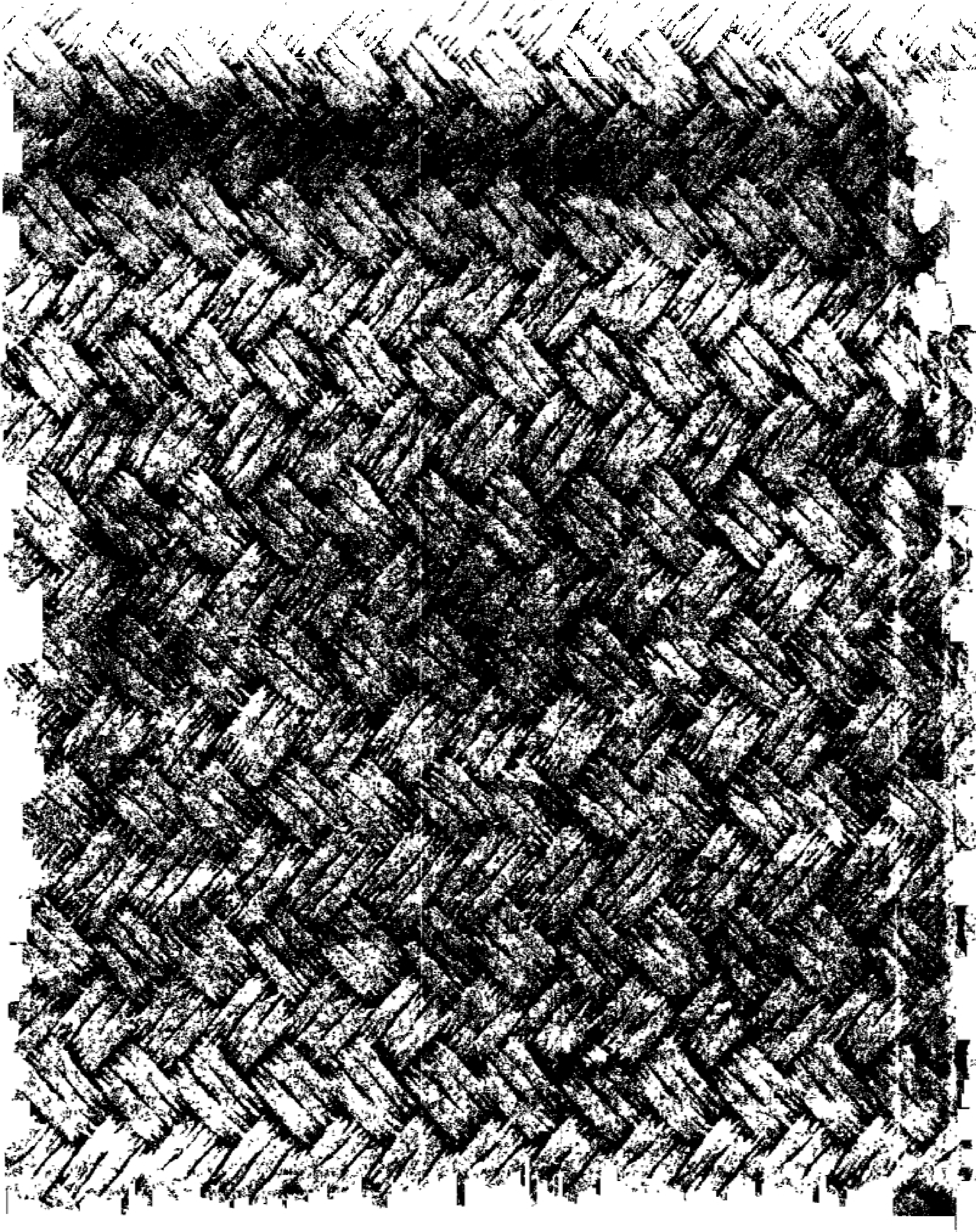

REMOVAL OF IRON FROM GROUND WATER

by

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A special study submitted for the
partial fulfilment of Diploma of the
Asian Institute of Technology

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ABSTRACT

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

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I INTRODUCTION

1.1 Statement

Safe, adequate and accessible supplies of water together with sanitation are recognized as the basic health needs and essential components of primary health care. The various sources that might be available are the surface waters, rain water and ground water . For the extraction of water, wells deep or shallow with or without handpumps are installed. Ground waters are preferable to surface waters because of lesser contamination , lesser susceptibility for seasonal variation and also can be with drawn long after drought condition .The major problem in ground water is the iron and manganese concentration above the desired level. This study however is limited to removal of iron only. Iron on the other hand is the necessary element for the human life. It is an element required for the formation of haemoglobin which is needed in transporting oxygen from the lungs to the tissue cells. A normal human adult requires 10 to 20 mg of iron intake per day. Deficiency of iron in human body causes certain forms of anaemia. The limits imposed on the concentration of iron in drinking water by World Health Organisation is based not from physiological consideration but from aesthetic and taste consideration. Allowable limit of iron for potable water is 0.1mg/l and a maximum of 1mg/l. Excessive amounts of iron may cause the following troubles:

1. Large amounts of iron will give an astringent or metallic taste to the water. The threshold of taste for iron is 1.8mg/l. (COHEN 1960)

2. Discolouration of industrial products such as paper, textiles leather ,ice etc.

3. Household utensils, glassware, dishes, fixtures (porcelain basins bath tubs etc.) are stained.

4.Clothes are stained.

5.Iron favours the growth of iron bacteria. These clog pipelines meters, nozzles and other water handling equipment, cutting down flow rates and frequently breaking loose in large clogging masses and imparts objectionable taste and odours to the water.

At present ground water extraction through handpumps is being considered as the desirable means for collecting safe water for domestic purposes in rural areas for various reasons eg. economy, technology and social aspects. Various researchers around the world have conducted studies with the purpose of devising a handpump that is simple and low cost such that it can be produced locally with the available skill and level of technology, a handpump that can withstand heavy use and misuse as well, and can be maintained and repaired at least for minor damages by the users themselves. However where wells with handpumps are the primary source of water in rural areas, high iron content in ground waters

could make the water unsuitable for domestic purposes. Therefore development of an iron removal device from handpump tubewell is essential for best utilisation of the handpumps in iron problem areas. The attempt in this study is to design a simple low cost unit which could be applicable for iron removal from ground water in the rural areas.

1.2 Objectives of the Study

The main objectives of the study are:

(i) to develop a simple treatment unit for the removal of iron from ground water extracted with a hand pump.

(ii) to examine the efficiency of the treatment unit and

(iii) to determine the effect of backwashing under low heads.

1.3 Scope of the Study

The preceeding section has established the need for a unit in conjunction with the tubewell in order to make the best utilization of the handpumps. The subject of study is to find the efficient,low cost treatment unit.The media used shall be coarse sand of effective size of about 3mm .The ground water from the deep well station of The Asian Institute Of Technology will be used as the raw water source. For higher concentrations of iron, artificial samples will be prepared making use of ferrous sulphate.

For backwashing purposes a force pump could be used to develop large heads but this attempt was proved unsuccessful for high initial cost of construction and maintenance problem of force pump.The only alternative then would be the construction of two filter units so that when one is taken out for washing , the other would be available for operation. If simple back water overflow does not help , then this would be the only simple alternative available.

