masoned. During the masonry work the supporting edges were also extended to support the perforated plates used for holding khoa for flocculation and filtration. Supporting edges were also built to support the aeration tray.

After the construction and sufficient curing the perforated plates and baffle walls were placed and watersealed. Then both the outer and inner sides of the plant were plastered and net cemented (grouted) to prevent leakage. Finally the aeration tray and cover slabs were placed on the top of the plant. Then the hose pipe was connected between the spout of the tubewell and the inlet of the plant. A drain was obtionally constructed to connect the drain pipes of the plant with it and also to facilitate the drainage of the excess water.

4.5 Working Principle of the Plant

Raw water from the tubewell flows to the narrow channel of the aeration tray through the hose pipe and overflows the weir. As a result thin film of water is formed and it comes in contact with air and the ferrous iron present in water is oxidized into ferric iron. The oxidation process is enhanced when the thin film advances over the undulated aeration tray over which gravels were also randomly spread. Some of the precipitates of ferric iron are left over the aeration tray and the rest enter the flocculation chamber. In this chamber the small flocs become larger conglomerating with each other and some of the precipitates are separated there. Then water with the remaining precipitates enters into the sedimentation chamber where the heavier flocs settle down due to gravity. Water then comes to the filtration chamber. In this chamber almost all the precipitates become separated and iron free water comes through the outlet pipe.

4.6 Sampling

4.6.1 General

A sample is a part taken from a large quantity and is presented as the representative of the whole amount. It is considered to be the representative of the whole, because subsequent conclusions, decisions and actions depend on the result of the sample initially collected. So the sampling technique must assure that the representative samples are collected and observed accurately.

4.6.2 Sampling Points

Sampling location is the point from which a sample is collected to represent the characteristics of the whole amount. In the present case, five locations were selected to collect the sample.

These were:-

- Inlet of the plant
- End of aeration tray
- Bottom of flocculation chamber
- Top of sedimentation chamber
- Outlet of the plant

The sampling points has been shown schematically in Fig. 4.1.

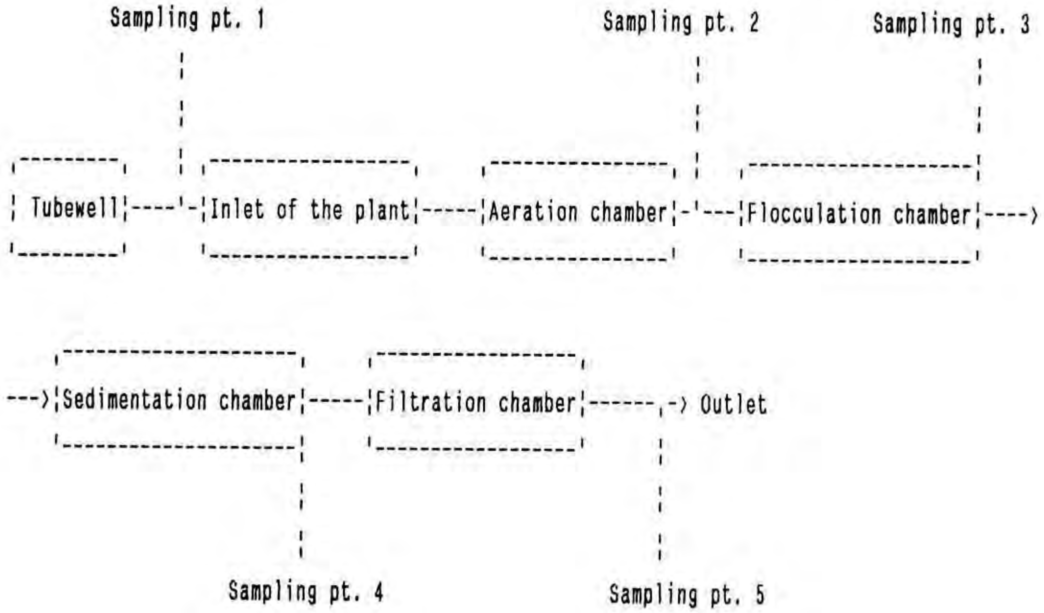


Fig. 4.1 Schematic Diagram of the Plant

Samples from inlet represented the characteristics of raw water coming from tubewell. Those from the end of aeration tray indicated the characteristics of aerated water. Similarly samples from the bottom of flocculation chamber and top of sedimentation chamber provided the characteristics of water after flocculation and sedimentation respectively. Samples from outlet provided the characteristics of finally treated water (i.e after aeration + flocculation + sedimentation + filtration).

4.6.3 Sampling Procedure

Samples were collected from the selected locations and kept into clear plastic jars with caps. The collected samples were transported to the laboratory with minimum time lag between collection and analysis so that no significant change occurred in the quality of samples. The yield of the plant and the people's interest in using tubewell water for various purposes were also observed.

4.6.4 Sampling Frequency

The samples for determining iron concentration were collected with a regular interval of 24 hours and the yields were measured at a regular interval of 48 hours.

4.7 Laboratory Test

The samples collected from the different locations of the plant were transported to the laboratory and physical and chemical qualities of raw water and treated water in various chambers were determined through extensive laboratory analysis.

Each sample was tested for iron concentration. Several samples were also tested for pH, alkalinity, hardness, dissolved CO_2 and dissolved O_2 to observe the characteristics of influent and effluent water.

4.7.1 Measurement of Iron Concentration

Samples were collected from various chambers of the plant and tested in the laboratory according to the following procedure:

Reagents used:

- Dilute hydrochloric acid
- Potassium permanganate solution
- Potassium thiocyanate solution
- Standard iron solution

Procedure:

- Firstly each sample was stirred very well to disperse the iron precipitates uniformly throughout the sample.
- 100 ml of each sample was taken in a Nessler tube.
- 5 ml of dilute hydrochloric acid was added to each tube.
- Than 2 drops of potassium permanganate were added. A pink color was formed after the addition of potassium permanganate. If pink color disappeared after 5 minutes, then more permanganate was added.
- 5 ml of potassium thiocyanate solution was added to the sample. A brown color was formed after the addition.
- Then the brown color formed was compared with the 'standard' prepared as follows:

* Added 100 ml of distilled water in a Nessler tube
* Added 5 ml of the dilute hydrochloric acid in the tube

* Added 5 ml of potassium thiocyanate solution in the tube
* Added 0.2 ml of standard Iron solution at a time until the color of the 'standard' and sample matched.

Calculation:

Amount of iron present in the sample (mg/l) = ml of the standard iron solution used.

4.7.2 Measurement of Plant Yield

The yield of the plant was measured on the basis of constant head yield measurement. The tubewell water falls into the flocculation chamber through the aeration plate. Then it goes to the sedimentation chamber and then to filtration chamber. During yield measurement the waterlevel in the flocculation chamber was kept almost constant. In the last chamber there is a overflow drain which does not allow water level to rise above a particular level in the last chamber and also in the 1st chamber since the headloss remains almost constant during pumping at constant rate.

But from the practical point of view the constant head yield measurement is very difficult to perform accurately. Actually this procedure is not feasible in the field. Besides, the water collectors of the villages are illiterate, so it is not possible for them to maintain the constant head during the collection of water. It is stated that a collector collects around 10 liters of water at a time which takes no longer than one minute [32]. Hence one minute pumping was applied to measure the yield of the plant.

4.7.3 Computation of Detention Time of Different Chambers

Volume of the flocculation chamber = 90 cm * 30 cm * 42 cm

= 0.11 m^3

Volume of the sedimentation chamber = 90 cm * 30 cm * 42 cm

= 0.11 m^3

Volume of the filtration chamber = 90 cm * 30 cm * 42 cm

= 0.11 m^3

Average tubewell yield = 20 liters/min

= 0.02 m^3/min

Detention time of the aeration chamber was determined by leaving a tracer at the top of the aeration chamber and letting it to flow due to gravity with the flow of water and measuring the time it took to reach the end of the aeration chamber. To determine the detention time of flocculation and filtration chamber typical porosity of the media was taken to be 0.40 according to Carman [31].

Detention time of the aeration chamber = 48 secs

= 0.8 min

Detention time of the flcculation chamber = V/Q = (0.11*0.40)/.02

= 2.2 min

Detention time of the sedimentation chamber = V/Q = 0.11/0.02

= 5.5 min

Detention time of the filtration chamber = V/Q = (0.11*0.40)/.02

= 2.2 min

4.8 Analysis of Data

The data found in the field and the laboratory test were analysed and different curves were plotted to show the variation of iron concentration with the duration, the percentage removal of iron with detention time, the yield of the tubewell with time, people's interest in using tubewell water for different purposes and people's interest in maintaining the plant.

CHAPTER 5
RESULTS AND DISCUSSIONS

5.1 General

The samples taken from different locations of the plant in a regular interval of 24 hrs. were tested in the laboratory for iron concentrations. The variation of yield with time was also observed at an interval of 48 hours. Finally the people's interest in using tubewell water and their acceptance of the plant after the construction was observed.

This chapter shows the variation of iron concentration with time, percentage removal of iron in various chambers of the plant, variation of yield with time both in tabular form and graphically and also the variation of pH, alkalinity, hardness, dissolved oxygen and CO_2 within the plant. Besides,this chapter describes the data which represents people's interest in using tubewell water and thier acceptance.

5.2 Performance of the Iron Removal Plant (IRP)

5.2.1 First Run

Removal of Iron

After the construction and operation of the plant samples of treated water were collected from different sampling points of the plant at a regular interval of 24 hrs. and tested in the laboratory for iron concentrations which are listed in Table 5.1. The iron concentration of raw water was found to be 20.0 mg/l.

Table 5.1 Variation of Iron Concentration of Water in Various Chambers of the Plant (1st Run)

Day of operation	Iron concentration of water (mg/l)				
	Raw water	Treated water			
		After aeration	After flocculation	After sedimentation	After filtration
1st	20.0	18.0	14.5	7.0	4.0
2nd	20.0	17.5	13.7	6.4	3.1
3rd	20.0	17.1	12.9	6.2	2.4
4th	20.0	16.5	12.0	6.0	1.6
5th	20.0	16.2	11.0	5.0	0.8
6th	20.0	15.8	10.1	4.5	0.6
7th	20.0	15.7	9.5	4.0	0.5
8th	20.0	15.7	10.0	4.6	0.6
9th	20.0	15.8	11.7	5.0	0.9

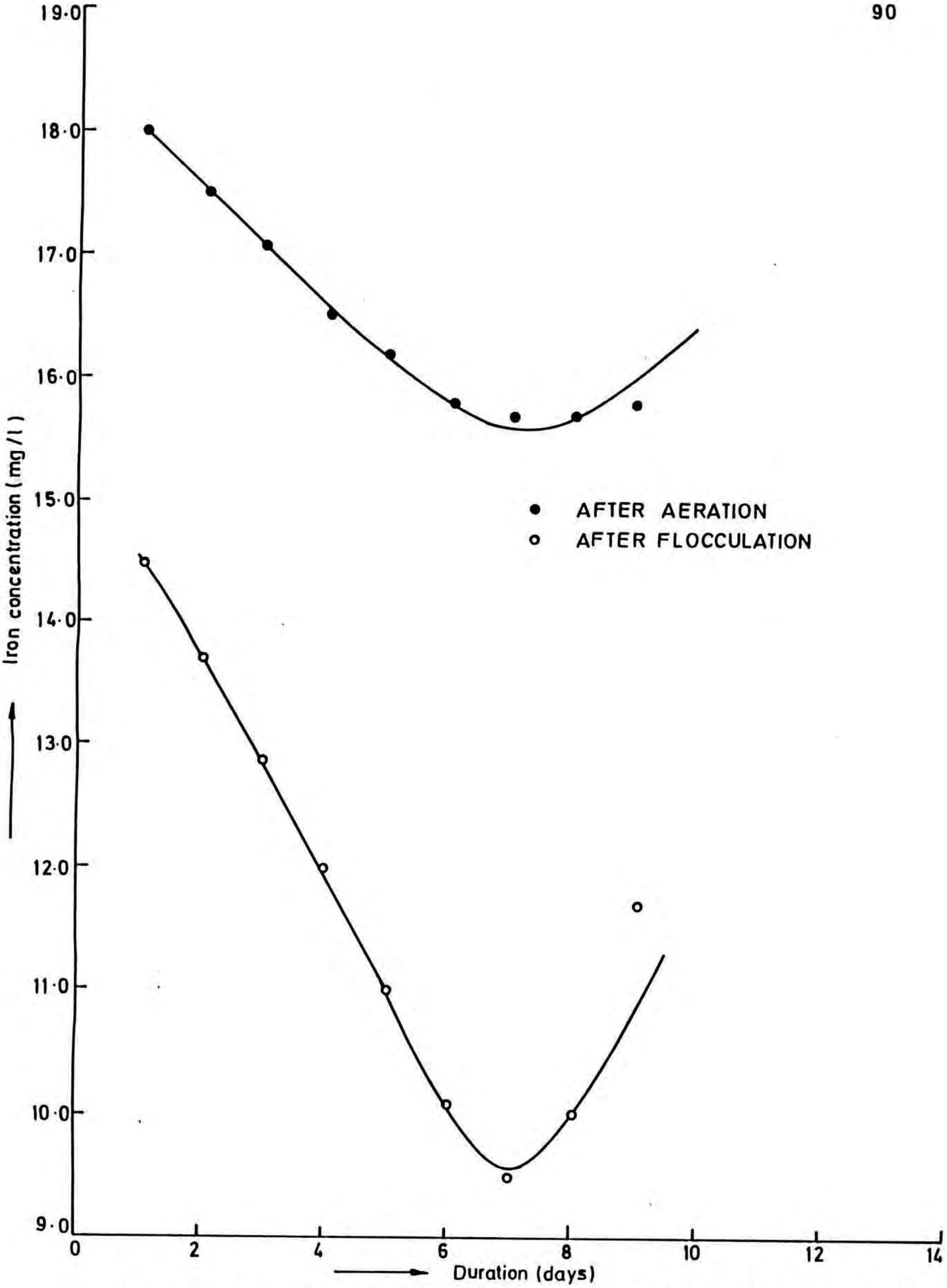


FIG. 5.1 VARIATION OF IRON CONCENTRATION OF WATER SAMPLE WITH DURATION (1ST RUN)

During the treatment, the iron concentration began to decrease gradually and minimum concentration (0.5 mg/l) was found in the filtration chamber on the 7th day of operation after which the concentration began to increase again. The iron concentrations (mg/l) of the samples taken from aeration and flocculation chamber have been plotted against the duration (days) and presented in Fig. 5.1.

Table 5.2 Percentage Removal of Iron from Water in Various Chambers (1st Run)

Day of operation	Cumulative percentage removal of iron			
	Upto aeration	Upto flocculation	Upto sedimentation	Upto filtration
1st	10.0	27.5	65.0	80.0
2nd	12.5	31.5	68.0	84.9
3rd	14.5	35.5	69.0	88.0
4th	17.5	40.0	70.0	92.0
5th	19.0	45.0	75.0	96.0
6th	21.0	49.5	77.5	97.0
7th	21.5	52.5	80.0	97.5
8th	21.5	50.0	77.0	97.0
9th	21.0	41.5	75.0	95.5

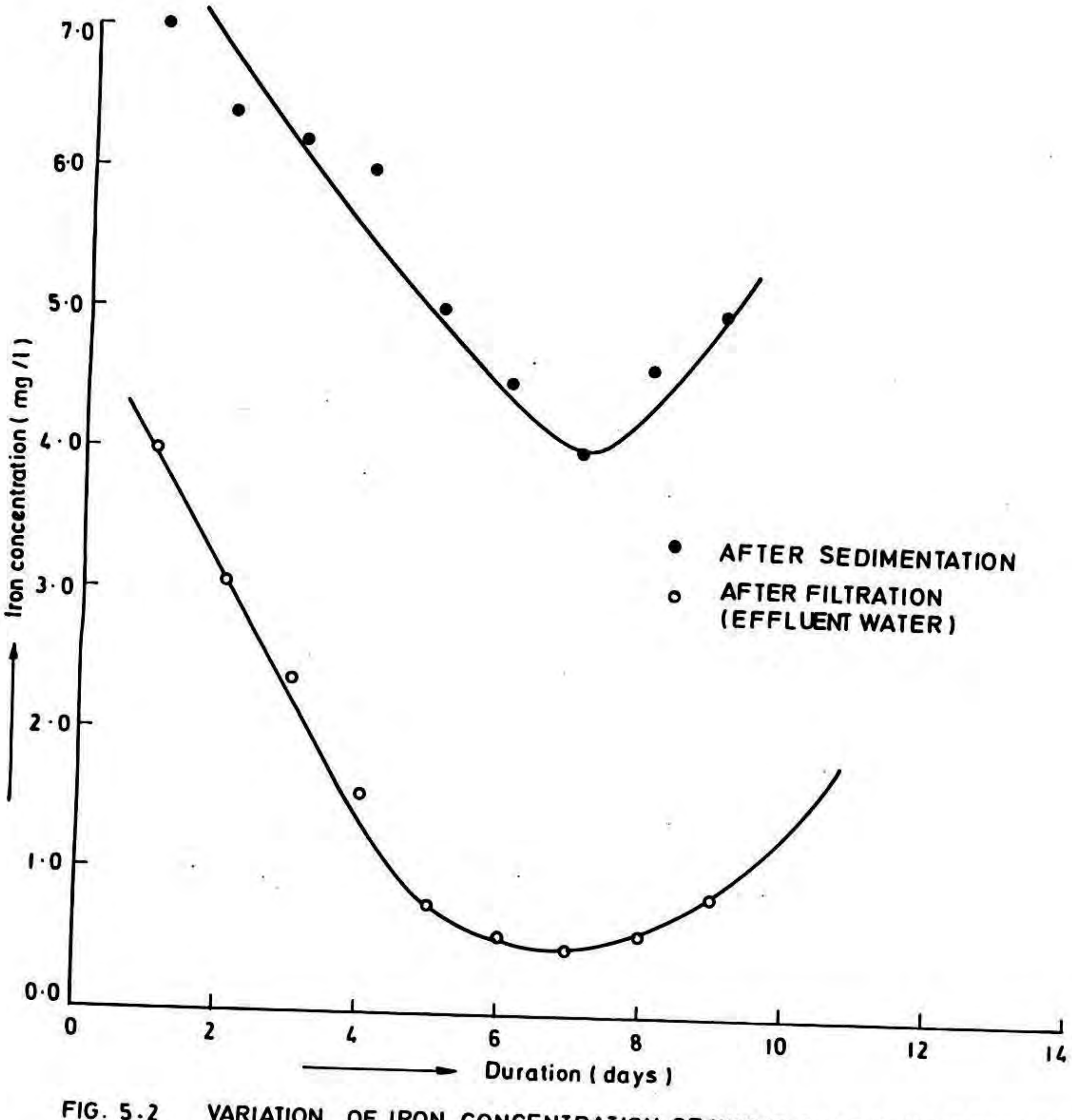


FIG. 5.2 VARIATION OF IRON CONCENTRATION OF WATER SAMPLE WITH DURATION (1ST RUN)

Similarly the iron concentrations (mg/l) of the samples from sedimentation and filtration chamber have been plotted against the duration (days) and presented in Fig. 5.2. The percentage removals of iron in different chambers of the plant have also been calculated which are shown in Table 5.2. The maximum percentage removal have been found to be 97.5% upto the filtration chamber.