II LITERATURE REVIEW

2.1 Chemistry of Iron

Iron exists in soils and minerals in the form of insoluble ferric oxide and iron sulfide. It also occurs in the form of ferrous carbonate which is slightly soluble. Iron in ground water commonly exists in the soluble ferrous state, usually ferrous carbonate. Appreciable amounts of ferrous carbonate may be dissolved by the reaction,

$$FeCO_3 + CO_2 + H_2O = Fe^{++} + 2HCO_3 \text{ ------------- } (1)$$

because ground waters usually contain significant amounts of carbon dioxide. This concentration results from bacterial oxidation of organic matter with which the water has been in contact and under the conditions, the carbondioxide is not free to escape to the atmosphere. Ferric oxide gets reduced to ferrous oxide possibly due to bacterial action and then dissolves carbondioxide to give ferrous bicarbonate according to the following reaction,

$$2Fe_2O_3 \text{ --------}\!> 4FeO + CO_2 \text{ -------------- } (2)$$

$$FeO + 2CO_2 + 2H_2O \text{ ------ } Fe(HCO_3)_2 + H_2O \text{ ------ } (3)$$

The removal process by oxidation is represented by the reaction

$$Fe(HCO_3)_2 \text{ ---------} Fe(OH)_2 + 2CO_2 \text{ ---------- } (4)$$

$$4\,Fe(OH)_2 + O_2 + 2H_2O \text{ ------- } 4Fe(OH)_3 \text{ ---------- } (5)$$

The solubility of iron depends upon the concentration of oxidizing agent and pH. Soluble iron exists mainly in bivalent state. But some trivalent ferric iron may also

exist in solution if the pH is low. In alkaline waters devoid of sulfides, phosphates and organic compounds iron will precipitate as ferrous hydroxides, ferrous carbonate, ferric hydroxide.The solubility is reduced in any form of alkalinity .

The basic equation describing the oxidation of ferrous iron by oxygen is

$$4Fe^{++} + O_2 + 10H_2O \text{ ------- } 4Fe(OH)_3 + 8H^{+} \text{ ------------- } (6)$$

As seen above, in equation no.(6), 1mg/l of oxygen will oxidize 7mg/l of ferrous iron.

The graphs developed by GHOSH and O'CONNER(1966) shows the solubility characteristics of ferrous iron in waters devoid of carbonate and sulfides species and the solubility characteristics of trivalent iron and also the characteristics of ferrous iron in alkaline waters. (figs 2.1, 2.2 and 2.3) The boundary of the shaded area defines the maximum solubility. At pH of 9 the total soluble ferrous iron in non carbonate bearing water is approximately 10^{-4} mol/litre (Fig 2.1) where as at the same pH in alkaline waters the solubility is 3.16x 10^{-7} mol/litre.(Fig 2.2 Carbonate bearing water) In Fig 2.3 the solubility of ferric iron is 10^{-10} mol/litre at pH of 9 which means that ferric hydroxide has more tendency to precipitate than ferrous iron in carbonate bearing water.

In an investigation made by STUMM and LEE (1961) on the oxygenation of the ferrous iron , they found the rate of

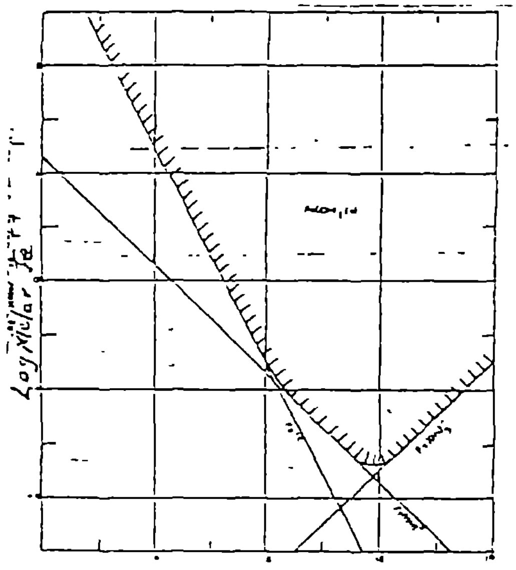


Fig 2.1 - Solubility of $Fe(OH)_{2(s)}$ in a Non - Carbonate, Non - Sulfide Solution

(Source: GHOSH and O'CONNOR, [illegible])

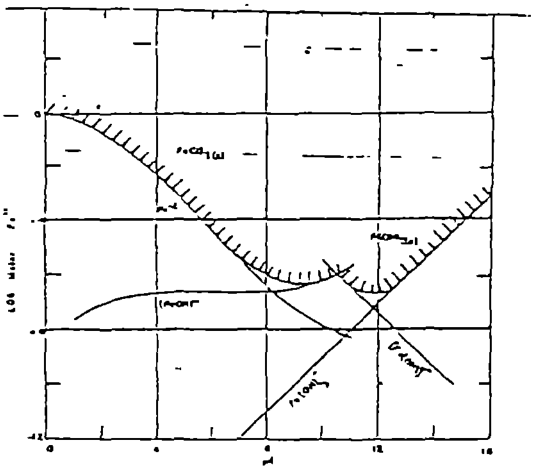


Fig 2.2 Solubility Of Ferrous Iron In A Carbonate-Bearing Water ($Alk = 10^{-2}$ eq/l)

(Source: GHOSH and O'CONNOR, [illegible])

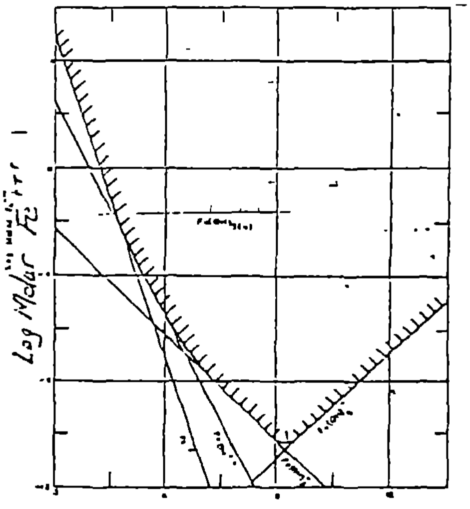


Fig 2.3 - Solubility of $Fe(OH)_{3(s)}$

oxygenation to be a function of ferrous iron concentration and the partial pressure of oxygen , p:

$$-d(Fe\ )/dt = k'\ (Fe\ )\ p \quad \text{-------------}(7)$$

where, k' is strongly dependent on pH. Their data indicated a 100 fold increase in the rate of oxidation of ferrous iron with an increase of one pH unit.

2.2 Filtration

Filtration is a process in which the suspended particles contained in the water is clarified while passing through the media pores. The fluid flow in the filter pores is laminar, that is, fluid viscous forces predominate over fluid inertia forces.The fluid flow has some similarity with Poiseuille flow in a capillary and there will be a velocity gradient in each pore, with zero velocity at the boundary with the grain surface and a maximum velocity near the pore centre.

When filtration has to be accomplished at a greater rate coarser sands are to be used. In rapid filtration the particles to be removed are smaller than the pores. It follows that if particles followed the fluid streamlines, many of them would never touch a grain surface and be removed from the flow.Therefore mechanisms of transport have to be considered which move the particles across the streamlines, so that they arrive adjacent to a grain

surface. When they arrive there, an attachment mechanism has to be considered.

The transport mechanisms are straining, interception, inertia, sedimentation, diffusion, hydrodynamic action, orthokinetic flocculation and combined transport mechanisms. Ives (1971) reported that there are several mechanisms available which all act simultaneously during filtration.However, their relative importance depend on the characteristics of the particles and the characteristics of flow and characteristics of the filter media.

Once the particles are in contact wilh the grains then attachment mechanism need to be considered. The attachment mechanisms are electrical double layer interactions , Vander Waals forces, Hydration and mutual adsorption.

2.3 Past Studies

A lot of work has been done on filtration and also a lot on removal of iron.WESTON(1914) determined the possibility of removing iron from ground water without using chemicals.Iron was induced to coagulate and the interference of organic matter was avoided by passing the water through submerged broken stones.Here the iron content was reduced from 0.9mg/l to 0.35mg/l.The contact between water and rough surface of the stones effect the displacement of carbondioxide by oxygen.The system consisted of a trickler

filled with broken stones followed by a subsidiary basin filled with coke and then by sand filter. Analysis of the media showed that iron removal began at once and was nearly complete before the filter unit was reached.

THANH and OUANO (1977) while doing their experimental investigation on the efficiency of turbidity removal by the horizontal prefilter using coarse media found that 58% removal of iron was also achieved.

A community type of iron removal plant had been constructed at Jikargacha and Narendapur in Jessore, (Bangladesh) which were in operation .(Farooque Ahmed,1981) The plant consisted of four units, aeration channel, sedimentation, adsorption and filtration chambers.The aeration channel was made of 4 PVC pipe partially filled with brick khoa and is slotted at the top. Water discharge through the mouth of the tubewell passes over the khoa and gets sufficiently aerated and then drips in the sedimentation chamber In the sedimentation chamber water falls on the charcoal bed at the top, which provides further aeration. Some portion of precipitated iron flocs settle at the bottom of the sedimentation tank. Water from the sedimentation chamber enters into the adsorption chamber at the bottom through small holes and flows upward. Small precipitated iron flocs adhere to the surface of khoa in

adsorption chamber and assist further removal of iron from tubewell water. Water from the adsorption chamber flows over a weir and enters into the filter bed where most of the remaining precipitated iron is strained by filter materials and almost iron free water is discharged.

FRANKEL, R.J.(1979) mentioned about an appropriate technology type of water filter consisting of two stages ; the first stage is made up of coconut fibres and the second stage uses burnt rice husks.It is believed that the quality of effluent from the process treatment is reasonably good fo most of the villages where investment in more expensive water treatment plants simply cannot be afforded. The plant was designed only for turbidity removal but it is possible that even iron could be removed to certain extent.

JOHN ZIRSCHKY and LIISA CARLSON (1980) in their paper have written overland flow as an effective process of iron and manganese removal from potable water.Iron and manganese removal of efficiencies as high as 97 percent have been found with one system.The theory lying behind is effective aeration and sedimentation and fitration of the resulting iron precipitate. Providing a large surface area for gas transfer, overland flow promotes the oxidation of Fe^{++}. Theoretically sedimentation is optimised by shallow sedimentation and the overland flow slope itself is a

shallow sedimentation basin. Particles need only settle a short distance before intercepting the slope, thereby being removed. First neither mechanical aeration nor chemicals are required to oxidise iron, thereby reducing energy and chemical costs.Sedimentation basins are not required for precipitation of iron.As the precipitate settled on the slope is not removed, the volume of sludge generated for disposal is considerably reduced.There are few mechanical systems which require maintenance, supervision, or energy usage. Removal of the precipitate from the surface of the recharge basins is required only approximately once a year, and the medium in the recharge basin is replaced about every two years.The only major mechanical components are the ground water and effluent pumping systems and the disinfection system.The disadvantages of this system include excessive land requirements for large systems and possible negative public perception of the effectiveness of overland flow for water treatment.

2.4 Other Methods of Iron Removal

The technique of oxidising ferrous iron to ferric iron by simple aeration has long before been used prior to filtration.LONGLEY J.M. et al(1962) found in their laboratory and field studies the removal of iron in the aerator to be 0.1 to 44 percent.

Manganese zeolite is also used in the filter and this granular black material has the ability to serve as the oxidising contact media as well as the filter medium. When the rated capacity of the manganese greensand (manganese zeolite) is reached, regeneration is accomplished with potassium permanganate. A layer of anthracite coal is usually placed above the manganese greensand media to capture suspended solids and organic material permitting longer filter runs. The operation is always restricted to pressure filtration.

The other methods include the use of various chemicals such as chlorine dioxide potassium permanganate etc.The use of YBF material as the filtering media also eliminates iron.It has been briefly described in the following paragraphs.

Chlorine dioxide, oxidizes iron much more rapidly than chlorine does. It is often used in conjunction with chlorination to ensure adequate chlorine residuals.But chlorine being relatively less expensive than chlorine dioxide, it is usually applied. The efficiency and speed of chlorine dioxide oxidation depend to a large degree on the pH of water where best results are obtained when the pH is higher than 7.0.

Removal of divalent iron by oxidation with potassium permanganate has been successful.Permanganate should be applied prior to sedimentation in a rapid mix operation to ensure adequate mixing.Several products of potassium permanganate have been commercialized under the name of manganese sand, manganese chamotte etc. none of which can be considered a final product.

Now the technologists have completed an epoch-making deironizing agent YBF based on their experiences about filter materials accumulated over many years.The strong oxidative power of YBF readily converts ferrous iron to ferric and adsorbs the latter off.It can completely remove the single formed ferric hydroxide oweing to the high filtering effect of clinoptirol type zeolite.The mixed ferric hydroxide can also be removed rapidly due to the high oxidative power and filtering effect of YBF.

YBF is the latest type of deironizing agent having both the abilities of filtration and deironization. Oraganic iron (iron fuminate) can also be removed with it after an appropriate pretreatment.The material does not need regeneration. Only a passage of water through the material is enough.This material can efficiently treat raw waters of concentrations 10mg/1 or more. Approach velocity is as high as 10 to 15 m/h.The other advantages include sufficient

effectiveness of contact and oxidation oweing to the unique rhombic form. Void is readily formed in the filter layer so that the deeper parts of the layer exhibits a deironizing effect.A high water passage speed can be employed which decreases the filter area. Clogging also is not a problem in this case.

Another method of iron removal is the subterranean treatment method. The method involves the pumping in of oxidised water at a rate of normal withdrawal.This creates a zone of oxidised water around the drilled well. During normal pumping,the ferrous iron bearing water enters this zone and most probably gets oxidised and strained off within the aquifer. The exact phenomenon is still unexplained . The raw water containing an iron concentration of 4 mg/l has succesfully been reduced to water of concentration of .1 mg/l. The pumping in of oxidised water has to be done once in every two weeks when the iron concentration exeeds the permissible limit.

III DESIGN AND EXPERIMENTAL INVESTIGATION (METHODOLOGY)

3.1 Design of Experimental Unit

The minimum discharge of the handpump has to be 0.25 l/s so that a container of 15 litres capacity gets filled in one minute.In order that discharge be obtained from the filter bottom as soon as is pumped, certain approach velocity or flow rate through the filter unit has to be considered. The assumption here is the grain size of 3 mm allows the approach velocity of atleast 2.5 m/h so that the flow would then be 2.5x0.6x0.6 m^3/h ie. $0.9m^3/h$ per 0.36 m^2 area of the filter bottom provided. The discharge is 0.25 l/s . This discharge can satisfy about 200 peoples need. People normally use 45 l to 50 l of water per day.The detailed calculation is shown in the appendix.