The detention time of different chambers (e.g. aeration, flocculation, sedimentation and filtration chamber) have also been calculated (Art. 4.7.3) considering continuous pumping which are shown in Table 5.3.

Table 5.3 Detention Time of Various Chambers

Name of the chambers	Detention time (minute)
Aeration chamber	0.8
Flocculation chamber	2.2
Sedimentation chamber	5.5
Filtration chamber	2.2

The percentage removals of iron in different chambers on the 1st and 7th day (minimum concentration day) of operation have been plotted against the detention time of the respective chambers

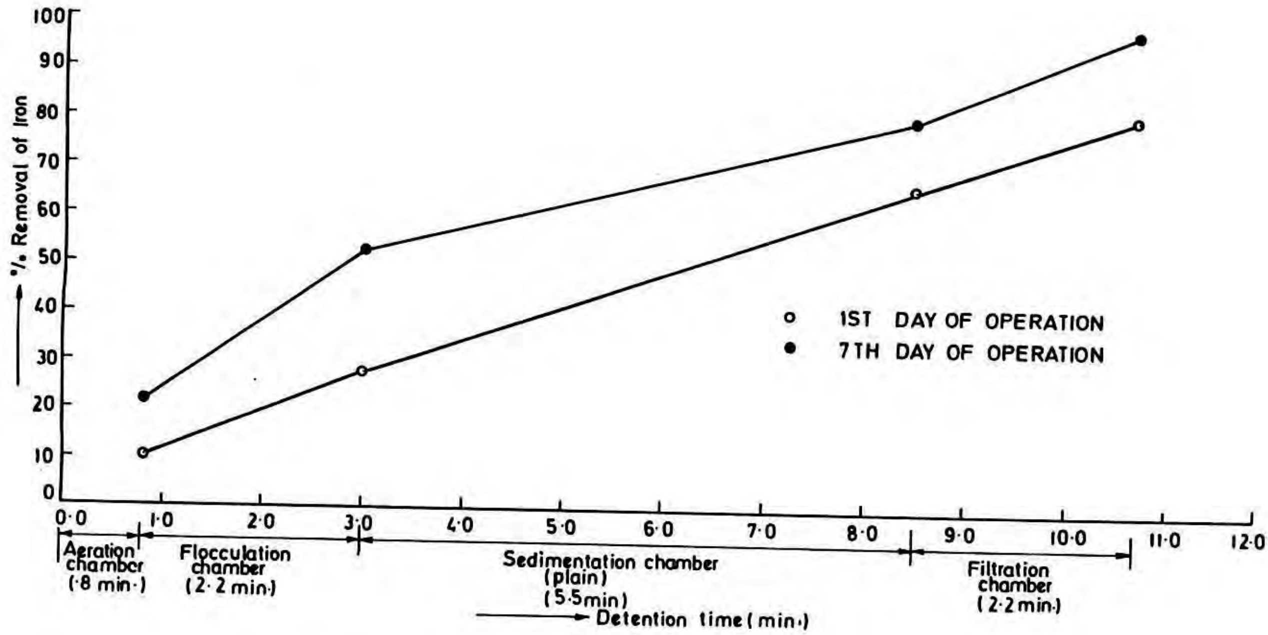


FIG. 5·3 VARIATION OF PERCENTAGE REMOVAL OF IRON IN VARIOUS CHAMBERS WITH DETENTION TIME (1ST RUN) which are shown in Fig. 5.3. These graphs show that the percentage removal of iron in the aeration chamber is low, that in the flocculation chamber is also low at first and then increases gradually, since the flocs become larger and a part of it settles down at the bottom. However the removal percentage is higher in the sedimentation chamber and in the filtration chamber also.

Yield of the Plant

The tubewell yield and the plant yield listed in Table 5.4 were measured according to the procedure mentioned in Art. 4.7.2 at a regular interval of two days.

Table 5.4 Variation of Plant Yield with Duration (1st Run)
(On the basis of 1 minute pumping)

Day of operation	Yield (liter/minute)
1st	8.2
3rd	7.8
5th	7.1
7th	6.2
9th	5.0

The plant yields (liter/min) have been plotted against duration (days) (Fig. 5.4) which show that the plant yield decreases

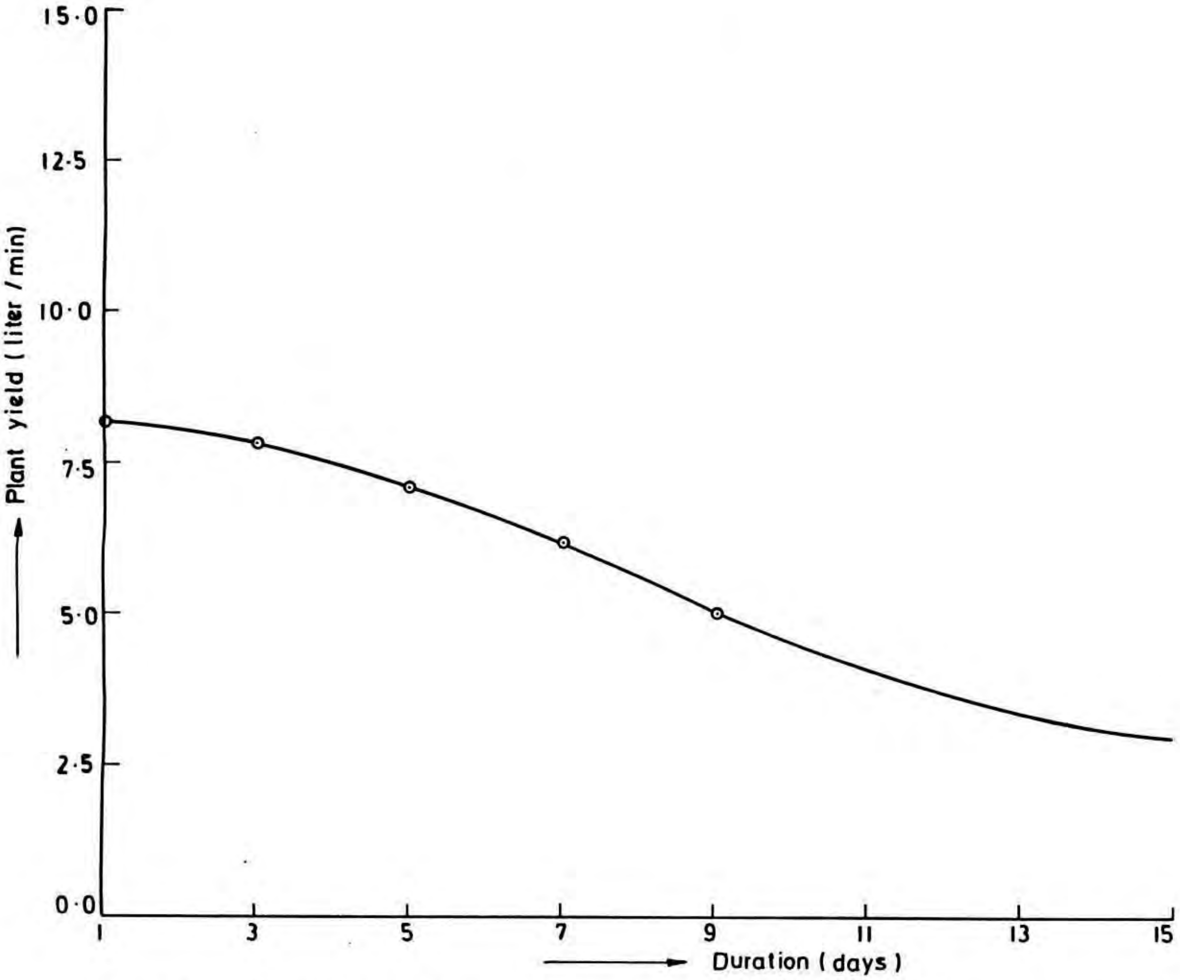


FIG 5·4 VARIATION OF PLANT YIELD WITH DURATION (IST RUN) gradually. The initial yield was found to be 8.2 liters/min. The yield on the 9th day was 5.0 liters/min. From the curve it has been found by extrapolation that on the 14th day (filler run) the yield is 3.2 liters/min which is not satisfactory.

Filter Run

On the 7th day of construction the concentration of iron was found to be minimum and on the following day it was found to increase again. Considering the decreasing and increasing rate to be equal, the filter run has been calculated as 7x2 = 14 days.

5.2.2 Second Run

When the iron concentration of treated water began to increase and the plant yield began to decrease, the plant was backwashed with the help of the backwash inlet and the wash out drain pipes and was operated again.

Removal of iron

In the same procedure as followed in the 1st run the samples were collected and tested for iron concentrations which have been presented in Table 5.5. The minimum concentration of Iron was 0.8 mg/l which was found in the filtration chamber on the 6th day of operation. It is nearly equal to the minimum concentration of iron found in the 1st run. The iron concentrations of the samples from aeration and flocculation chamber have been plotted against the duration which are shown in Fig. 5.5. Similarly the iron concentrations of the samples from sedimentation and filtration chamber have also been plotted against the duration which are shown in Fig. 5.6. The percentage removals of iron in various chambers have been listed in Table 5.6 and those on the 1st and last day (minimum concentration day) have been plotted against the detention time (Table 5.3) which are shown in Fig. 5.7. The maximum percentage removal was found to be 96.0 which is nearly the same as in the 1st run.

Table 5.5 Variation of Iron Concentration of Water in Various Chambers of the Plant (2nd Run)

Day of operation	Iron concentration of water (mg/l)				
	Raw water	Treated water			
		After aeration	After flocculation	After sedimentation	After filtration
1st	20.0	18.1	14.8	8.1	4.2
2nd	20.0	17.7	13.9	7.8	3.5
3rd	20.0	17.3	13.0	6.7	2.7
4th	20.0	16.8	12.1	6.3	1.8
5th	20.0	16.4	11.0	5.7	1.1
6th	20.0	15.9	10.3	4.9	0.8
7th	20.0	15.9	11.2	5.8	1.0

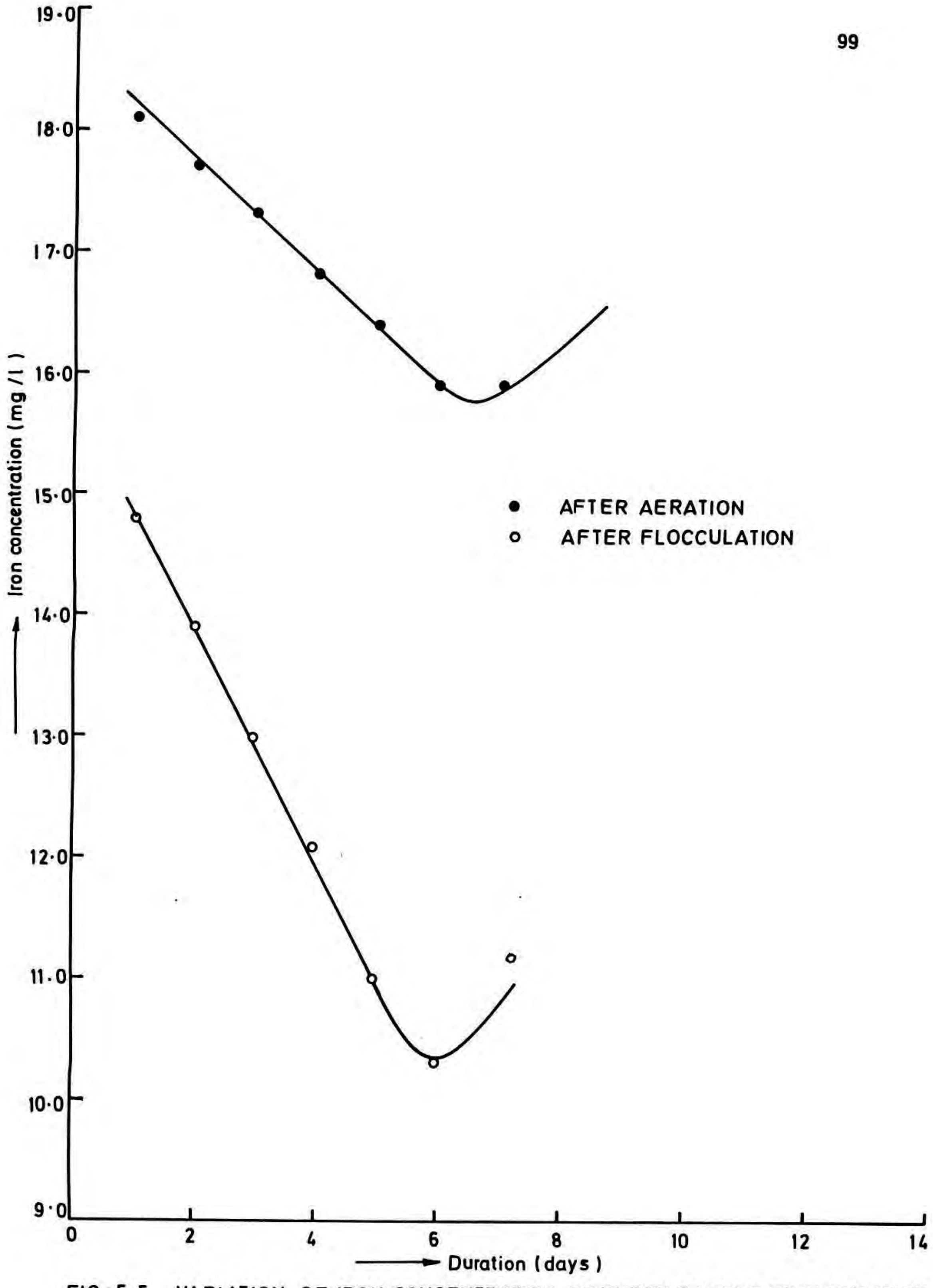


FIG. 5·5 VARIATION OF IRON CONCENTRATION OF WATER SAMPLE WITH DURATION (2ND RUN)

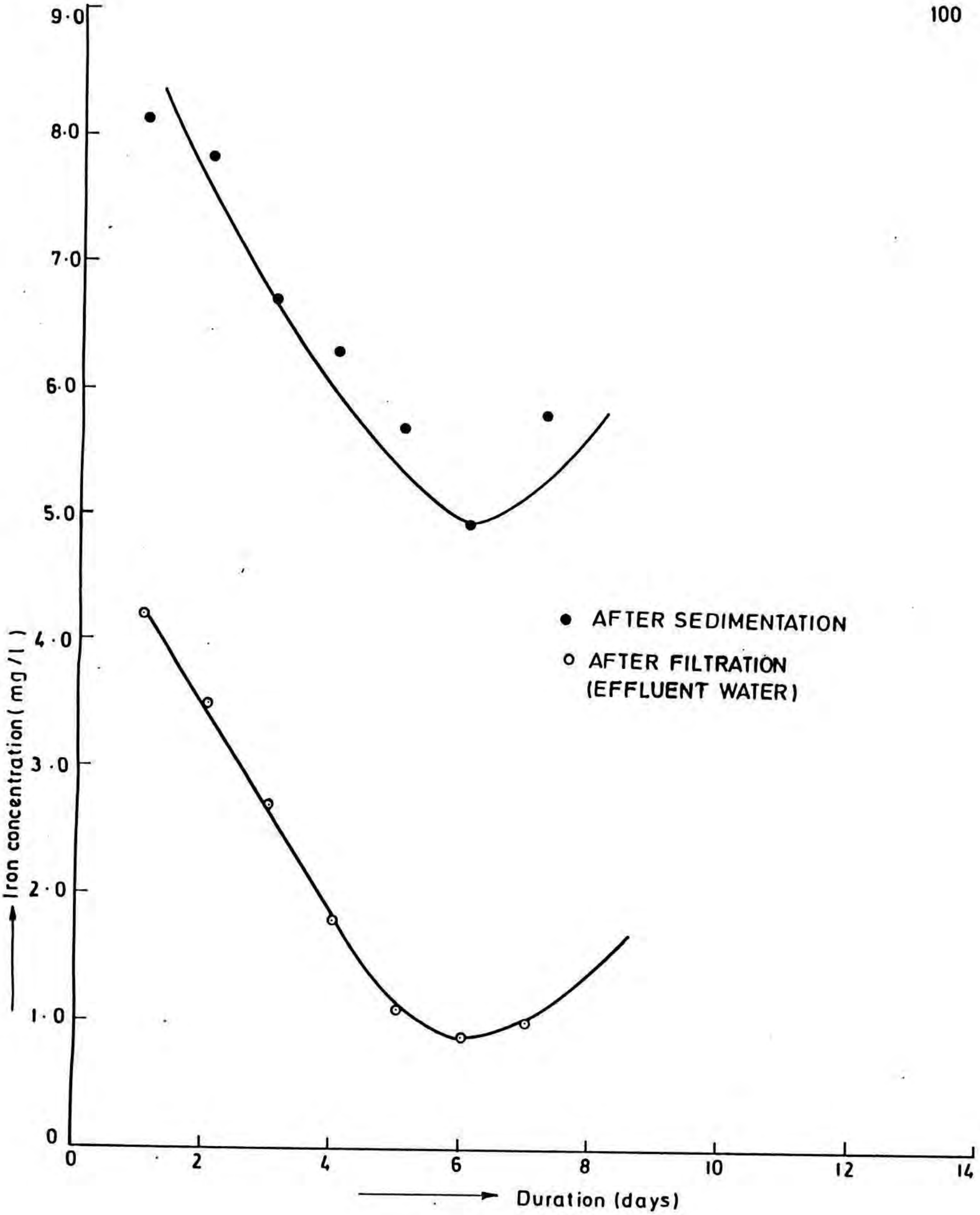


FIG 5·6 VARIATION OF IRON CONCENTRATION OF WATER SAMPLE WITH DURATION (2ND RUN)

Table 5.6 Percentage Removal of Iron from Water in Various Chambers (2nd Run)

Day of operation	Cumulative percentage removal of iron			
	Upto aeration	Upto flocculation	Upto sedimentation	Upto filtration
1st	9.5	26.0	59.5	79.0
2nd	11.5	30.5	61.0	82.5
3rd	13.5	35.0	66.5	86.5
4th	16.0	39.5	68.5	91.0
5th	18.0	45.0	71.5	94.5
6th	20.5	48.5	75.5	96.0
7th	20.5	44.0	71.0	95.0

Yield of the Plant

The plant yields were measured according to the same procedure as followed before and the values have been listed in Table 5.7. The yields have also been plotted against the duration which is shown in Fig. 5.8. The initial yield was found to be 8.0 liters/min which is nearly the same as in the 1st run. From the curve it has been found by extrapolation that on the 12th day (filter run) the yield is 2.9 liters/min which is not satisfactory.

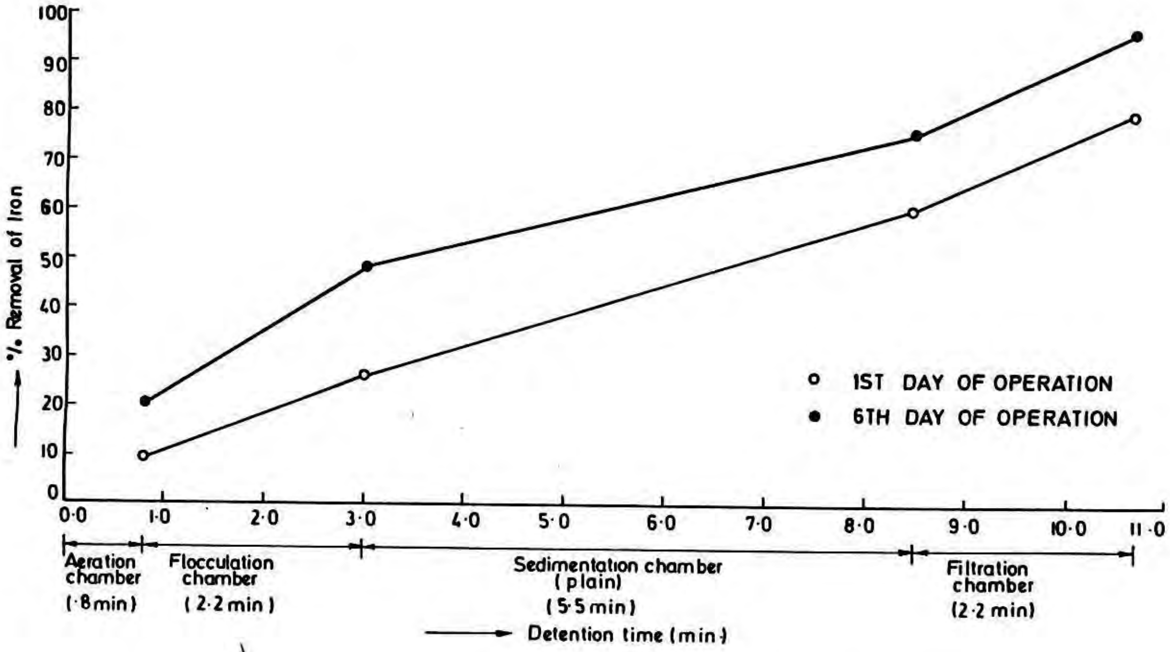


FIG. 5.7 VARIATION OF PERCENTAGE REMOVAL OF IRON IN VARIOUS CHAMBERS WITH DETENTION TIME (2ND RUN)

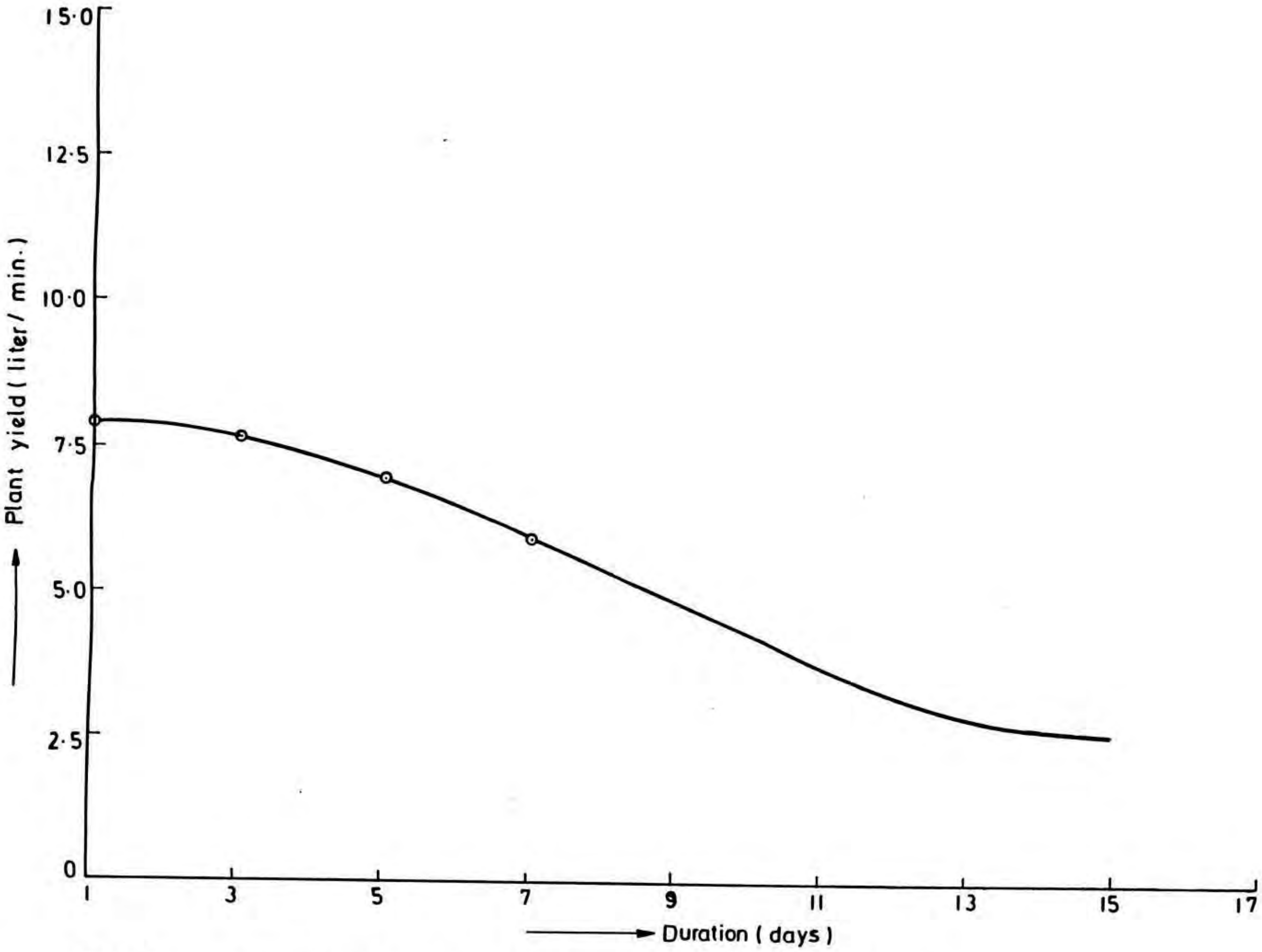


FIG 5.8 VARIATION OF PLANT YIELD WITH DURATION (2ND RUN)

Table 5.7 Variation of Plant Yield with Duration (2nd Run)
(On the basis of 1 minute pumping)

Day of operation	Yield (liter/minute)
1st	8.0
3rd	7.7
5th	7.0
7th	6.0

Filter Run

On the 6th day of operation the concentration of iron was found to be the minimum and then it began to increase again. Assuming the decreasing and increasing rate to be equal the filter run was calculated as 6x2 = 12 days.

5.3 Problems Encountered and Possible Modifications in the Plant

5.3.1 Problems Encountered

A number of problems was encountered in the performance of the plant. These can be explained as follows:

--- Since plain sedimentation was adopted in the design, the percentage removal upto the sedimentation chamber was low (77.0%). As a result the ultimate removal was only 97.5 percent. In the case of plain sedimentation, the sludge deposit at the bottom becomes huge and scouring of sludge occurs.

--- A major problem encountered was too low yield. The initial yield was 8.2 liters/min which is much inadequate. This inadequacy of yield may cause people to be inclined to use other impure surface water sources (e.g. ponds, rivers etc.). It is assumed that the rapid clogging and very low head over the delivery pipe are the main causes of low yield.

--- The most severe problem encountered was the low filter run. In the 1st run the filter run was found to be 14 days and in the 2nd run it was only 12 days. People don't get any interest to clean the plant once in 12 days. As a result the main problem, i.e. the maintenance problem remains unsolved. It is thought that the sloughing of iron flocs and scouring of sludge deposited at the bottom of filtration chamber are the main reasons for low filter run.

5.3.2 Modification of the Plant

To remove the problems encountered in the performance of the plant it was thought that several modifications would have to be done in the plant. These modifications can be described as follows:

---If tube settlers are placed in the sedimentation chamber, it would help the sedimentation chamber to increase the percentage removal of iron because of the increase of the surface area and decrease of the fall distance in the sedimentation chamber. Consequently the overall iron removal efficiency would be increased. The sludge deposits at the bottom would not be enough to be scoured. Besides the clogging in the filtration chamber would be less which would increase yield as well as filter run. Hence tube settlers were placed in the sedimentation chamber of the modified plant.

-- If an additional narrow sedimentation chamber (plain) after the filtration chamber is constructed, it would increase the overall iron removal efficiency and the filter run. As a result of the construction of this chamber the position of the delivery pipe would be changed, i.e. the effluent water would come out from the top of the sedimentation chamber instead of coming out from the bottom of the filtration chamber as was in the previous plant. This would avert the scoured deposit to come with the effluent water and the overall iron removal efficiency as well as the filter run would be increased.

Consequently the increase in head of the delivery outlet due to the change in the position of it would increase the yield much. So an additional narrow sedimentation chamber was constructed after the filtration chamber and the location of the delivery pipe was changed in the modified plant.

The modified plant was constructed beside a tubewell and its performance was studied in a similar way as in the previous plant and discussed in the following articles.

The plan and sectional elevations of the modified plant have been shown in Fig. 5.9, 5.10 and 5.11 . The modifications have also been shown in Plate No. 3, 4 & 5.

5.3.3 Computation of Detention Time of Different Chambers of the modified Plant

Volume of the flocculation chamber = 90 cm * 30 cm * 42 cm

= 0.11 m^3

Volume of the sedimentation chamber = 90 cm * 30 cm * 42 cm

= 0.11 m^3

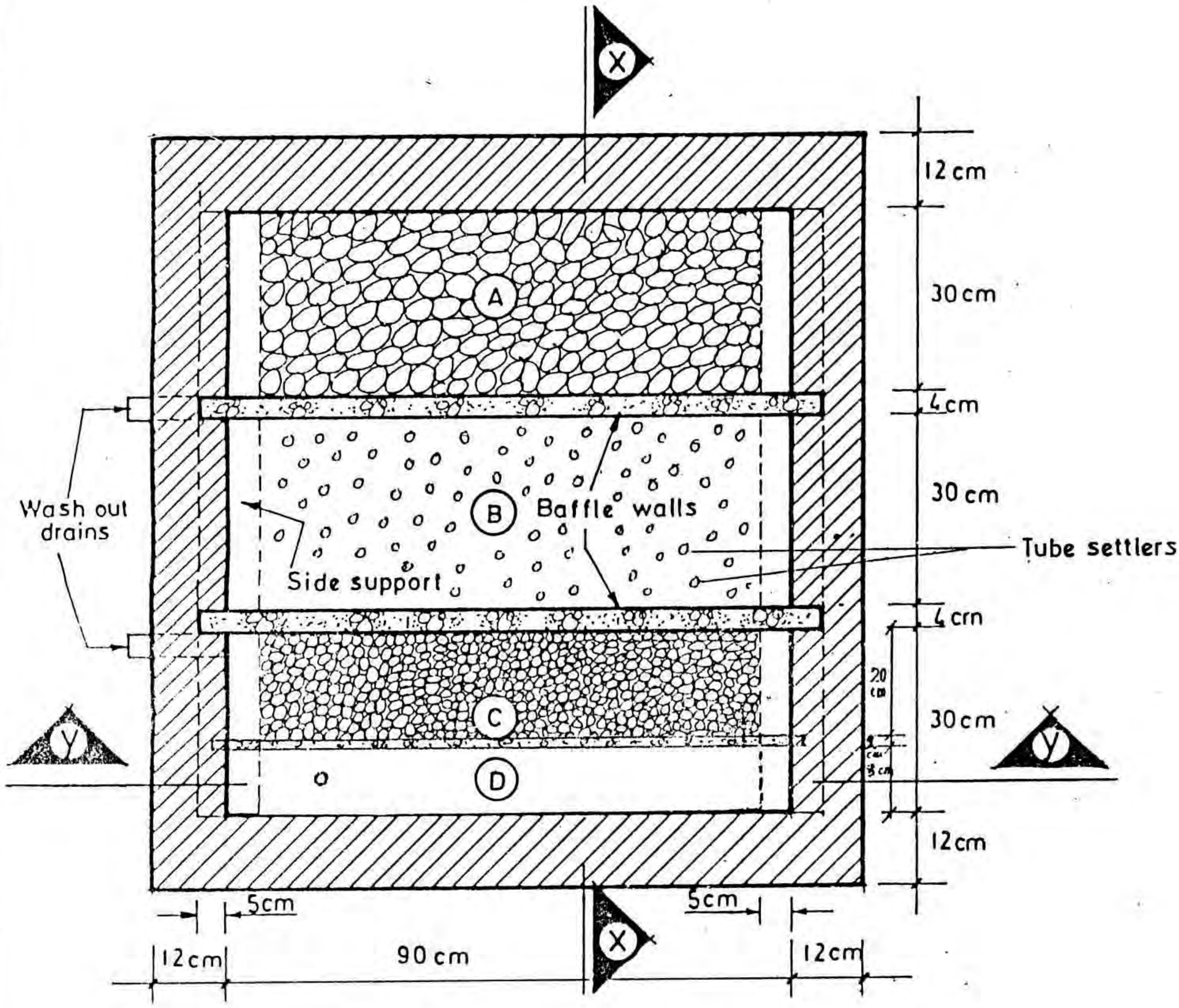
Volume of the filtration chamber = 90 cm * 20 cm * 42 cm

= 0.075 m^3

Volume of the narrow sedimentation chamber (plain) = 90 cm * 8 cm * 42 cm

= 0.03 m^3

Since no modification was made in the aeration chamber of the plant, the detention time of the aeration chamber remained the same as was in the previous plant. According to Carman [31], the typical porosity of the media used in the flocculation and filtration chamber is 0.40. Since tubesettlers were placed in the sedimentation chamber, the open space in the sedimentation



(A) FLOCCULATION CHAMBER

(B) SEDIMENTATION CHAMBER (WITH TUBE SETTLER)