The experimental unit consists of a sumpwell of capacity of about $2m^3$, a handpump fixed over this tank (sumpwell). The hand pump delivers raw water into the first chamber from where it overflows into the filtration chamber which is the main unit and in actual field construction this is the only unit that is going to be provided in conjunction with the handpump.For this study this tank has been constructed of steel. The dimension of the tank is 0.8 x 0.6 x $0.9m^3$ In actual practice it shall be constructed of brick masonry, stone masonry, or even concrete.The media depth provided is 0.6m of coarse sand of effective size 3mm. This coarse

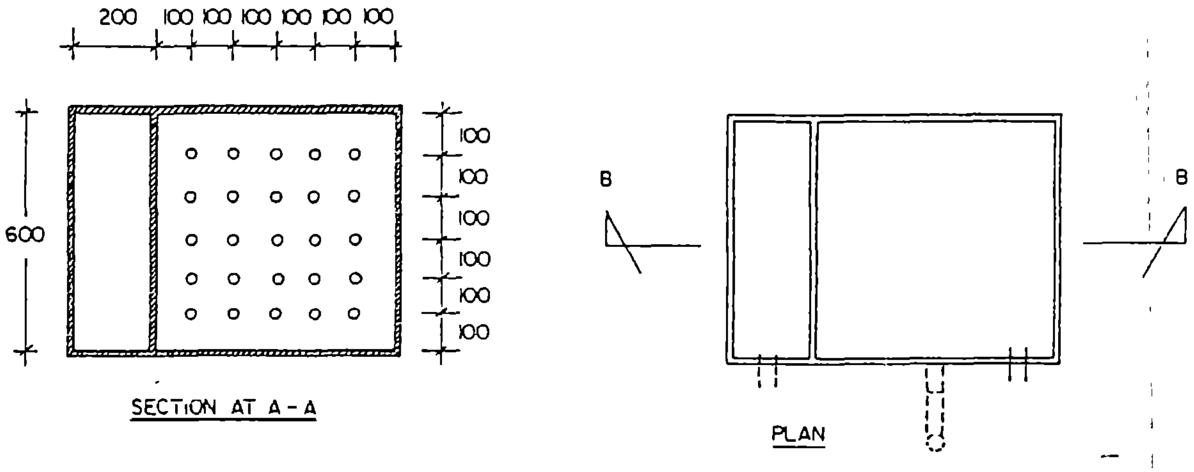
aggregate is supported underneath by a perforated steel plate which is provided with strainers. An underdrainage has been provided to collect the filtered water. The filtered water is then collected through the tap provided a little above the level of media. An overflow pipe has been provided at the top as shown in the Fig 3.1 .

The water level is always maintained in the filter media at the level of the tap so that air pockets will not form , thus eliminating negative heads once it has operated. Care must be taken at the start. High flow rate has to be maintained through the filter without affecting its efficiency of iron removal.The gradation of the material should be such that water can be collected as soon as it is pumped. For this reason coarse sand of size 3mm has been used. For low head backwash a head of 1.5m has been maintained.At the time of cleaning, the feeding line is closed and the backwash line opened. In actualpractice clean water is used for cleaning purposes.However in this case same raw water was used. The object here is to dislodge the accumulated iron particles and to wash off.The washed water overflows through the overflow provided.

3.2 Experimental stages

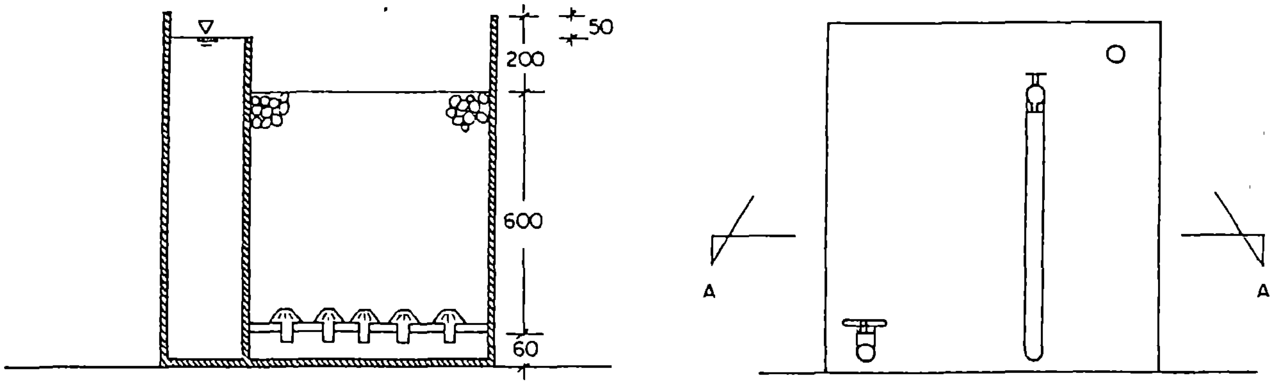
The various steps of experimentation were as follows:

1.Before starting the experiment chemicals necessary for analysing various forms of iron were prepared. A calibration curve was plotted for standerdising the



SECTION AT A – A

PLAN



SECTION AT B – B

ELEVATION

Fig. 3.1 – Filtration Chamber

Scale 1 : 20

All Dimensions in mm

spectrophotometer.(Fig. A2 in the Appendix). Similarly the curve in Fig. A1 is the curve for fixing the predetermined flow by adjusting the heigth of the float of the rotameter.

2.Preparation of raw water:

Unchlorinated deepwell water of AIT was used and ferrous sulphate added to it to obtain the desired concentration of iron. Ground water actually contain iron in ferrous state and are in dissolved form . But in raw water some of the ferrous iron gets oxidised to ferric state and as such analysis of both states of iron has to be done for raw water as well as the treated water.

3.the sample analysis of iron in raw water (Fe^{++} Fe^{+++})

4.The raw water was pumped from the tank (sumpwell) by a submersible pump instead of the handpump.Handpump shall be used only for backwash purposes.An electric pump is made use of simply, to hasten the experiment so that the filter run may be known quickly.

5.The sample analysis of iron in the filter effluent.(Fe^{++} Fe^{+++})

6.Filtration was done for raw waters of concentration of 2.5 mg/l, 5mg/l,10mg/l and 15mg/l. The assumtion here was that if the filter does not clog soon then filter conditions do not change drastically and the efficiency of the media for various concentrations of raw water can then be visualized.In fact the filtering capacity deteriorates with longer operation.

7.Head loss measurement was also done.For this purpose a piezometer had been installed at the bottom of the outlet.(tap point) The sampling points have been shown in the Fig 3.2. The samples were collected at every thirtyfive minutes interval so that each run gave three sampling times and since the number of sampling points were two, each run yield six samples.