(C) FILTRATION CHAMBER

(D) PLAIN SEDIMENTATION CHAMBER

FIG 5·9 PLAN OF THE MODIFIED IRON REMOVAL PLANT

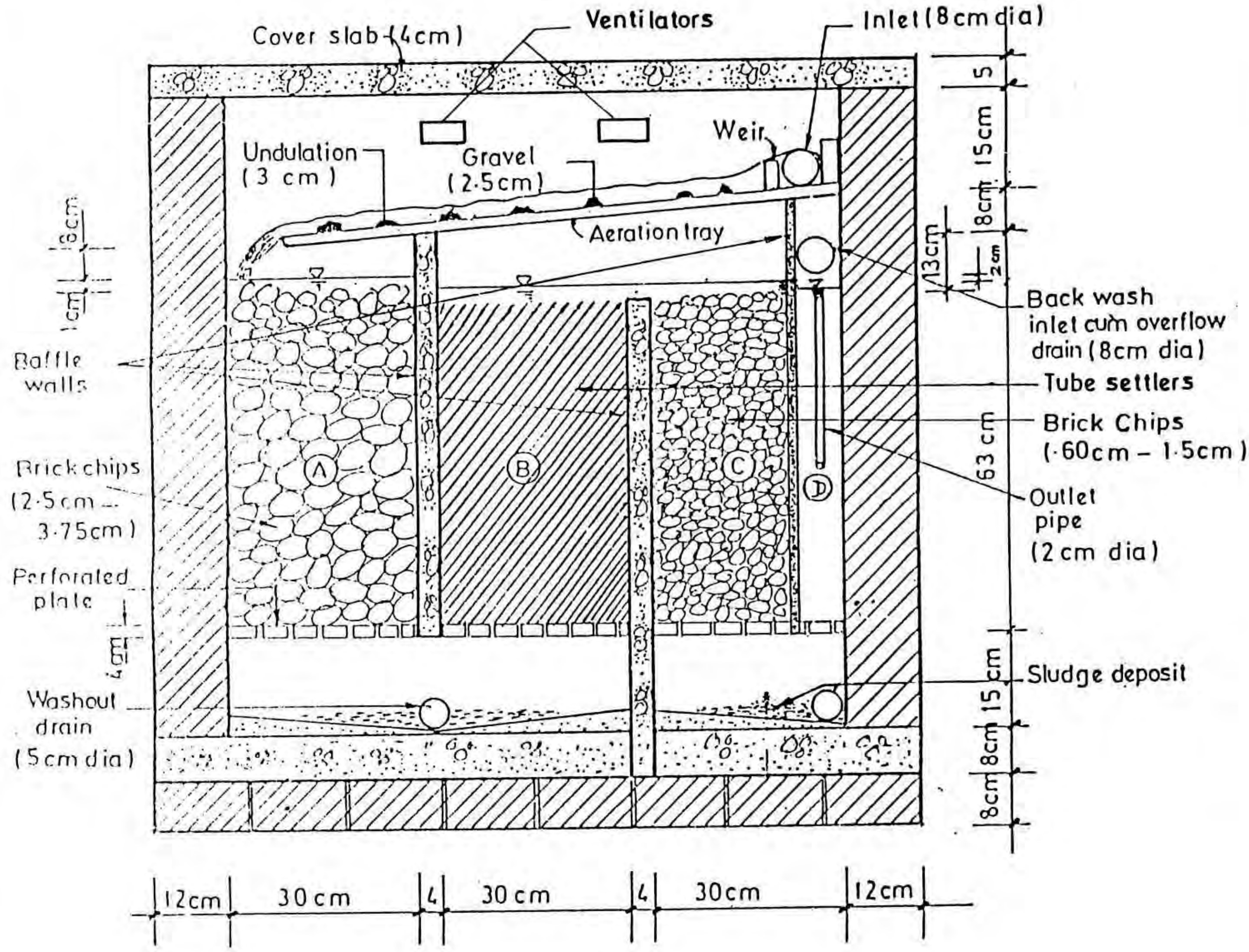


FIG. 5.10 LONGITUDINAL SECTION X–X OF THE MODIFIED PLANT

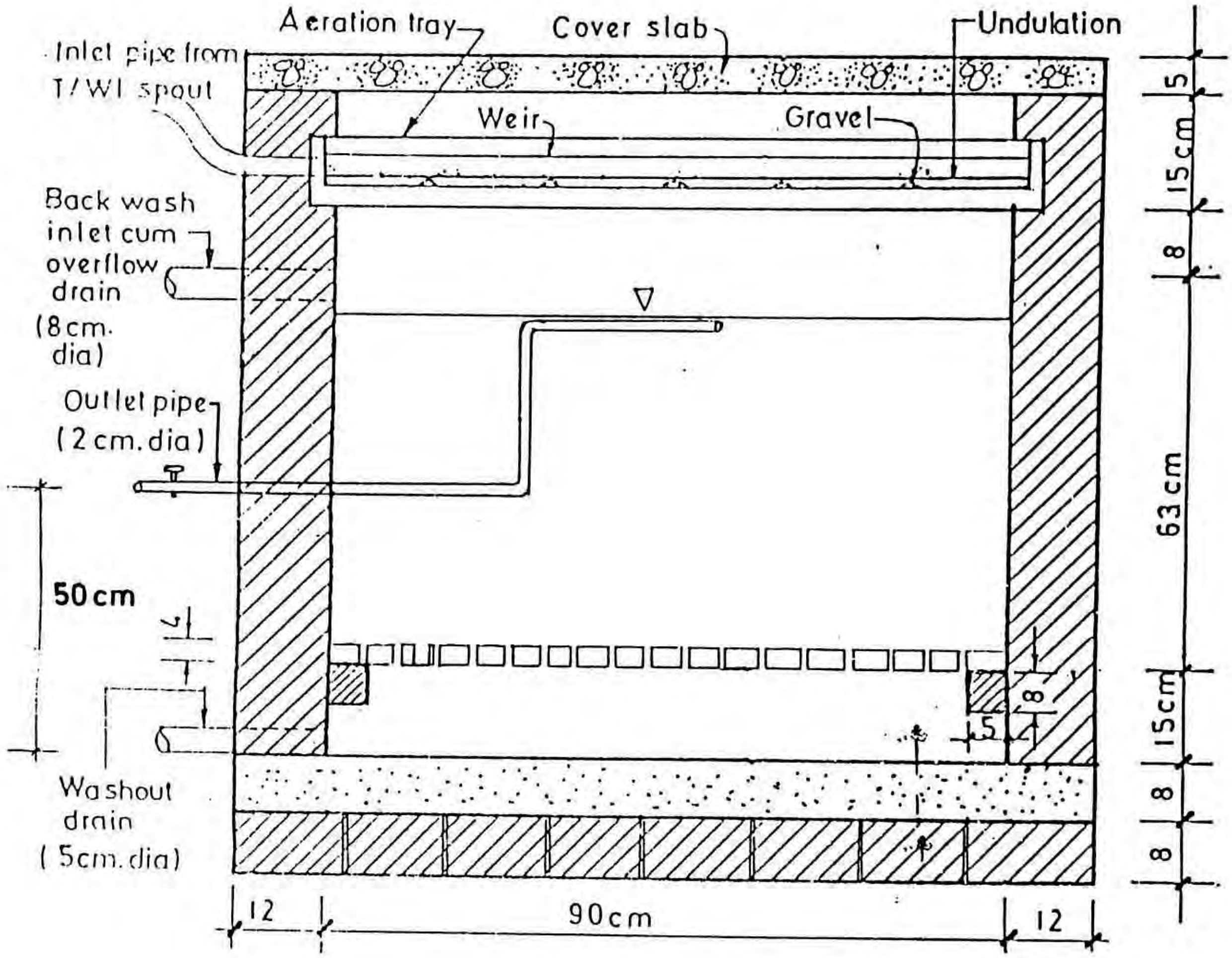


FIG. 5.11 a TRANSVERSE SECTION Y – Y OF THE MODIFIED PLANT

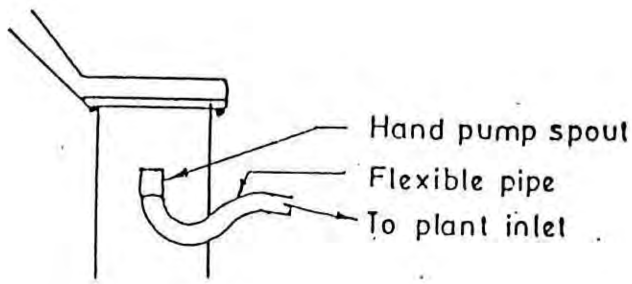


FIG. 5.11 b T / WL SPOUT AND THE FLEXIBLE PIPE CONNECTION OF THE MODIFIED PLANT

Plate No. 3 Modified Iron Removal Plant showing Different Chambers

Plate No. 4 Modified Iron Removal Plant showing Different Chambers with media

Plate No. 5 Sample Collection from the Modified Iron Removal Plant chamber can assumed as 90%.

So, detention time of the aeration chamber = 0.8 min

Detention time of the flocculation chamber = (0.11*0.40)/0.02

= 2.2 min

Detention time of the sedimentation chamber

with tubesettlers = (0.11*0.90)/0.02

= 5.0 min

Detention time of the filtration chamber = (0.075*0.40)/0.02

= 1.5 min

Detention time of the narrow sedimentation

chamber (plain) = 0.03/0.02

= 1.5 min

The detention time of each chamber has been presented in tabular form in Table 5.8.

Table 5.8 Detention Time of Various Chambers of the Modified Plant

Name of the chambers	Detention time (minute)
Aeration chamber	0.8
Flocculation chamber	2.2
Sedimentation chamber (with tubesettlers)	5.0
Filtration chamber (+ plain sedimentation)	3.0

5.4 Performance of the Modified Plant

5.4.1 First Run

<u>Removal of Iron</u>

In the modified plant tube settlers were placed in the sedimentation chamber and an additional thin strip acting as a plain sedimentation chamber was built after the filtration chamber and the position of the outlet was changed a bit. The iron concentrations of the samples taken from various chambers were measured and has been presented in Table 5.9.

The iron concentrations of the samples from the aeration chamber and flocculation chamber have been plotted against the duration which are shown in Fig 5.12. Similarly the iron concentrations of the samples from the sedimentation chamber and filtration chamber have been plotted against the duration and shown in Fig. 5.13. In this plant water quality was improved a lot. The minimum iron concentration was found to be 0.15 mg/l. The percentage removal of iron has been calculated and presented in Table 5.10. The percentage removals on the 1st and last day (minimum concentration day) have been plotted against the detention time (Table 5.8) which are shown in Fig. 5.14. The percentage removal of iron was quite satisfactory in the sedimentation chamber and upto sedimentation the maximum removal was about 97.1%. The overall iron removal percentage was about 99.3% which was also satisfactorily acceptable.

Table 5.9 Variation of Iron Concentration of Water in Various Chambers of the Modified Plant (1st Run)

Day of operation	Iron concentration of water (mg/l)				
	Raw water	Treated water			
		After aeration	After flocculation	After sedimentation	After filtration
1st	20.5	18.1	14.4	6.1	3.8
2nd	20.5	17.6	13.6	5.4	3.0
3rd	20.5	17.2	12.9	5.0	2.2
4th	20.5	16.7	11.9	3.9	1.4
5th	20.5	16.5	11.0	3.2	1.1
6th	20.5	16.0	10.0	2.8	0.8
7th	20.5	15.8	9.7	2.3	0.4
8th	20.5	15.4	10.0	1.8	0.3
9th	20.5	15.4	11.1	1.2	0.2
10th	20.5	15.5	11.4	0.9	0.18
11th	20.5	15.6	11.7	0.6	0.15
12th	20.5	15.8	12.0	1.0	0.19

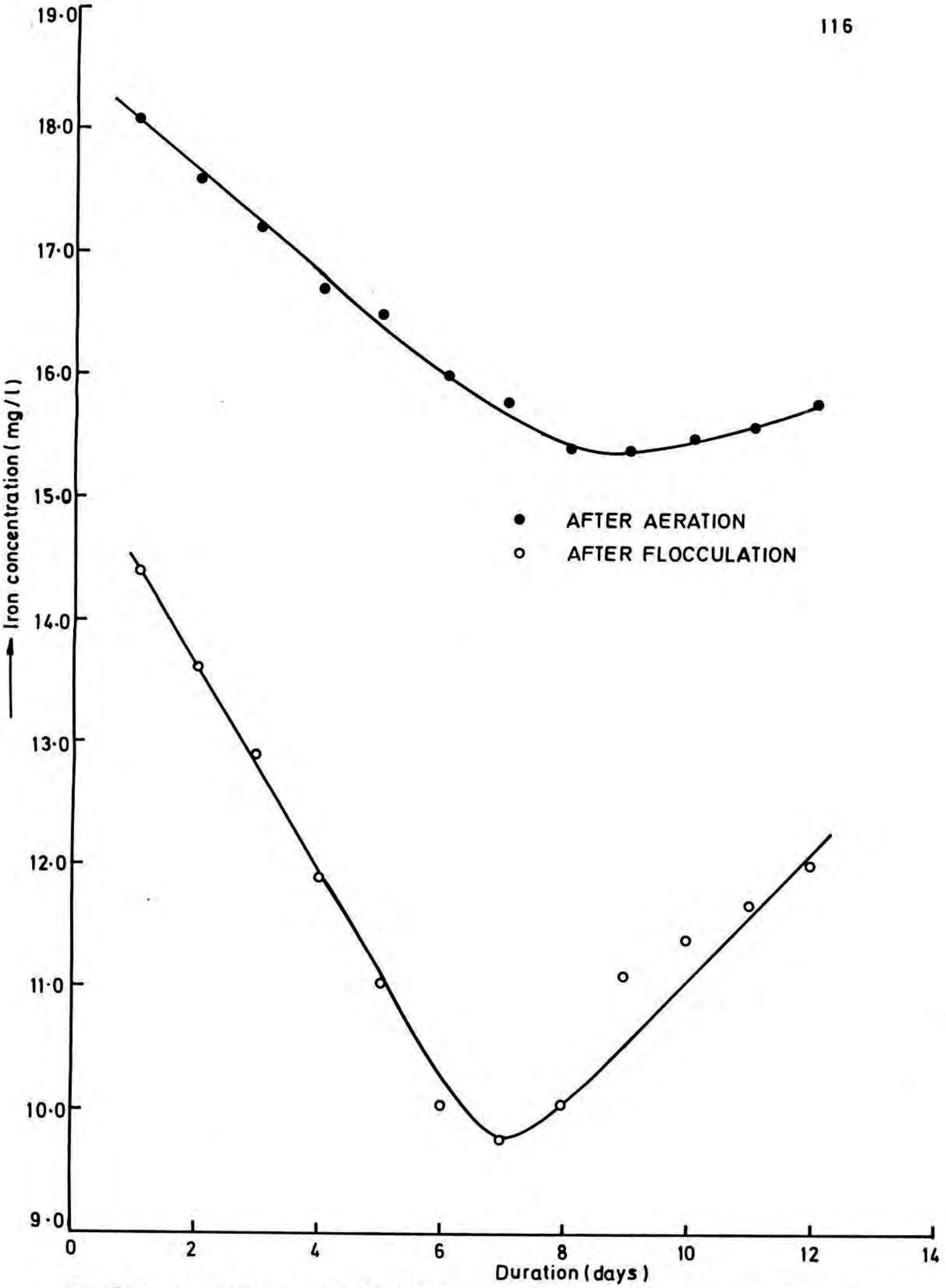


FIG 5.12 VARIATION OF IRON CONCENTRATION OF WATER SAMPLE OF THE MODIFIED PLANT WITH DURATION (1ST RUN)

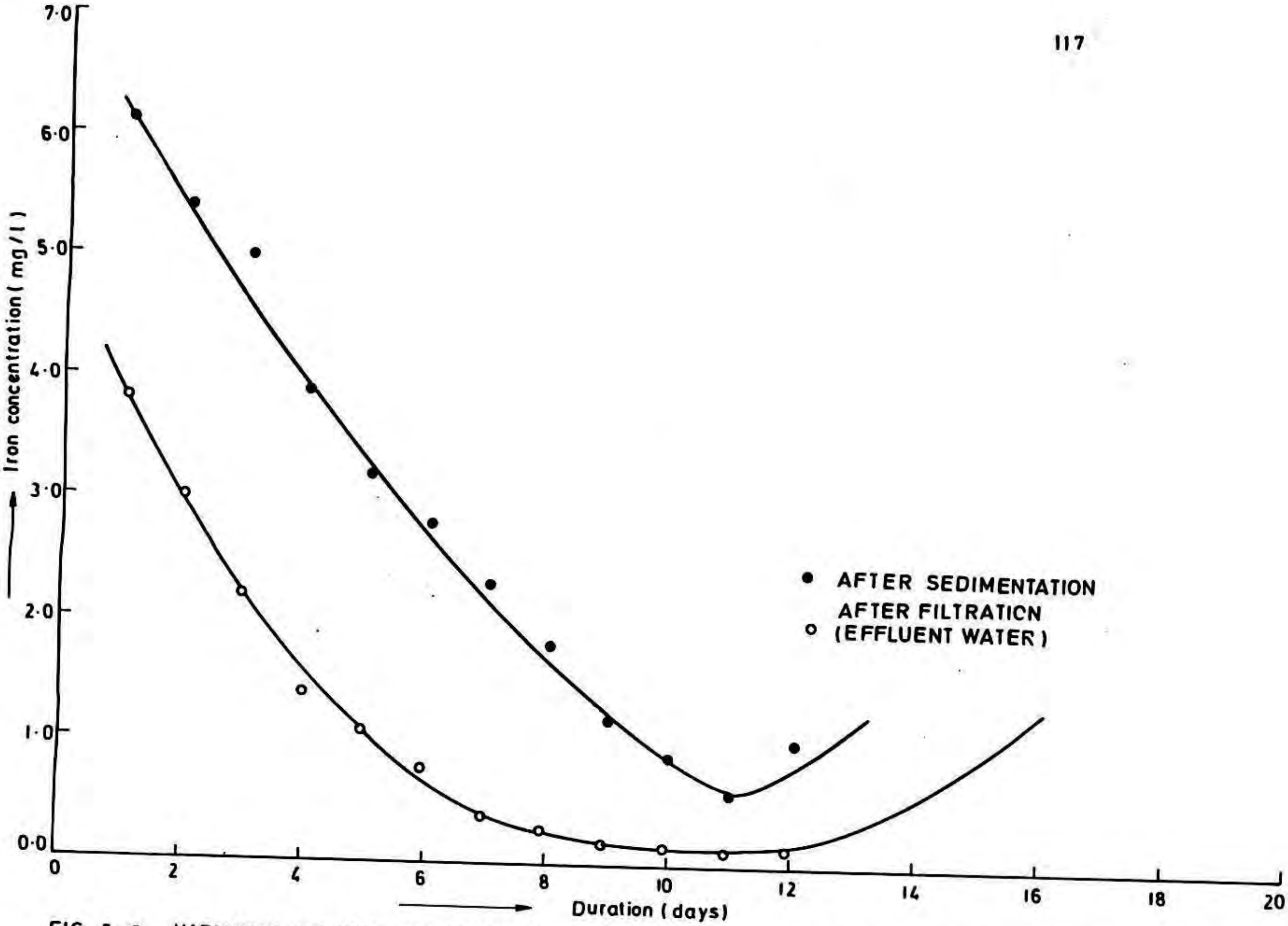


FIG. 5·13 VARIATION OF IRON CONCENTRATION OF WATER SAMPLE OF THE MODIFIED PLANT WITH DURATION (1ST RUN)

Table 5.10 Percentage Removal of Iron from Water in Various Chambers of the Modified Plant (1st Run)

Day of operation	Cumulative percentage removal of iron			
	Upto aeration	Upto flocculation	Upto sedimentation	Upto filtration
1st	11.7	29.8	70.2	81.5
2nd	14.1	33.7	73.7	85.4
3rd	16.1	37.1	75.6	89.3
4th	18.5	42.0	81.0	93.2
5th	19.5	46.3	84.4	94.6
6th	22.0	51.2	86.3	96.1
7th	22.9	52.7	88.8	98.0
8th	24.9	51.2	91.2	98.5
9th	24.9	45.9	94.1	99.0
10th	24.4	44.4	95.6	99.1
11th	23.9	42.9	97.1	99.3
12th	22.9	41.5	95.1	99.1

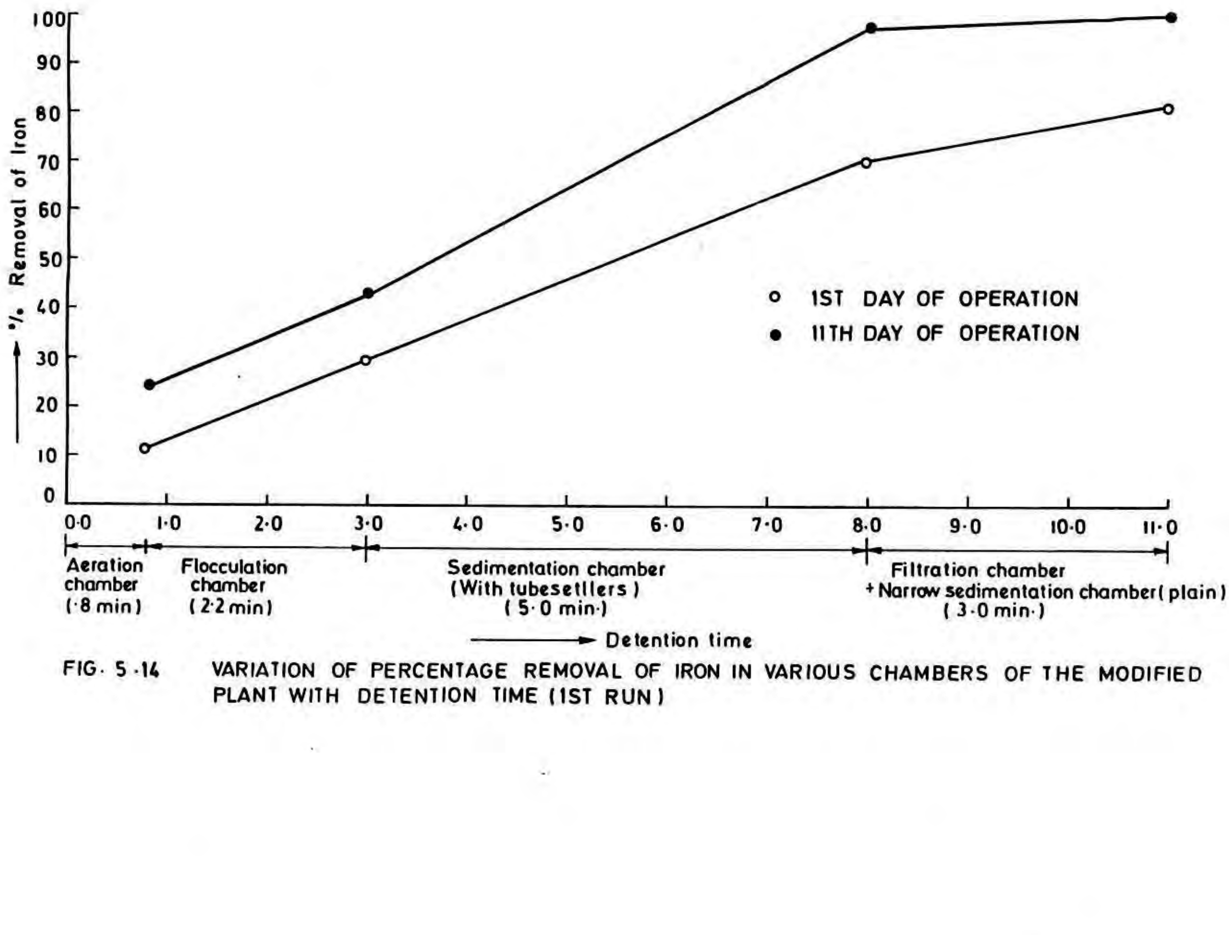


FIG. 5·14 VARIATION OF PERCENTAGE REMOVAL OF IRON IN VARIOUS CHAMBERS OF THE MODIFIED PLANT WITH DETENTION TIME (1ST RUN)

Yield of the Plant

The plant yields were measured according to the procedure mentioned in Art. 4.7.2 and have been presented in the Table 5.11. The yields have been plotted against the duration which is shown in Fig. 5.15. The initial plant yield was found to be 14.4 liters/min which is much better than that in the previous plant. The average plant yield increased by about 75.6 percent.

Table 5.11 Variation of Plant Yield of the Modified Plant with Duration (1st Run)
(On the basis of 1 minute pumping)

Day of operation	Yield (liter/minute)
1st	14.4
3rd	14.0
5th	13.4
7th	12.5
9th	11.5
11th	10.4
13th	9.2

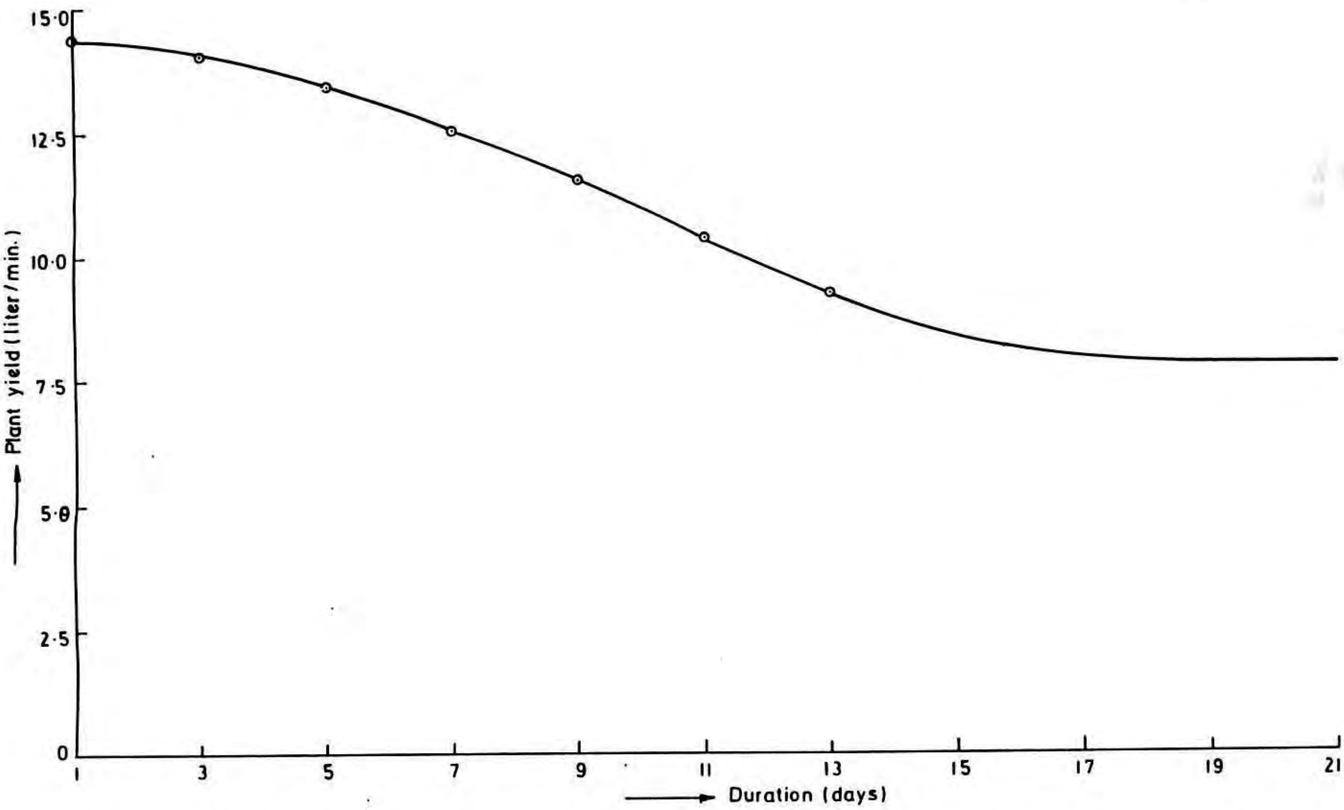


FIG. 5.15 VARIATION OF PLANT YIELD OF THE MODIFIED PLANT WITH DURATION (IST RUN)

Filter Run

On the 11th day of operation the concentration of iron was found to be the minimum and then it began to increase again. Assuming the decreasing and increasing rate to be equal the filter run was determined as 11x2 = 22 days.

5.4.2 Second Run

When the iron concentration of treated water began to increase and the plant yield began to decrease, the modified plant was backwashed and operated. In this run the iron removal efficiency, the plant yield were more or less the same as were in the 1st run. The filter run remained the same as was in the 1st run (22 days) which is also quite satisfactory.

Removal of Iron

The iron concentrations of the samples from various chambers have been listed in Table 5.12. The variation of iron concentration of the samples from aeration chamber and flocculation chamber with duration has been shown in Fig. 5.16 and that of the samples from sedimentation and filtration chamber with duration has been shown in Fig. 5.17. The minimum iron concentration of treated water in this run was found to be 0.3 mg/l which is satisfactorily acceptable. The percentage removals of iron were also calculated (Table 5.13) and the variations of percentage removal of iron on

Table 5.12 Variation of Iron Concentration of Water in Various Chambers of the Modified Plant (2nd Run)

Day of operation	Iron concentration of water (mg/l)				
	Raw water	Treated water			
		After aeration	After flocculation	After sedimentation	After filtration
1st	20.5	18.2	14.5	9.0	5.1
2nd	20.5	17.8	13.9	7.6	4.3
3rd	20.5	17.5	12.8	7.2	3.2
4th	20.5	16.9	12.0	6.1	1.7
5th	20.5	16.7	11.1	4.9	1.5
6th	20.5	16.2	10.2	4.1	1.2
7th	20.5	15.9	9.8	3.0	0.8
8th	20.5	15.6	10.1	2.5	0.6
9th	20.5	15.6	11.2	2.0	0.47
10th	20.5	15.6	11.6	1.4	0.3
11th	20.5	15.7	12.1	2.1	0.5
12th	20.5	-	-	-	0.7
13th	20.5	-	-	-	1.0
14th	20.5	-	-	-	1.2
15th	20.5	-	-	-	1.6
16th	20.5	-	-	-	1.9
17th	20.5	-	-	-	2.1
18th	20.5	-	-	-	2.4
19th	20.5	-	-	-	2.8
20th	20.5	-	-	-	3.2
21st	20.5	-	-	-	4.0
22nd	20.5	-	-	-	5.2

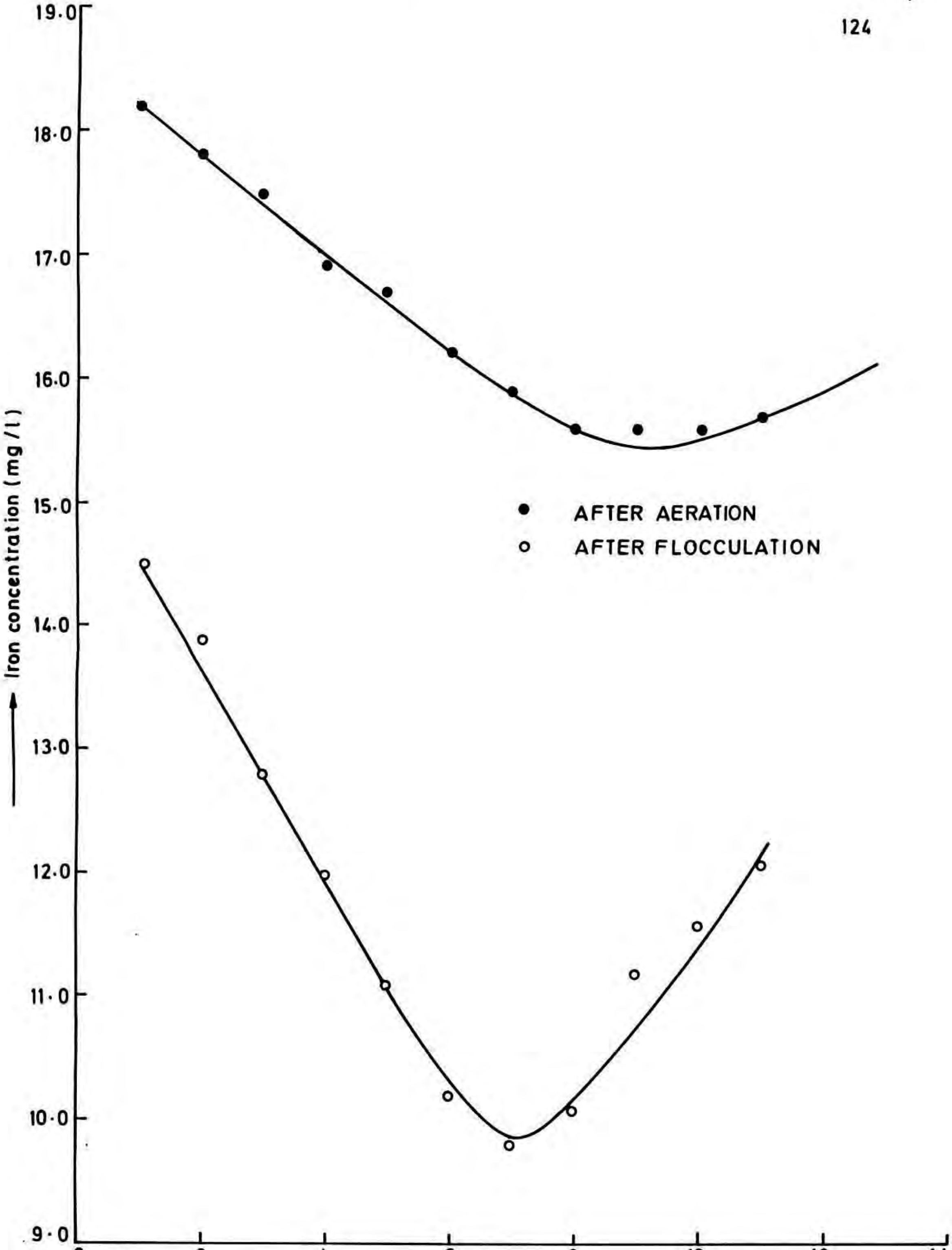


FIG. 5.16 VARIATION OF IRON CONCENTRATION OF WATER SAMPLE OF THE MODIFIED PLANT WITH DURATION (2ND RUN)

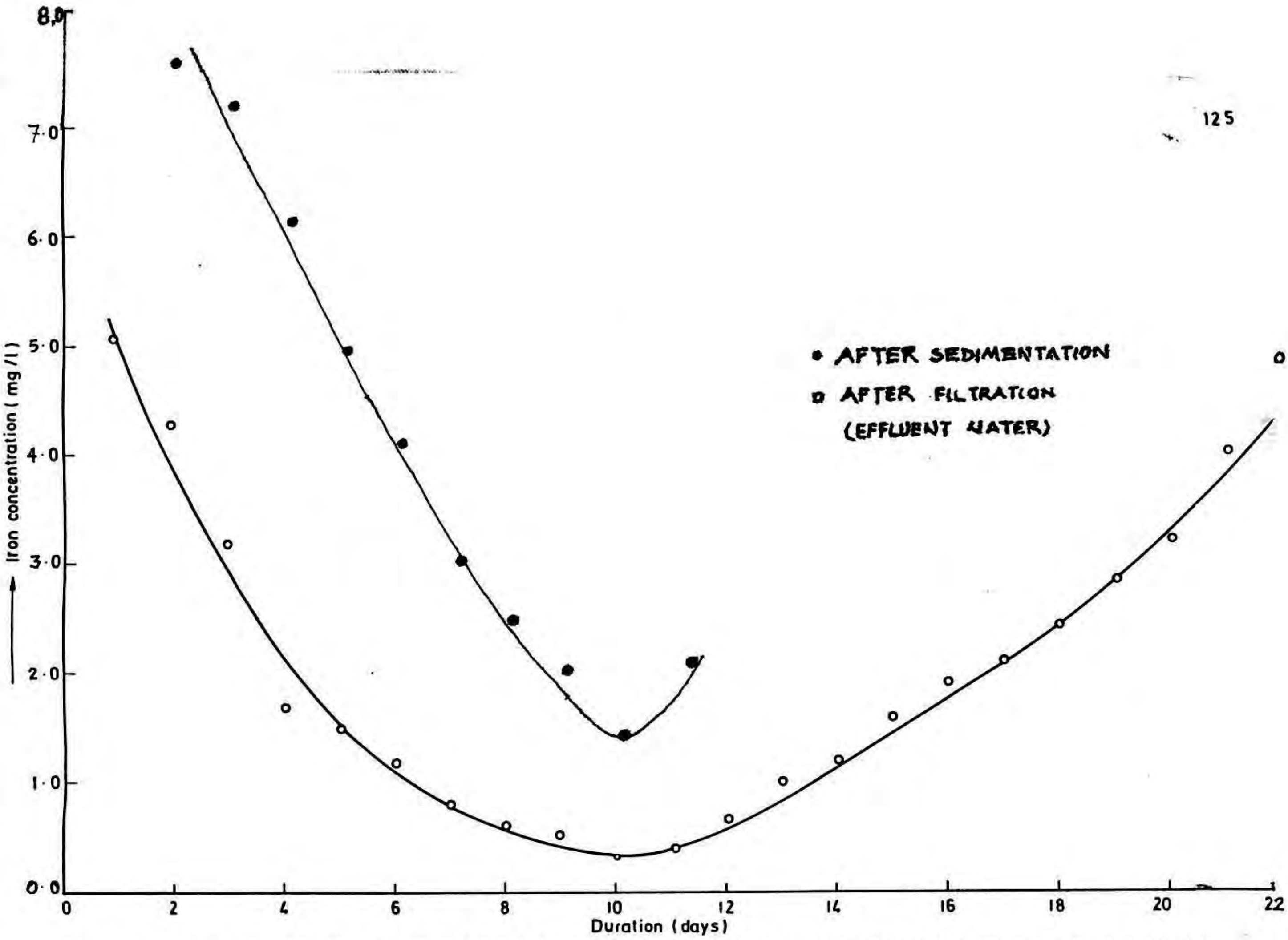


FIG. 5·17 VARIATION OF IRON CONCENTRATION OF WATER SAMPLE OF THE MODIFIED PLANT WITH DURATION (2ND RUN)

Table 5.13 Percentage Removal of Iron from Water in Various Chambers of the Modified Plant (2nd Run)

Day of operation	Cumulative percentage removal of iron			
	Upto aeration	Upto flocculation	Upto sedimentation	Upto filtration
1st	11.2	29.3	56.1	75.1
2nd	13.2	32.2	62.9	79.0
3rd	15.6	37.6	64.9	84.4
4th	17.6	41.5	70.2	91.7
5th	18.5	45.9	76.1	92.7
6th	20.9	50.2	80.0	94.1
7th	22.4	52.2	85.4	96.1
8th	23.9	50.7	87.8	97.1
9th	23.9	45.4	90.2	97.7
10th	23.9	43.4	93.2	98.5
11th	23.4	41.0	89.8	97.6

the 1st day and minimum concentration day in different chambers with detention time have been shown in Fig. 5.18. The maximum percentage removal was found to be 98.5% which is nearly the same as in the first run.