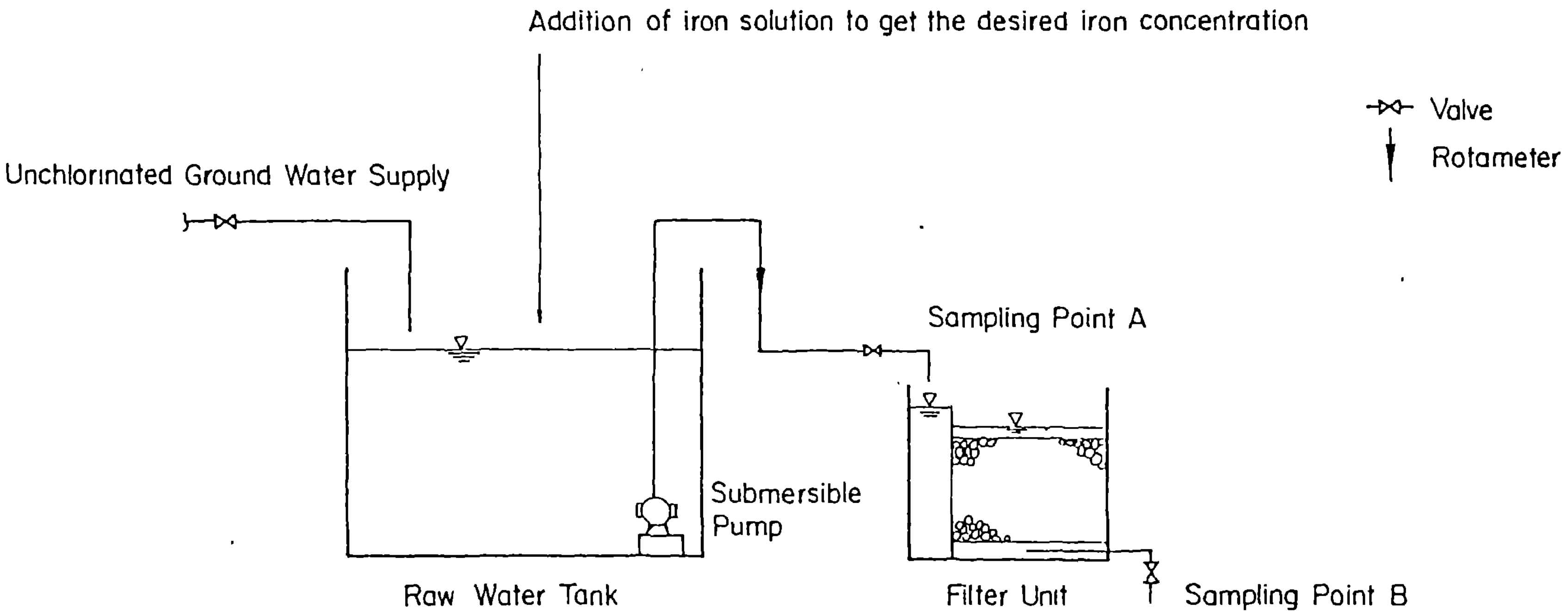


Fig. 3.2 – Schematic Diagram of Experimental System
(Not to Scale)

IV RESULTS AND DISCUSSIONS

4.1 Characteristics of Ground Water

The chemical analysis of ground water reveals that the concentration of total iron ranges from .05 to .2 mg/l and the ferrous iron from .01 to 0.06mg/l.

4.2 Removal of Ferrous iron

As the raw water tank was open, almost all ferrous iron was converted to ferric iron because of the aeration due to the recirculated pumped water. Thus no conclusion could be drawn regarding the removal of ferrous iron. The treated water practically contained no ferrous iron. The raw water sample when analysed after 15 minutes of operation indicated a ferrous iron of 0.4 mg/l and the effluent contained no detectable ferrous iron. This may be due to the fact that the rate of oxidation of ferrous iron is proportional to the ferrous iron concentration and the partial pressure of oxygen. The oxidation is also dependent on the concentration of hydroxyl ion.

4.3 Removal of Total Iron

The percentage removal of total iron at a concentration of 2.5mg/l was found to be 42%±2% ,that for 5mg/l, 54%±2%: For 10 mg/l, the removal is 60%±2% and that for 15 mg/l , 69%±2% . The influent and effluent iron concentration has been tabulated through Table 4.1 to 4.4 and the percentage removal in Table 4.5.

Table 4.1-Effluent conc. for Influent conc. of about 5mg/l

Sample no.	Head cm*	Head loss cm**	Discharge l/s	Influent conc. mg/l	Effluent conc. mg/l
1	10	1.5	0.25	2.8	1.2
2	10	1.5	0.25	3.1	1.8
3	10	1.5	0.25	3.1	1.7
4	10	1.5	0.25	3.2	1.7
5	10	1.5	0.25	3.1	1.7
6	10	1.5	0.25	3.1	1.8
7	10	1.5	0.25	3.1	1.5
8	10	1.5	0.25	3.1	1.7
9	10	1.5	0.25	3.4	1.7
10	10	1.5	0.25	3.2	1.5
11	10	1.5	0.25	3.1	1.6
12	10	1.5	0.25	3.1	1.7
13	10	1.5	0.25	3.1	1.5
14	10	1.5	0.25	2.8	1.7
15	10	1.5	0.25	2.8	1.7

Table 4.2-Effuent conc. for influent conc. of about 5.0mg/l

Sample no.	Head cm*	Head loss cm**	Discharge l/s	Influent conc. mg/l	Effluent conc. mg/l
1	10	1.5	0.25	5.1	2.4
2	10	1.5	0.25	4.8	2.4
3	10	1.5	0.25	4.8	2.4
4	10	1.5	0.25	4.8	2.4
5	10	1.5	0.25	4.5	2.4
6	10	1.5	0.25	4.7	2.4
7	10	1.5	0.25	5.1	2.3
8	10	1.5	0.25	4.7	2.4
9	10	1.5	0.25	4.5	2.4
10	10	1.5	0.25	4.4	1.5
11	10	1.5	0.25	4.5	2.0
12	10	1.5	0.25	4.5	2.0
13	10	1.5	0.25	5.2	2.4
14	10	1.5	0.25	5.1	2.4
15	10	1.5	0.25	5.1	2.4

* The head actually fluctuated between 8 to 12 cms.
** The head loss fluctuated between 1 to 2 cms.

Table 4.3-Effluent conc. for Influent conc. of about 10 mg/l

sample no.	head cm*	head loss cm**	discharge lps	influent conc. mg/l	effluent conc. mg/l
1	10	1.5	0.25	8.8	3.4
2	10	1.5	0.25	8.7	3.4
3	10	1.5	0.25	8.8	3.4
4	10	1.5	0.25	8.2	3.4
5	10	1.5	0.25	8.3	3.4
6	10	1.5	0.25	8.2	3.4
7	10	1.5	0.25	9.1	3.6
8	10	1.5	0.25	9.3	4.0
9	10	1.5	0.25	9.3	4.0
10	10	1.5	0.25	6.7	3.4
11	10	1.5	0.25	8.2	3.7
12	10	1.5	0.25	8.7	3.4
13	10	1.5	0.25	8.7	2.9
14	10	1.5	0.25	8.8	2.9
15	10	1.5	0.25	8.8	3.2

Table 4.4-Effluent conc. for Influent conc. of about 15 mg/l
(concentration about 15.0 mg/l)

Sample no.	Head cm*	Head loss cm**	Discharge l/s	Influent conc. mg/l	Effluent conc. mg/l
1	10	1.5	0.25	12.8	3.6
2	10	1.5	0.25	12.8	4.0
3	10	1.5	0.25	12.3	3.7
4	10	1.5	0.25	15.2	4.7
5	10	1.5	0.25	15.2	4.7
6	10	1.5	0.25	15.2	4.3
7	10	1.5	0.25	15.6	4.7
8	10	1.5	0.25	15.4	4.5
9	10	1.5	0.25	15.6	4.7
10	10	1.5	0.25	15.5	4.6
11	10	1.5	0.25	15.5	4.5
12	10	1.5	0.25	15.4	4.5
13	10	1.5	0.25	15.5	4.6
14	10	1.5	0.25	15.5	4.5
15	10	1.5	0.25	15.5	4.5