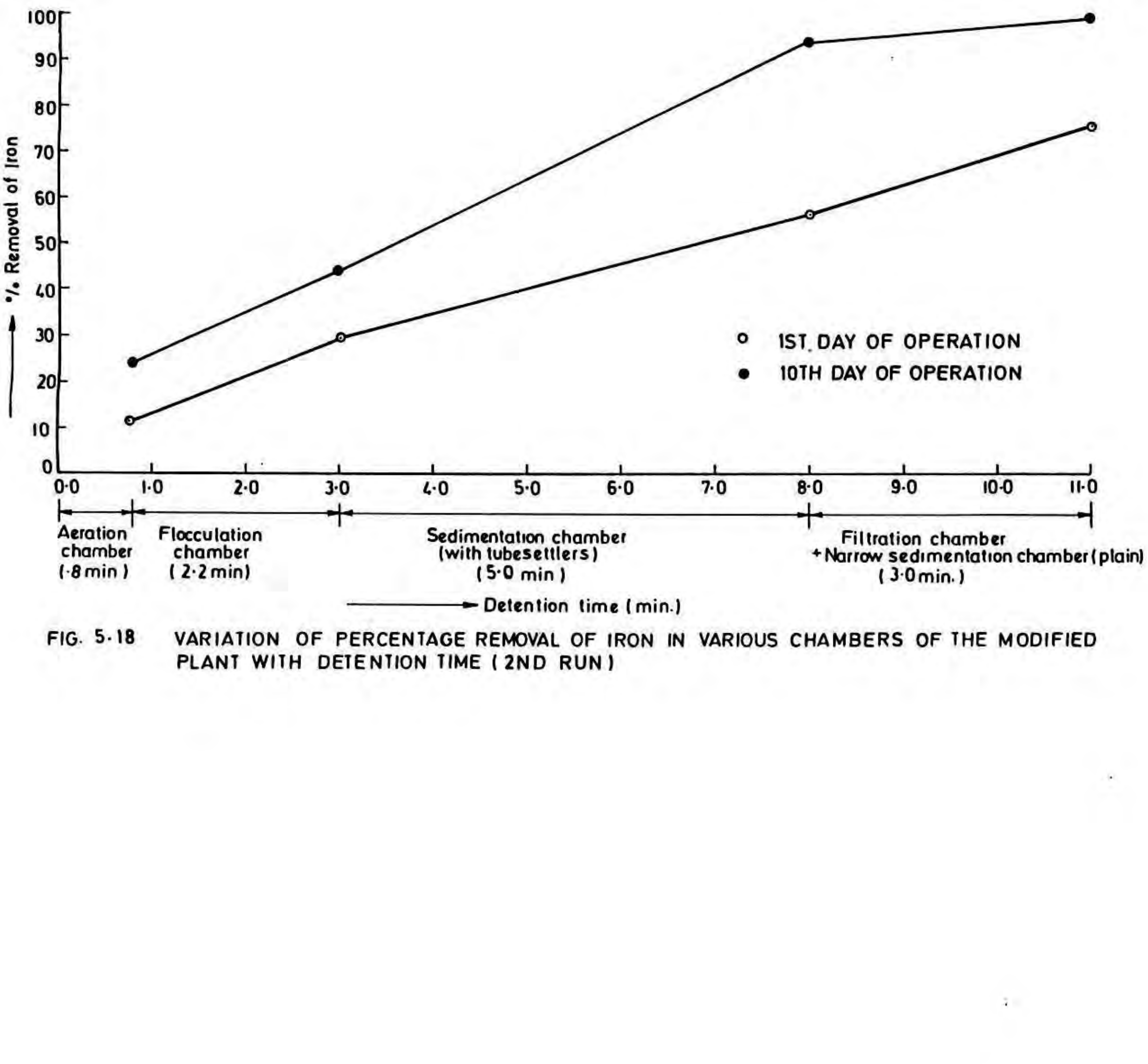


FIG. 5·18 VARIATION OF PERCENTAGE REMOVAL OF IRON IN VARIOUS CHAMBERS OF THE MODIFIED PLANT WITH DETENTION TIME (2ND RUN)

Yield of the Plant

The plant yields have been shown in Table 5.14. The yields have been plotted against the duration which are shown in Fig. 5.19. The initial yield was 14.2 liters/min which is also nearly the same as the yield in the first run (14.4 liters/min). On the 22nd day (filter run) the yield was found to be 7.5 liters/min which is satisfactory.

Table 5.14 Variation of Plant Yield of the Modified Plant with Duration (2nd Run)
(On the basis of 1 minute pumping)

Day of operation	Yield (liter/minute)
1st	14.2
3rd	13.8
5th	13.1
7th	12.0
9th	10.7
11th	9.3

Filter Run

On the 10th day of operation the concentration of iron was found to be the minimum and on the following day it was found to increase again. In this run the samples were collected and tested

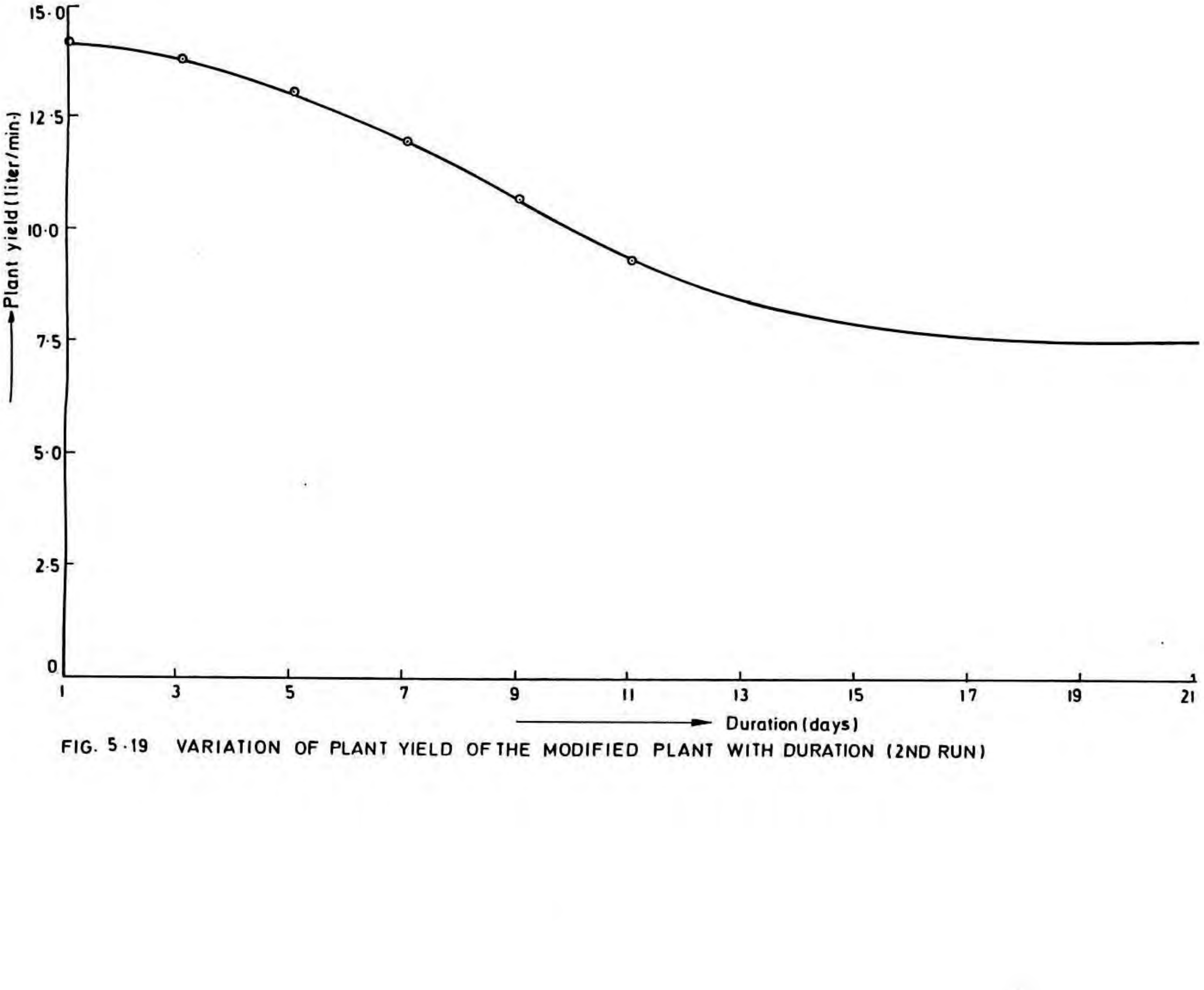


FIG. 5·19 VARIATION OF PLANT YIELD OF THE MODIFIED PLANT WITH DURATION (2ND RUN) until the iron concentration of the sample exceeded the value which was observed on the 1st day of operation and this happened on the 22nd day of operation. So the filter run of this run was assumed to be 22 days which equals the filter run of the 1st run.

5.5 Other Water Quality Parameters and People's Acceptance

5.5.1 Other Water Quality Parameters

On the 11th day of 1st run of the modified plant, samples were collected from different chambers and tested in the laboratory for iron concentrations, pH, alkalinity, hardness, dissolved O_2 and dissolved CO_2 which have been presented in Table 5.15.

pH and alkalinity increased within the different chambers. But iron concentration decreased by 99.3 percent. Hardness and dissolved CO_2 also decreased finally. Dissolved O_2 increased during aeration and decreased gradually within the other chambers. The dissolved oxygen concentration of raw water was found to be 3.0 mg/l. When raw water was being withdrawn, it was aerated to some extent due to the open space at the top of the tubewell and small pores in the flexible pipe connected to the spout.

Table 5.15 Variation of Different Water Quality Parameters within the Chambers of the Modified Plant (11th day of 1st Run)

Day of sampling	Water quality parameters	Concentration at different sampling points				
		Inlet (Raw water)	After aeration	After flocculation	After sedimentation	Outlet (Treated water)
	Iron, mg/l	20.5	15.6	11.7	0.6	0.15
	pH	6.6	6.9	7.1	7.2	7.3
11th	Alkalinity, mg/l	320.0	330.0	345.0	360.0	380.0
day	Hardness, mg/l	450.0	445.0	425.0	410.0	400.0
	Dissolved O_2, mg/l	3.0	7.0	6.0	4.5	2.5
	Dissolved CO_2, mg/l	140.0	80.0	60.0	50.0	40.0

5.5.2 People's Opinion about the Non-usage of Tubewell Water in Iron Problem Areas

During the survey of the project area several households were interviewed and people expressed their opinons about the causes of the non-usage of tubewell water in iron problem areas. The opinions are presented in Table 5.16 and graphically represented in Fig. 5.20. From the survey it is evident that aesthetics is the main reason for the non-usage of iron content water. Staining clothes and utensils is also a vital reason for the non-usage of tubewell water in iron problem areas. Odor, taste and making hair

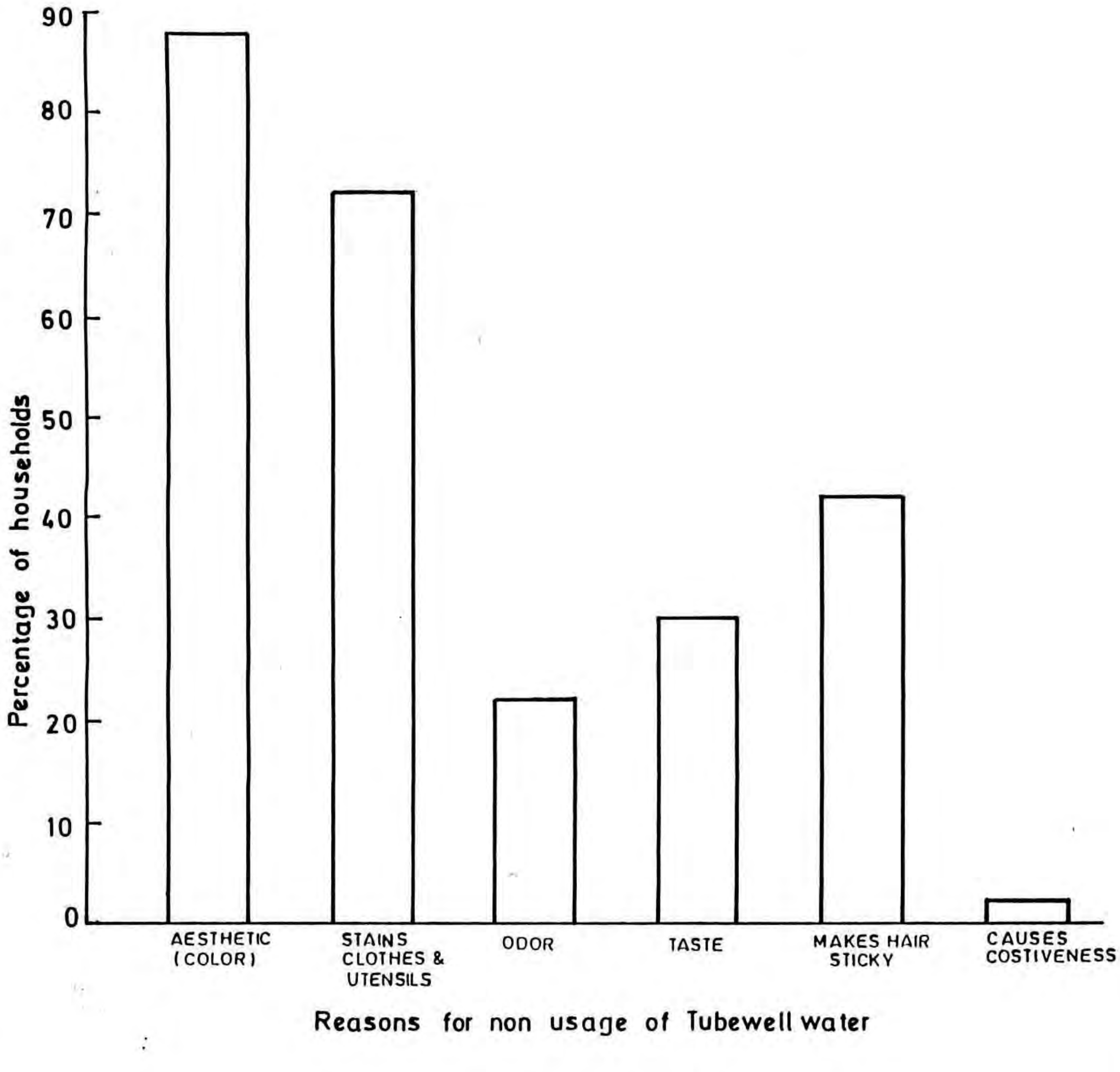


FIG. 5.20 GRAPHICAL REPRESENTATION OF THE REASONS FOR NON USAGE OF T/W WATER IN IRON PROBLEM AREAS

sticky also affect the usage of iron content water to some extent. The usage of tubewell water in iron problem areas causes costiveness to very little extent.

Table 5.16 Reasons for Non-usage of Tubewell Water in an Iron Problem Area (Percentage)

Aesthetic (color)	Stain clothes and utensils	Odor	Taste	Makes hair sticky	Causes costiveness
88.0	72.0	22.0	30.0	42.0	2.0

5.5.3 Different Water Sources used in Different Purposes

Another inteview was taken about the water sources used by households for various domestic purposes in iron problem areas which have been shown in Table 5.17. A graphical representation of the purposes for the use of tubewell water in iron problem areas has been made in Fig. 5.21. The survey reveals that cent percent people use tubewell water for drinking and other than tubewell water for bathing in iron problem areas. 90% people use tubewell water for cooking, but only 34% use it for washing utensils. On the other hand 96% people use other than tubewell water for laundry, sanitary and other purposes.