* The head actually fluctuated between 8 to 12 cms

** The head loss fluctuated between 1 to 2 cms.

Table 4.5-The percentage removal of Iron at different concentration

Influent conc. mg/l	Effluent conc. mg/l	Percentage removal %
3.1	1.8	42
3.1	1.7	45
3.2	1.7	47
3.1	1.5	48
5.1	2.4	53
5.1	2.3	55
4.4	2.0	54
4.5	2.0	55
8.8	3.4	61
8.7	3.4	61
8.8	3.2	64
9.3	4.0	57
12.8	3.6	72
15.2	4.3	72
15.6	4.7	70
15.4	4.5	71

A graph has been fitted to depict the trend of removal with concentration. The graph has been shown in Fig. 4.1. A curve of best fit found was a geometric curve for the obtained removals of iron . The relation of best fit is,

$$Fe_f^{+++} = a\,(Fe_i^{+++})^{b}$$

where Fe_f^{+++}, iron on the left hand side is the final iron concentration in mg/l and Fe_i^{+++}, on the right the initial concentration in raw water. The values of constants a and b were obtained as,

$$a = 0.817$$

$$b = 0.639$$

Hence the equation is

$$Fe_f^{+++} = 0.817\,(Fe_i^{+++})^{0.639} \text{ ----------------- } (8)$$

The details of the regression analysis is shown in Table 4.10

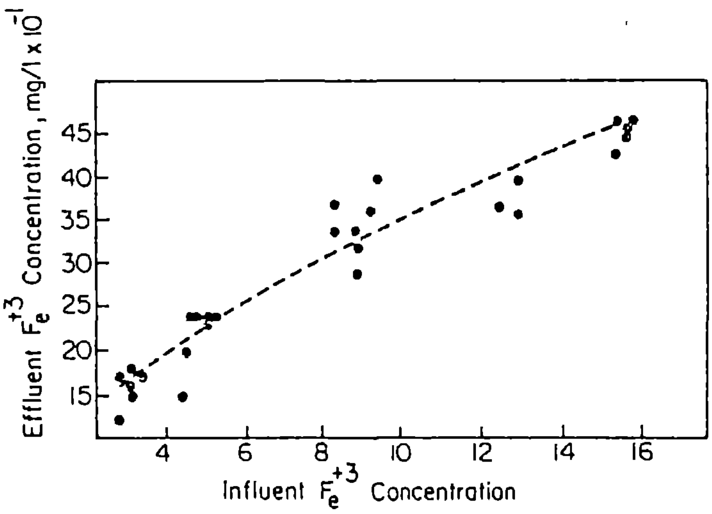


Fig.4 1 - Variation of Effluent Concentration with Change in Influent F_e^{+3} Concentration

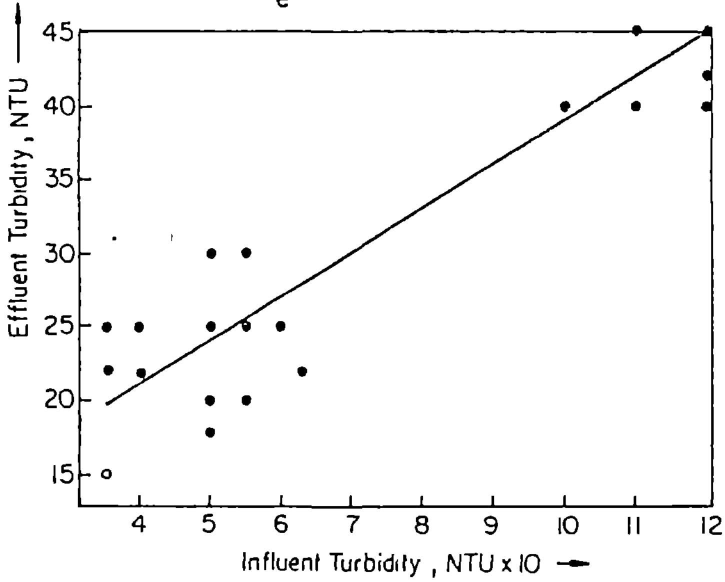


Fig.4.2 - Graph Showing Trend of Turbidity Removal

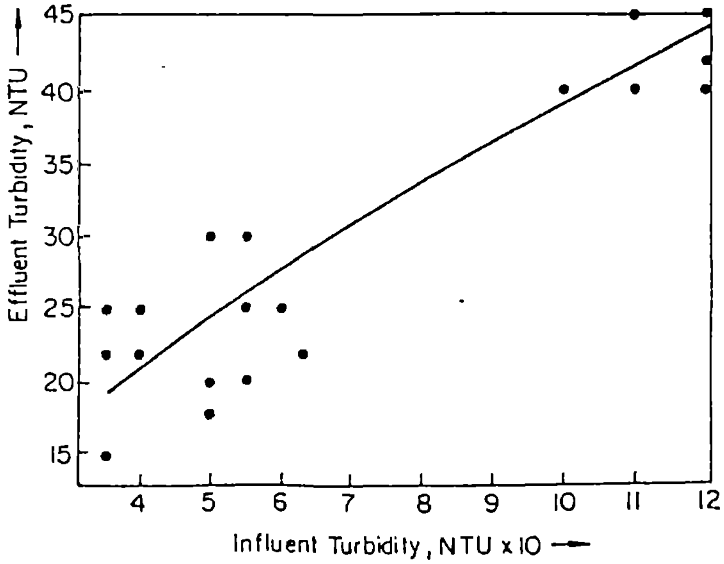


Fig.4.3 - Graph Showing Trend of Turbidity Removal

4.4 Turbidity removal

The best line fitting the observations was a linear line for which the coefficient of correlation is 0.944 and the coefficient of determination of 0.892 The standard error is 3.705 .For the geometric curve the coefficient of correlation is 0.861 and coefficient of determination of .741.The standard error is .210. The curves have been shown in Fig.4.2 and Fig. 4.3 .The tables of observation have been presented in tables through Table 4.6 to 4.9 .The details of regression analysis has been shown in Table 4.11 and 4.12 . The linear relation takes the form as:

$$Tu_f = 0.299\ (Tu_i) + 9.035 \quad \text{--------} (9)$$

The geometric relation takes the form

$$Tu_f = 1.436\ (Tu_i)^{0.717} \quad \text{-----------------} (10)$$

Table 4.6-Turbidity removal for Influnt conc. of 2.5 mg/l

Sample no.	Head cm*	Head loss cm**	Discharge 1/s	Influent Turbidity NTU	Effluent Turbidity NTU
1	10	1.5	0.25	35	15
2	10	1.5	0.25	35	25
3	10	1.5	0.25	35	20
4	10	1.5	0.25	40	22
5	10	1.5	0.25	40	22
6	10	1.5	0.25	35	20
7	10	1.5	0.25	40	25
8	10	1.5	0.25	35	22
9	10	1.5	0.25	35	20
10	10	1.5	0.25	40	25
11	10	1.5	0.25	40	25
12	10	1.5	0.25	35	20
13	10	1.5	0.25	35	20
14	10	1.5	0.25	40	22
15	10	1.5	0.25	40	25