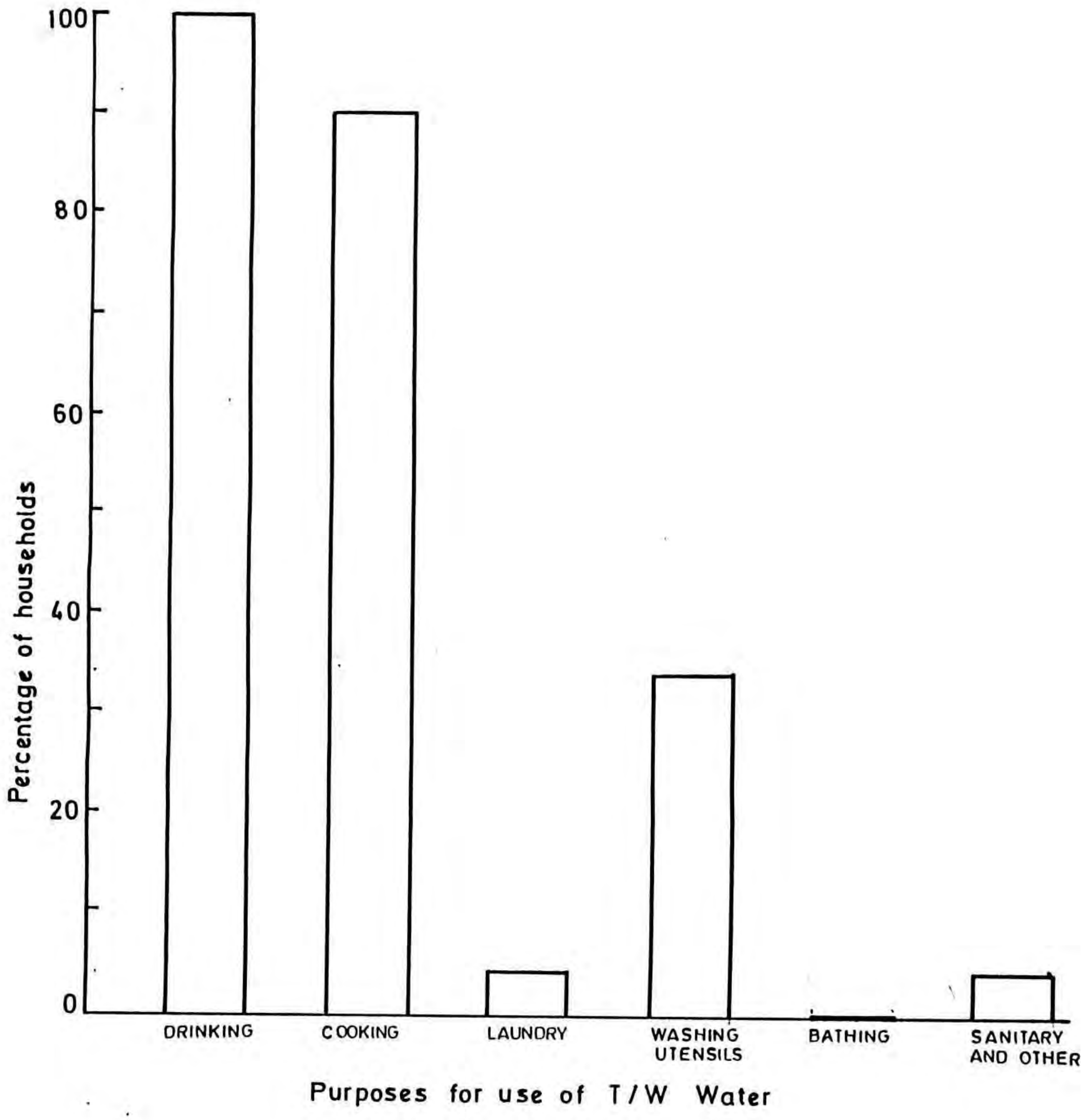


FIG. 5.21 GRAPHICAL REPRESENTATION OF THE PURPOSES FOR USE OF T/W WATER IN IRON PROBLEM AREAS

Table 5.17 Water Sources used by Households for Various Domestic Purposes in Iron Problem Areas (Percentage)

Source	Drinking	Cooking	Laundry	Washing utensils	Bathing	Sanitary and other
Tubewell	100.0	90.0	4.0	34.0	0.0	4.0
Other	0.0	10.0	96.0	66.0	100.0	96.0

5.5.4 People's Opinion About Water Quality in Iron Problem Areas

In different iron problem areas (like Dhamrai Bazar, Kalampur Bazar & Baratia, Dhulibhita, Sutipara) some households were interviewed about their general opinion on water quality. Their opinions (e.g. excellent, good, medium, bad and very bad) have been plotted in Fig. 5.22 against the iron content of tubewell water. It was observed that water having iron concentration less than 3.0 mg/l was of no objection to the people and they called such water as good.

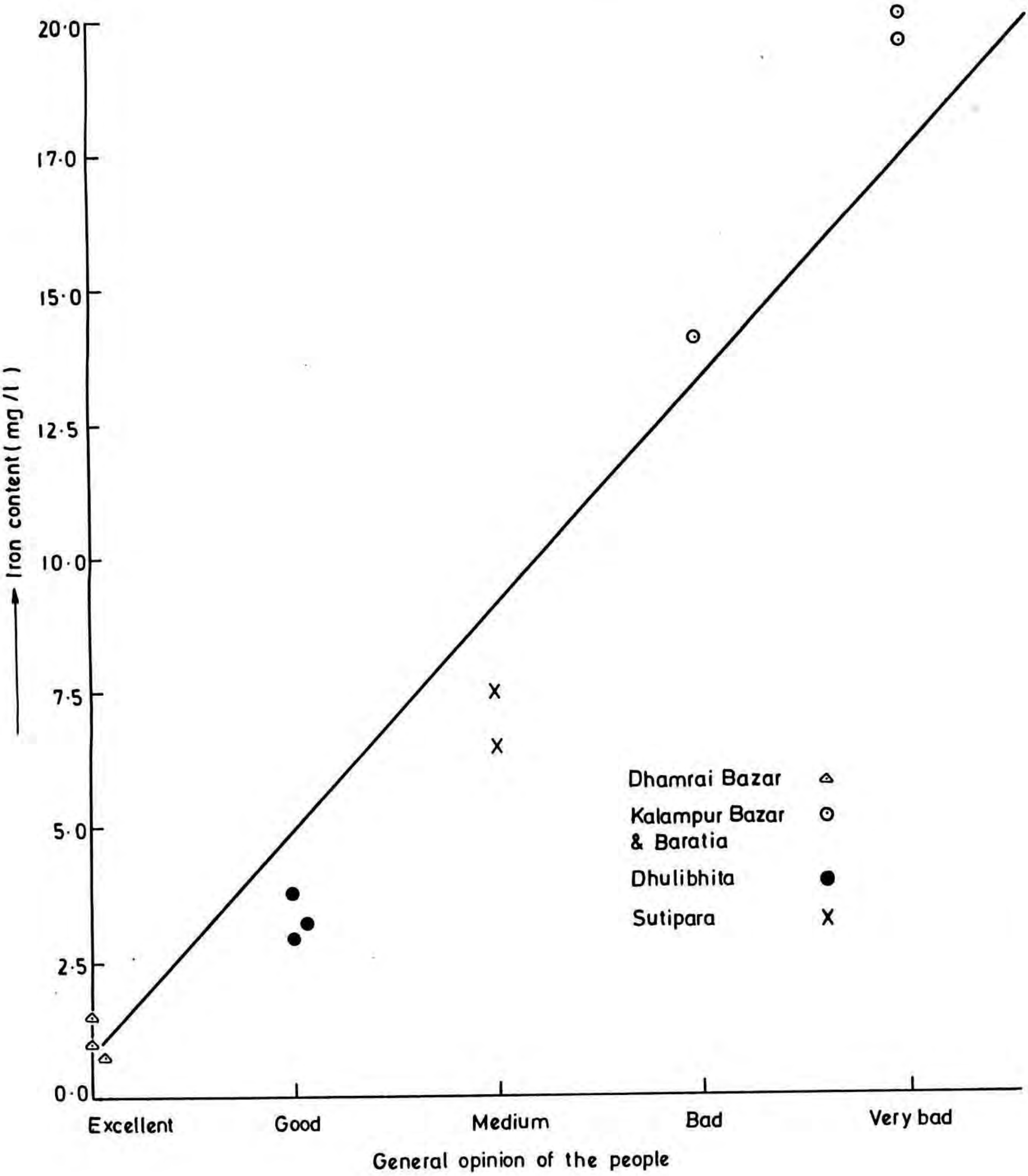


FIG. 5 ·22 IRON CONTENT AND PEOPLES' OPINION ABOUT WATER QUALITY IN IRON PROBLEM AREAS

5.5.5 People's Acceptance of the Modified Iron Removal Plant

After the construction of the plant the households using the plant were interviewed and the people expressed their opinions whether they were satisfied with the effluent water quality, plant yield and the cleaning procedure. The opinions are presented in Table 5.18. and graphically represented in Fig. 5.23. 18 households were using the plant and no. of beneficiaries was approximately 162. From the survey it was observed that cent percent people were satisfied with effluent water quality, but only 60% were satisfied with yield and 57.5% were satisfied with the cleaning procedure.

Table 5.18 Beneficiaries' Opinion about the Performance of the Modified Plant (percentage)

Satisfied with effluent water quality		Satisfied with yield		Satisfied with the cleaning procedure	
Yes	No	Yes	No	Yes	No
100.0	0.0	60.0	40.0	57.5	42.5

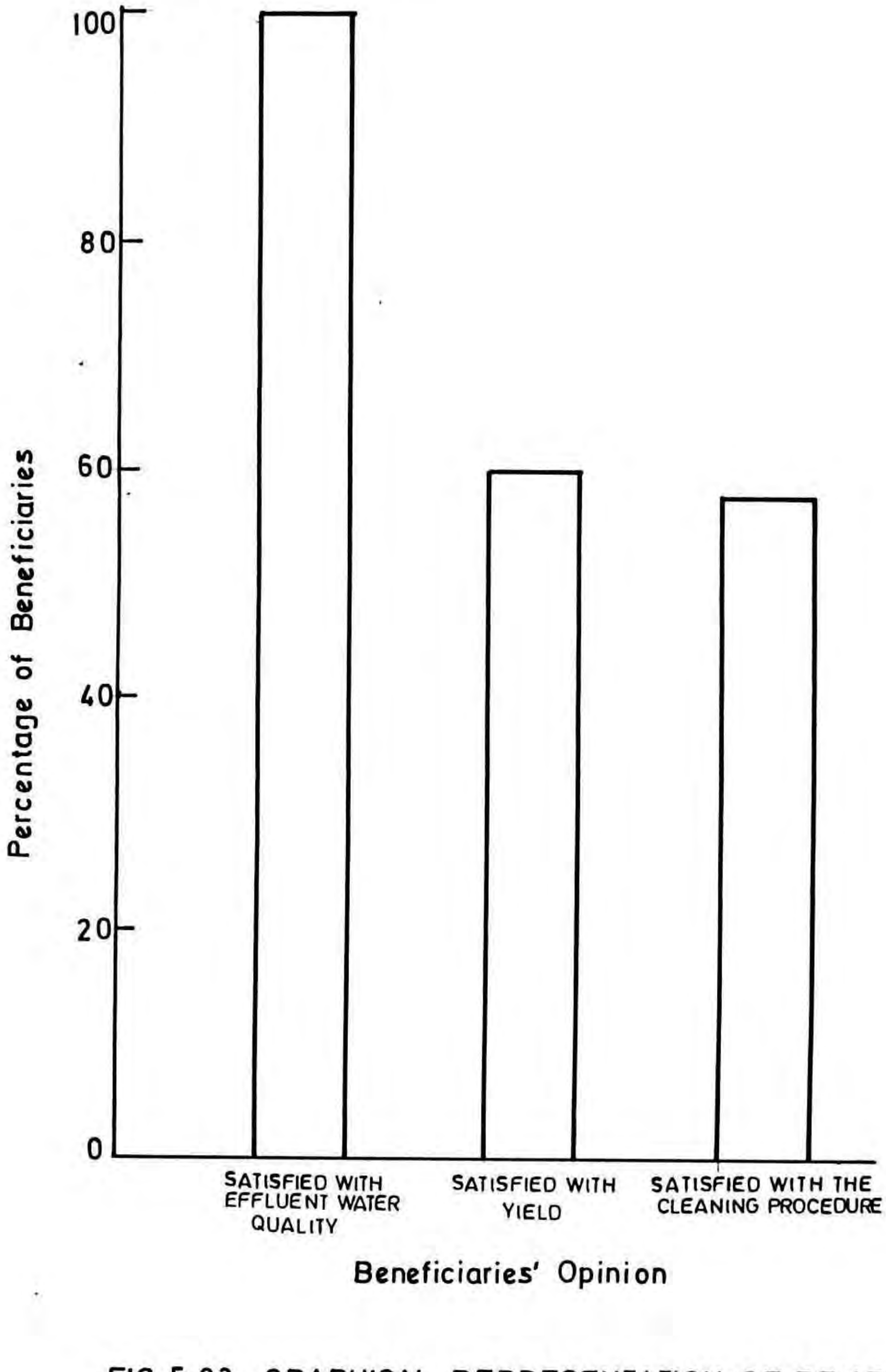


FIG. 5·23 GRAPHICAL REPRESENTATION OF BENEFICIARIES' OPINION ABOUT THE PERFORMANCE OF THE MODIFIED PLANT

After the construction of the plant the households near the plant were also intervived about their use of effluent water for different purposes which is shown in Table 5.19. Total no. of households using water from the plant was 18. But only 11 households were interviewed because of the absence of the househead and due to the privacy of the housewives. From the interview it was observed that all the households believed that plant effluent water was better, but only 6 households were interested in maintaining the plant. 5 households were found to use plant water for all purpose, 3 for all purpose except bathing, 3 for drinking and cooking and none for only drinking.

Table 5.19 Use of Effluent Water for Different Purposes

No. of households using water	No. of households use water for				No. of households believe that plant water is better	No. of households	
	All purpose	All purpose except bathing	Drinking & cooking	Only drinking		are interested in maintaining	are not interested in maintaining
11	5	3	3	0	11	6	5

The plant was also surveyed six months after the construction and it was found in operation. The people were using the plant without any difficulty. They were satisfied with the effluent water quality, the plant yield and the cleaning procedure.

5.6 Comparison between the two Plants

The previous plant and the modified plant can be compared in the following ways:

-- Maximum percentage removal of iron in the previous plant was 97.5 percent and in the modified plant it was found to be 99.3 percent. So the latter was more acceptable to get better quality of water.

--- The maximum plant yield was 8.2 liters/min in the previous plant and in the modified plant it was 14.4 liters/min which is about 75.6 percent higher.

--- The filter run in the modified plant was found to be 22 days, whereas in the previous plant it was only 14 days. The filter run in the modified plant was increased by 57.1 percent.

--- Due to the change in the position of outlet point in the modified plant it was advantageous for the users to collect water from the plant.

--- Since tube settlers were used in the modified plant, scouring from the bottom of the sedimentation chamber was unlikely to occur.

5.7 Comparison between the Modified Plant and the UNICEF Plant

A comparison has been made between the modified plant and the UNICEF plant regarding the iron removal efficiency, filter run and yield of the plants which has been presented in Table 5.20. The comparison shows that the modified plant is superior to the UNICEF plant with respect to the iron removal efficiency, filter run as well as cost per yield.

Table 5.20 Comparison between the Modified Plant and the UNICEF Plant

Parameters	Modified Plant	UNICEF Plant
Iron Removal upto Sedimentation (%)	97.1	39.0
Ultimate Iron Removal (%)	99.3	85.0
Filter Run (days)	22.0	14.2 (average)
Maximum Yield Obtained (liter/min)	14.4	13.15
Cost/Yield (Tk./liter of yield per min)	220.50	325.70

5.8 Discussion

Iron content water indirectly affects the health of rural people. Obviously the aesthetic problem is the main problem caused by the presence of iron. But due to the aesthetic reason the rural people do not use tubewell water and they use water from unprotected sources like ponds, rivers etc. which is not desirable from the hygiene point of view. This also happens due to the traditional habits of the rural people and their lack of awareness about the causes of water borne diseases. So the solution is the construction of iron removal plants in iron problem areas alongwith the massive campaign on health education.

In early days a number of iron removal plants were constructed but many plants were left abandoned due to the maintenance problem. For example UNICEF has designed an iron removal plant which is effective in iron removal. But its filter run is too low. So the people do not feel any interest to maintain the plants. As a result the main purpose of constructing an iron removal plant as well as the development of rural water supply system is not achieved.

In the modified plant the iron removal efficiency is higher compared to that of the UNICEF plant. Since UNICEF had not used a flocculation chamber prior to the sedimentation, iron removal in sedimentation chamber was 39% percent which is not satisfactory. On the other hand in the modified plant the percentage removal of iron in the sedimentation chamber was 97.1 percent which is quite satisfactory. As a result the ultimate removal efficiency was also increased to 99.3 percent, whereas it was only 85% in the UNICEF improved plants.

The average filter run in the UNICEF plant was only 14.2 days. But in the modified plant it is 22 days -- about an increase of 55.0 percent. Since filter run is the main problem in maintaining the plant the modified plant would be maintained easily. The cleaning procedure is also acceptable to 57.5 percent of the users (Table 5.18). The effluent water quality is also acceptable to cent percent of the users (Table 5.18).

The primary yield of the modified plant was 14.4 liters/min which is 75.6 percent higher than the yield of the previously designed plant. The decreasing rate of the yield is not so high. On the 11th day the yield was found to be 10.4 liters/min which is only 27.8 percent lower than the initial yield.