Table 4.7-Turbidity removal for Influnt conc. of 5.0 mg/l

Sample no.	Head cm*	Head loss cm**	Discharge l/s	Influent Turbidity NTU	Effluent Turbidity NTU
1	10	1.5	0.25	55	25
2	10	1.5	0.25	50	30
3	10	1.5	0.25	55	30
4	10	1.5	0.25	50	25
5	10	1.5	0.25	50	18
6	10	1.5	0.25	55	20
7	10	1.5	0.25	55	25
8	10	1.5	0.25	50	20
9	10	1.5	0.25	50	20
10	10	1.5	0.25	63	22
11	10	1.5	0.25	60	25
12	10	1.5	0.25	60	25
13	10	1.5	0.25	60	25
14	10	1.5	0.25	60	25
15	10	1.5	0.25	60	25

Table 4.8-Turbidity removal for Influnt conc. of 10.0 mg/l

Sample no.	Head cm*	Head loss cm**	Discharge l/s	Influent Turbidity NTU	Effluent Turbidity NTU
1	10	1.5	0.25	110	45
2	10	1.5	0.25	110	45
3	10	1.5	0.25	110	40
4	10	1.5	0.25	110	40
5	10	1.5	0.25	110	45
6	10	1.5	0.25	110	45
7	10	1.5	0.25	100	40
8	10	1.5	0.25	110	45
9	10	1.5	0.25	110	45
10	10	1.5	0.25	110	45
11	10	1.5	0.25	110	45
12	10	1.5	0.25	110	45
13	10	1.5	0.25	110	45
14	10	1.5	0.25	110	45
15	10	1.5	0.25	110	40

Table 4.9-Turbidity removal for Influnt conc. of 15.0 mg/l

Sample no.	Head cm*	Head loss cm**	Discharge l/s	Influent Turbidity NTU	Effluent Turbidity NTU
1	10	1.5	0.25	120	40
2	10	1.5	0.25	120	42
3	10	1.5	0.25	120	40
4	10	1.5	0.25	120	40
5	10	1.5	0.25	120	45
6	10	1.5	0.25	120	45
7	10	1.5	0.25	120	45
8	10	1.5	0.25	120	40
9	10	1.5	0.25	120	45
10	10	1.5	0.25	120	50
11	10	1.5	0.25	120	45
12	10	1.5	0.25	120	45
13	10	1.5	0.25	120	45
14	10	1.5	0.25	120	40
15	10	1.5	0.25	120	45

* The head fluctuated between 8 to 12 cms
** The head loss fluctuated between 1 to 2 cms

Table 4.10 Results of Regression Analysis of the Total Iron Reduction with the Concentration of the Raw water.

R = 0.971

R squared = 0.944

Standard error = 0.095

Analysis of Variance

Source	Sum of the Squares	dF	Mean Square	F Ratio
Regression	8.792	1	8.792	972.39
Residual	0.524	58	.0090	

Table 4.11 Results of Regression Analysis of the Turbidity Reduction with the Change in influent Turbidity

A = 0.299

B = 9.035

R = 0.944

R squared = 0.892

Standard error = 3.705

Analysis of Variance

Source	Sum of the Squares	dF	Mean Square	F Ratio
Regression	6566.33	1	6566.33	478.30
Residual	796.25	58	13.73	

Table 4.12 Results of Regression Analysis of the Turbidity Reduction with the Change in influent Turbidity

A = 0.717

B = 1.436

R = 0.861

R squared = 0.741

Standard error = 0.210

Analysis of Variance

Source	Sum of the Squares	dF	Mean Square	F Ratio
Regression	7.33	1	7.33	165.59
Residual	2.57	58	0.04	

4.5 Head loss and Filter Backwash

Regarding head losses,the filter unit operated with a head of 10cms of supernatant water and the head loss fluctuated within 1 and 2 cms. The purpose of backwash is to fluidise the filter bed and dislodge the accumulated particles.The head of 1.5m was insufficient to fluidise the heavy sand bed of 0.6 m deep.There was simple overflow of water. No doubt certain cleansing effect is definitely possible but the method is not that effective.The filter did not clog during the operation and there was no appreciable head loss as well and as such it was not possible to determine the filter run.

The quantity estimate of the extra unit that has to be constructed in addition to handpump is given below:

Table 4.13-Quantity estimate of the Filter Unit

Description of work	no.	L (m)	B (m)	H (m)	Quantity
Earthwork	1	1.0	1.3	0.3	0.39
Bricksoling	1	1.0	1.3	0.3	0.39
Brickwork	1	1.1	0.8	0.1	0.09
Long wall	2	1.1	0.1	0.9	0.20
Short wall	3	0.6	0.1	0.9	0.16
Total					0.45
Plastering	6	0.6	--	0.9	3.24
(inside)	2	0.2	--	0.9	0.36
Bottom	1	0.6	0.6	--	0.36
Bottom	1	0.2	0.6	--	0.12
Total					4.08
Plastering	2	1.3	--	1.0	2.60
(outside)	2	0.6	--	1.0	1.20
	2	1.3	0.1	--	0.26
	3	0.6	0.1	--	0.18
Total					4.24

Table 4.14-Cost estimate of the Filter Unit

Description of the work in B	Quantity	Unit Cost in B̸	Total cost in B̸
Earthwork	0.39 m^3	20/m	7.80
Brick soling	0.39 m^3	40/m	15.60
Brick masonry	0.45 m^3	1200/m	540.00
Plastering	4.08 m^2	200/m	816.00
Plastering	4.24 m^2	180/m	763.20
Total Cost			2142.60

The brick masonry shall be constructed in 1:3 cement mortar. Plastering shall be in 1:2 cement mortar with 2% water proofing compound for inside plastering and without water proofing compound for outside plastering.

V CONCLUSIONS

1.A series of filtering units is necessary to produce an effluent of iron concentration less than 1mg/l , the number of units depending on the raw water iron concentration.

2.The percentage removal of iron increases with the increase in the concentration of the raw water.

3.For washing purposes two chambers in one unit is necessary so that when one is taken out for cleaning, the other would be available for operation. Filter backwashing under low heads is not possible in case of sand media.

VI RECOMMENDATIONS

The study had been conducted for a discharge of 0.25 1/s and for a sand media of depth of 0.6m .Besides the raw water ferrous iron content was negligible due to the oxidation of the ferrous state of iron in the raw water tank due to the recirculated pumped water. The following studies are recommended which has been listed below:

1. The filter performance with the change in depth of media should be considered and to estimate the optimum depth for a particular flow rate.
2. The effect of the filtration rates on the filter performance should be considered. Furthermore, the optimum filtration rate should also be determined.
3. The study on the efficiency of the unit with other filter medium.
4. The study on backwasing under low heads for lighter filter medium such as YBF .
5. The efficiency of aeration in various filter medium.
6. The filter run should also be determined. For this a long period of study is necessary.
7. The feasibility of using two or more than two units to obtain the effluent of desired concentration.

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APPENDIX

CALCULATIONS FOR FIXING THE DIMENSIONS OF THE FILTER UNIT

Assuming the per capita water demand to be 45 l/d, 200 people will require ,

200 x 45 = 9000 litres per day.

Assuming water demand to be satisfied within 12 hrs, the discharge required is,

9000/(12 x 3600)=0.2 l/s

Here a discharge of 0.25 l/s is taken for design. The filtration assumed is, 2.5m/h or 2.5 m^3/m^2 h. Thus the area required is,

$$0.25 \times 10 \times 3600 / 2.5 = 0.36 \ m^2$$

Hence a square bottom of side 0.6 m has been provided.