Hence on the basis of the iron removal efficiency, plant yield, filter run, cleaning procedure and maintenance facilities, the modified plant can totally be acceptable to the rural people.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions are drawn on the basis of the results obtained from the research work:

(i) The main reasons for non-usage of tubewell water in an iron problem area are aesthetics and staining clothes and utensils. In an iron problem area tubewell water is used mainly for drinking and cooking. In the areas where iron concentration is more than 3 mg/l, iron removal plants need to be constructed.

(ii) An aeration tray with a weir at the beginning, several undulations across the tray and gravels randomly placed over the tray is very much efficient in increasing dissolved oxygen which oxidizes soluble ferrous iron into insoluble ferric iron.

(iii) A plant with sedimentation chamber without tube settlers remove 80% iron upto sedimentation whereas that with tube settlers remove 97.1% iron upto sedimentation which indicates an increase in iron removal efficiency upto sedimentation by about 21.4% which is consequently followed by an increase in filter run as well as the plant yield.

(iv) Brick chips used as coarse media in flocculation chamber cause small flocs to become larger in size and enhance settling characteristics and prevent rapid decrease of permeability and thereby increase plant yield and filter run.

(v) An iron removal plant with a gravity flow aerator, a coarse media flocculator, a plain sedimentation tank and a coarse media filtration chamber can remove maximum 97.5 percent of iron from tubewell water. The filter run of such a plant is 14 days. The maximum yield is 8.2 liters/min which decreases gradually upto the cleaning period.

(vi) An iron removal plant with a gravity flow aerator, a coarse media flocculator, a sedimentation tank with tube settlers placed at an inclination, a coarse media filtration chamber and finally a narrow plain sedimentation chamber can remove maximum 99.3 percent of iron from tubewell water without being cleaned upto 22 days (filter run). The yield is about 14.4 liters/min which indicates an increase of about 75.6% compared to the yield of the first plant.

(vii) The effluent water quality of the modified plant is satisfactorily acceptable to cent percent people. The yield is acceptable to 60% people. The cleaning procedure as well as the filter run is also acceptable to 57.5% people.

6.2 Recommendations for Future Study

(i) The degree of aeration is dependent on the intensity of roughness of the aeration plate. It is also dependent on the flow velocity as well as the velocity variation. In the present case flow rate, as well as velocity was assumed constant. But actually the degree of aeration varies with the fluctuations in the velocity. So further study should be extended to consider the effect of fluctuating velocity of flow on aeration which would change the overall iron removal efficiency.

(ii) In the flocculation chamber 2.5 - 3.75 cm brick chips were used. The variation in the aggregate size would change the intensity of floc formation and thereby the iron removal efficiency and the filter run would be changed, as the clogging of the aggregates is dependent partially on the aggregate size and the iron content of raw water. It is therefore suggested that the aggregate size in the flocculation chamber should be varied and the performance of the flocculation chamber as well as the whole plant should be studied.

(iii) In the sedimentation chamber tube settlers were used to increase the percentage removal of iron and the filter run. The tube settlers were placed at an angle of 60^{o}. The placement of tube settlers is also an important factor in removing iron efficiently. So the angle of placement and the size of the tube settlers should be varied to observe the performance of the plant.

(iv) 0.60 cm-1.5 cm brick chips were used as filter media in the filtration chamber. The iron removal efficiency, the filter run and the plant yield depend partially on the size of filter media which influences the clogging intensity of the filter. Hence it is suggested that the filter media size should be varied to observe the overall iron removal efficiency and the filter run.

(v) Due to field limitations, 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 to what extent the plant should be flushed out.

(vi) In order to ensure a high standard of regular cleaning and maintenance of the plant adequate inspection program should be maintained by DPHE, Bangladesh. Alongwith the rural people should be motivated not to use water from unprotected sources and provided with hygiene education specially the knowledge of water borne diseases.

(vii) Finally 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 these plants which would increase the tubewell water consumption also.

BIBLIOGRAPHY

1. Ahmed, F. "Design Parameters for Rural Water Supplies in Bangladesh", M.Sc. Engineering Thesis, Dept. of Civil Engineering, BUET, Dhaka, Bangladesh, April, 1981.

2. Ahmed, M.F., Hossain, D., Khan, L.I., Badruzzaman, A.B.M., Chowdhury, N.I., "Potable Water Supply in Iron Problem Rural Areas of Bangladesh", Final report, Department of Civil Engineering, BUET, Dhaka, Bangladesh, October, 1989.

3. Ahmed, F. "Low Cost Iron Removal from Handpump Tubewells", University of Strathclyde, U.K., September, 1987.

4. Bell, G.R., "Removal of soluble iron by filtration", Journal AWWA, 57(1), 458, 1965.

5. The American Water Works Association, Inc., "Water Quality and Treatment", (3rd Ed.), McGraw Hill Book Company (1971).

6. Ahmed, F. and Smith, P.G. "Design and Performance of a Community type Iron Removal Plant for Hand Pump Tubewells", Journal of the Institution of Water Engineers and Scientists, Vol. 41, April 1987, No. 2, pp 167 to 172.

7. Dixit, R.C., Pathak, B.N., "Iron Removal Studies at Howrah", Central Public Health Engineering Research Institute, Nagpur-3, presented at the Third Annual Convention, Indian Water Works Association, Birla Kreeda Kendra Chowpaty, Bombay, January, 1971, Vol. III.

8. Anon 1986, Department of Public Health Engineering, Govt. of the People's Republic of Bangladesh, Unpublished Data.

9. A Report on "The Development of an Iron Removal Plant for Hand Pump Tubewells", Prepared by Department of Public Health Engineering, Govt. of the People's Republic of Bangladesh and UNICEF, Dhaka, Bangladesh.

10. A Report on "Study of Improved Iron Removal Plants", WHO/DPHE/UNICEF, April-June, 1990.

11. Wong, Joseph M., "Chlorination - Filtration for Iron and Manganese Removal", Journal AWWA, January 1984.

12. Equina, N.R., "Iron and Manganese Removal by Horizontal Prefiltration", Master's Thesis, Asian Institute of Technology, Thailand, 1979.

13. Czekalla, C., Mevius, W., Hanert, H., "Quantitative Removal of Iron and Manganese by Microorganisms in Rapid Sand Filters", Water Supply, 3 1, 1985, Pergamon Press, Oxford, U.K., 1985, 111-123, En.

14. Seekonk, Mass., "Removing Iron and Manganese from Groundwater", Journal AWWA, 76 11, 1984, 67-68, 92, En.

15. Ogedengbe, O., Olasupo, S.A., Adeniji, O. "Powdered Palm Kernel Shells for Domestic Water Filters", Filtrat. Sep., 1984, 115-117, En.

16. Zirschky, J., Carlson, L., "Overland Flow for Iron Removal from Potable Water", Journal AWWA, 76 1, 1984, 80-83, En.

17. Frankel, R.J., "Operation of the Coconut Fiber/Burnt Rice Husks Filter for Supplying Drinking Water to Rural Communities in South-East Asia", Am. J. Public Health, 69 1, 1979, 75-76, En.

18. Kibret, A., "Dry Filter-Application in Water Treatment for Iron Removal", Water Supply and Sanitation Publications No. 27, 1986, Finland.

19. Wang, B.Z., Tian, J.Z., Yin, J., "Purification of Polluted Source Water with Ozonation and Biological Activated Carbon", Aqua, 6, 1986, 351-357, En.

20. Bajracharya, K. "Removal of Iron from Ground Water" Asian Institute of Technology Special Study Project Report No. EV-84-1, Bangkok, Thailand, 1984.

21. Ghosh, Mriganka M., O'Connor, John T., Engelbrecht, R.S., "Precipitation of Iron in Aerated Ground Waters", Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 92, No. SA1, Ferbruary, 1966.

22. Stumm, W., Lee, G.F., "The Chemistry of Aqueous Iron", Schweizerische Zeitschrift fur Hydrologie, Birkhauser Verlag, Basel, Vol. XXII, 1960, pp 295-319.

23. Feachem, R., McGarry M., Mara D., "Water, Wastes and Health in Hot Climates", John Wiley & Sons (1977).

24. Stumm, W., Lee, G.F., "Oxygenation of Ferrous Iron", Industrial and Engineering Chemistry, Easton, Pa., Vol. 53, 1961, p.143.

25. Leclerc, A., Trivu, T., "Desorption and Retentivity of Filtering Materials", J. Sanitary Engg. Div., A.S.C.E. 98 SA6, 937.

26. Walker, R., "Water Supply, Treatment and Distribution", Prentice-Hall, Inc. Englewood Cliffs, New Jersey, (1978).

27. Huisman, L., Sundaresan, B.B., De Azevedo Netto, J.M., Lanoix, J.N., "Small Community Water Supplies", Edited by E.H. Hofkes, Technology of SWSS in Developing Countries, John Wiley & Sons, 1981.

28. Clark, John W., Viessman, Warren Jr., Hammer, Mark J. "Water Supply and Pollution Control", Third Ed., Harper & Row, Publishers (New York), 1977.

29. Ghosh, M.M., O'Connor, J.T., Engelbrecht, R.S.(1967), "Iron and Manganese Removal by Filtration", Water and Sewage Works, 114, 123.

30. Sung, W., Forbes, E. (1984), "Some Considerations on Iron Removal", Journal of Environmental Engineering, American Society of Civil Engineers (A.S.C.E.), 110(6), 1048.

31. Carman, P.C., Fluid Flow through Granular Beds", Trans. Inst. Chem. Engrs. (London), 15, 150(1937).

32. Ahmed, F. and Smith, P.G., "A Field Study into Patterns of Domestic Water Consumption in Rural Areas of Bangladesh", Pergamon Journals Limited, IWSA, Aqua No. 3, pp 149-153, 1987, Great Britain.

33. Hammer, Mark J., "Water and Wastewater Technology (SI Version)", John Wiley & Sons, Inc. (1977).

34. Fair, G.M., Geyer, J.C., Okun, D.A., "Water and Wastewater Engineering", John Wiley and Sons, Inc. 1966.

35. Metcalf & Eddy, Inc. "Wastewater Engineering: Treatment Disposal Reuse", TATA McGraw Hill Publishing Company Ltd., New Delhi, (1979).

36. Montogomary, James M., Consulting Engineers, "Water Treatment Principles and Design", John Wiley and Sons. Inc. 1985.

37. Salvato, J.A., "Environmental Engineering and Sanitation (3rd Edition, John Wiley and Sons Inc. (1982).

38. Steel, E.W., McGhee, J., "Water Supply and Sewerage", McGraw-Hill Kogakusha, Ltd. (1979).

39. Twort, A.C., Law, F.M., Crowley, F.W., "Water Supply" (3rd Ed.), Arnold International Student Edition, AISE, 1985.

40. Hardenbergh, W.A., Rodie, Edward B., "Water Supply and Waste Disposal", Allied Publishers Private Limited, 15 Graham Road, Ballard Estate, Bombay-1, 1972.

41. Schroeder, Edward D., "Water and Wastewater Treatment", McGraw Hill Company, 1977.

42. Duggal, K.N., "Elements of Public Health Engineering", S. Chand & Company Ltd., 1984, New Delhi.

43. Arceivala, S.J., "Wastewater Treatment & Disposal", Marcel Dekker, Inc., 1981.

44. Dijk, J.C. Van, Oomen, J.H.C.M., "Slow Sand Filtration for Community Water Supply in Developing Countries", WHO International Reference Centre for Community Water Supply, Technical Paper No. 11, Dec. 1978.

45. Cairncross, S., Carruthers, I., Curtis, D., Feachem, R., Bradley, D., Baldwin, G., "Evaluation for Village Water Supply Planning". John Wiley & Sons, 1980.

46. Aziz, M.A., "A Text Book of Water Supply Engineering", Hafiz Book Centre, Dhaka, Bangladesh.

47. Husain, S.K., "Text Book of Water Supply and Sanitary Engineering", Oxford & IBH Publishing Co., 1976.

48. W. Wesley Eckenfelder, Jr., "Water Quality Engineering for Practicing Engineers", Barnes & Noble, Inc. New York, 1970.

49. Hahn, R.W., "Fundamental Aspects of Water Quality Management", Technomic, Westport, Conn., 1972.

50. Ramalho, R.S., "Introduction to Wastewater Treatment Processes", Academic Press, New York, 1977.

51. Anon 1976, "Rural Water Supply Construction Projects in Bangladesh: Plan of Operation", Govt. of the People's Republic of Bangladesh, UNICEF and WHO.

52. Skoda, J.D.; Mendis, J.B. and Chia, M., "A Survey in Rural Bangladesh on Diarrhoeal Morbidity, Water Usage and Related Factors", Final Report, July 1979, UNICEF, Dhaka.

53. Aowal, A.F.A., "Design of an Iron Eliminator for Hand Tubewells", J. Indian WWA, 1981.

54. George, A.D., Chaudhuri, M., "Removal of Iron from Groundwater by Filtration through Coal", Journal AWWA, July 1977.

55. Fair, G.M., Geyer, J.C., Okun, D.A., "Elements of Water Supply and Wastewater Disposal", 2nd ed., John Wiley and Sons, 1971.

56. Vigneswaran, S., Tam, D.M., Visvanathan, C., Thanh, N.C., Schulz, C.R., "Water Filtration Technologies for Developing Countries", Environmental Sanitation Reviews, No. 12, December 1983, ESIC, Bangkok, Thailand.

APPENDICES

APPENDIX A-1

INTERVIEW QUESTIONNAIRE

(Pre-construction Survey
at Dhamrai Upazilla)

1. Village ----------- 2. Date -----------
3. House No. ---------- 4. Religion
5. Name of Informant and
Relation with househead: -----------------------------------
6. Occupation: ---------------------
7. Level of Education:

Nothing	Primary	Secondary	Above Secondary
☐	☐	☐	☐

8. Total number of household: (Indicating male and female)

Male	Female	Total
☐	☐	☐

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

	yes	no
a) Tubewell water has a cloudy appearance	☐	☐
b) Cooked food and clothes, and utensils become colored	☐	☐
c) Tubewell water has a bad taste and odor	☐	☐
d) Hair becomes sticky	☐	☐
e) Tubewell water causes costiveness	☐	☐
f) Take more time in boiling rice and dal	☐	☐

g) Other reasons, if any

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10. Sources of Water for Domestic Purposes:

Nature of consumption	Tubewell	Other
Drinking		
Cooking		
Laundry		
Washing Utensils		
Bathing		
Sanitary and other		

11. Water Quality of the nearest tubewell:

The Tubewell water is -

- ☐ Excellent
- ☐ Good
- ☐ Medium
- ☐ Bad
- ☐ Very bad

APPENDIX A-2

INTERVIEW QUESTIONNAIRE

(Post-construction Survey
at Dhamrai Upazilla)

1. Village ------------------ 2. Date -----------
3. House No. ------------- 4. Religion --------
5. Name of the Informant and
   Relation with household:
6. Occupation ---------------------
7. Level of Education:

Nothing	Primary	Secondary	Above Secondary
☐	☐	☐	☐

8. Total number of household: (Indicating male and female)

Male	Female	Total
☐	☐	☐

9. Beneficiaries' Opinion about the Performance of the Plant:

	Yes	No
a) Satisfied with effluent water quality	☐	☐
b) Satisfied with yield	☐	☐
c) Satisfied with the cleaning procedure	☐	☐

10. Use of Effluent water for Different purposes:

a) Uses effluent water for -

- ☐ All purpose
- ☐ All purpose except bathing
- ☐ Drinking & cooking
- ☐ Only Drinking

b) Believes that plant effluent water is better ----- ☐ yes ☐ no

11. Interest in maintaining the plant:

☐ Interested in maintaining

☐ Not interested in maintaining

APPENDIX B-1

MATERIALS AND COST OF THE MODIFIED PLANT

(on the basis of up-to-date price)

Sl. No.	Item	Quantity	Rate	Cost (Tk.)
1.	1st Class Bricks (Masonry+khoa making)	400 nos.	Tk. 1800 per 1000	720/-
2.	Cement	5 bags	Tk. 150 per bag	750/-
3.	Sand (best quality) (+ carrying)	20 cft	Tk. 300 per 100 cft	60/-
4.	16 gauge wire mesh	25 sft	Tk. 7 per sft	175/-
5.	Padlow	1 kg	Tk. 40 per kg	40/-
6.	3/4"pvc pipe for tube settlers	250 ft	Tk. 2 per ft	500/-
7.	Miscellaneous (rubber tubes, clips, elbow, polythin, net etc.)			30/-
8.	Mason	3 days	Tk. 120 per day	360/-
9.	Labour (Masonry+khoa making)	4 days	Tk. 60 per day	240/-
10.	Brick carrying cost			200/-
11.	Miscellaneous (drain pipes, caps etc.)			100/-
			Total cost:	3,175/-

APPENDIX B-2

MATERIALS AND COST OF THE UNICEF PLANT

(on the basis of up-to-date price)

Sl. No.	Item	Quantity	Rate	Cost (Tk.)
1.	1st Class Brick	350 nos	Tk. 1800 per 1000	630/-
2.	Sand (best quality)	20 cft	Tk. 300 per 100 cft	60/-
3.	Cement	5 bags	Tk. 150 per bag	750/-
4.	Khoa making	10 cft	Tk. 5 per cft	50/-
5.	1/8-5/8" 1st class khoa	5 cft	Tk. 25 per cft	125/-
6.	Mango wood	0.6 cft	Tk. 300 per cft	180/-
7.	C.G.I sheet	2 nos.	Tk. 240	480/-
9.	Mason	5 days	Tk. 120 per day	600/-
10.	Helper	5 days	Tk. 60 per day	300/-
11.	Carpenter	as reqd.	L.S.	250/-
12.	Carriage	as reqd.	L.S.	250/-
13.	Contingencies		L.S.	208/-
			Total Cost :	4,283/-