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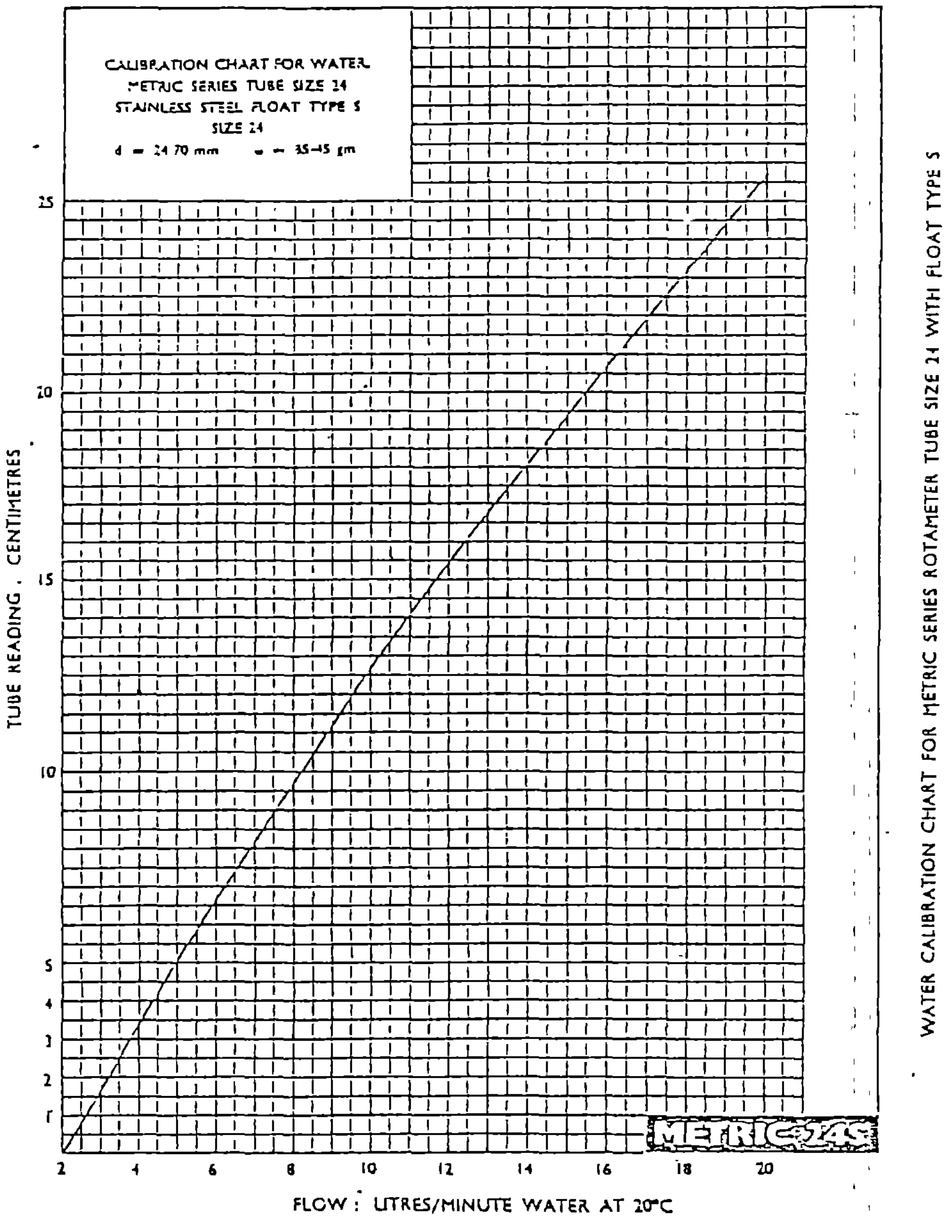

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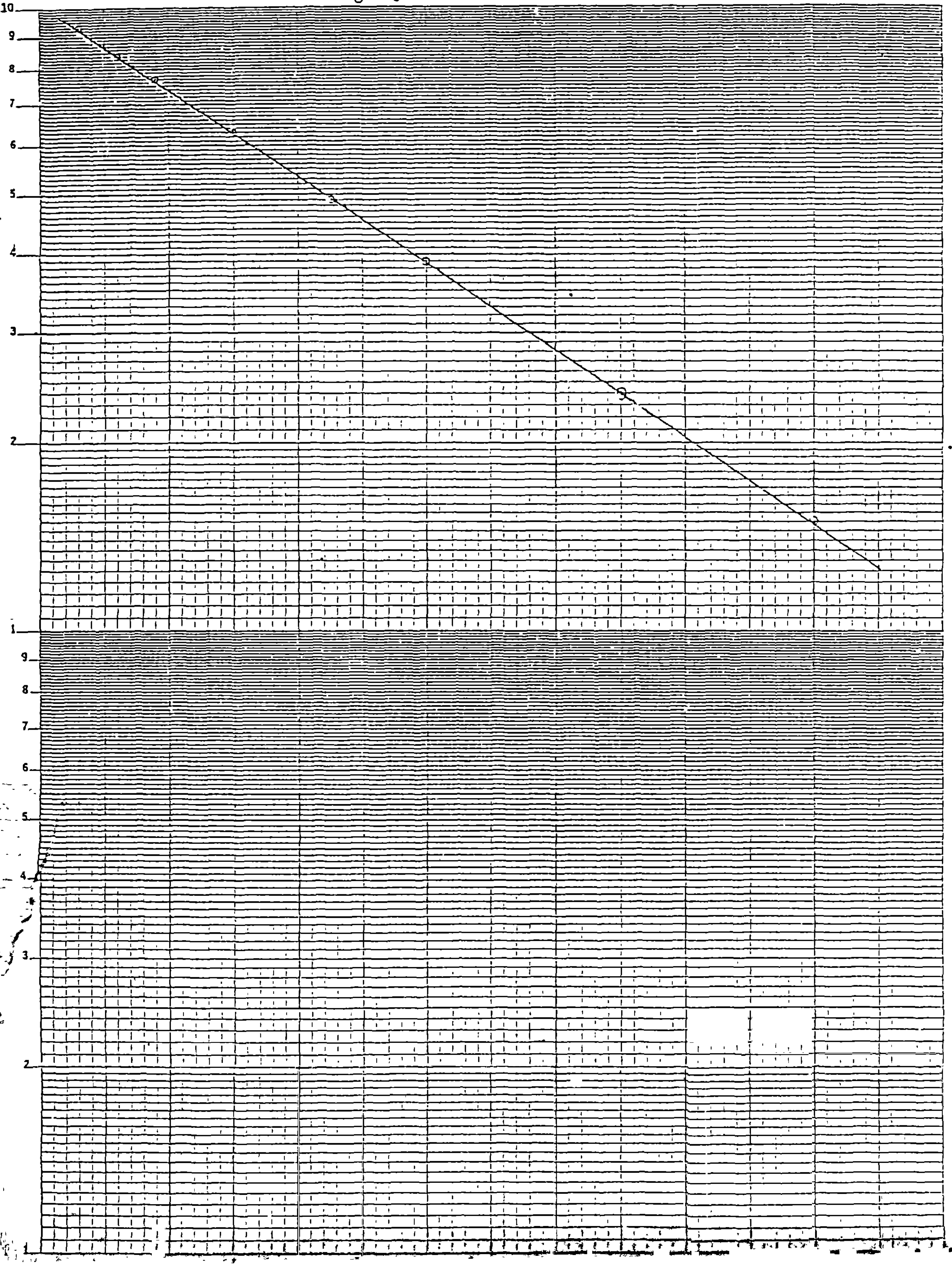
Fig. A2 Calibration Curve

Calibration Curve

1cm Light path

2nd May 1984



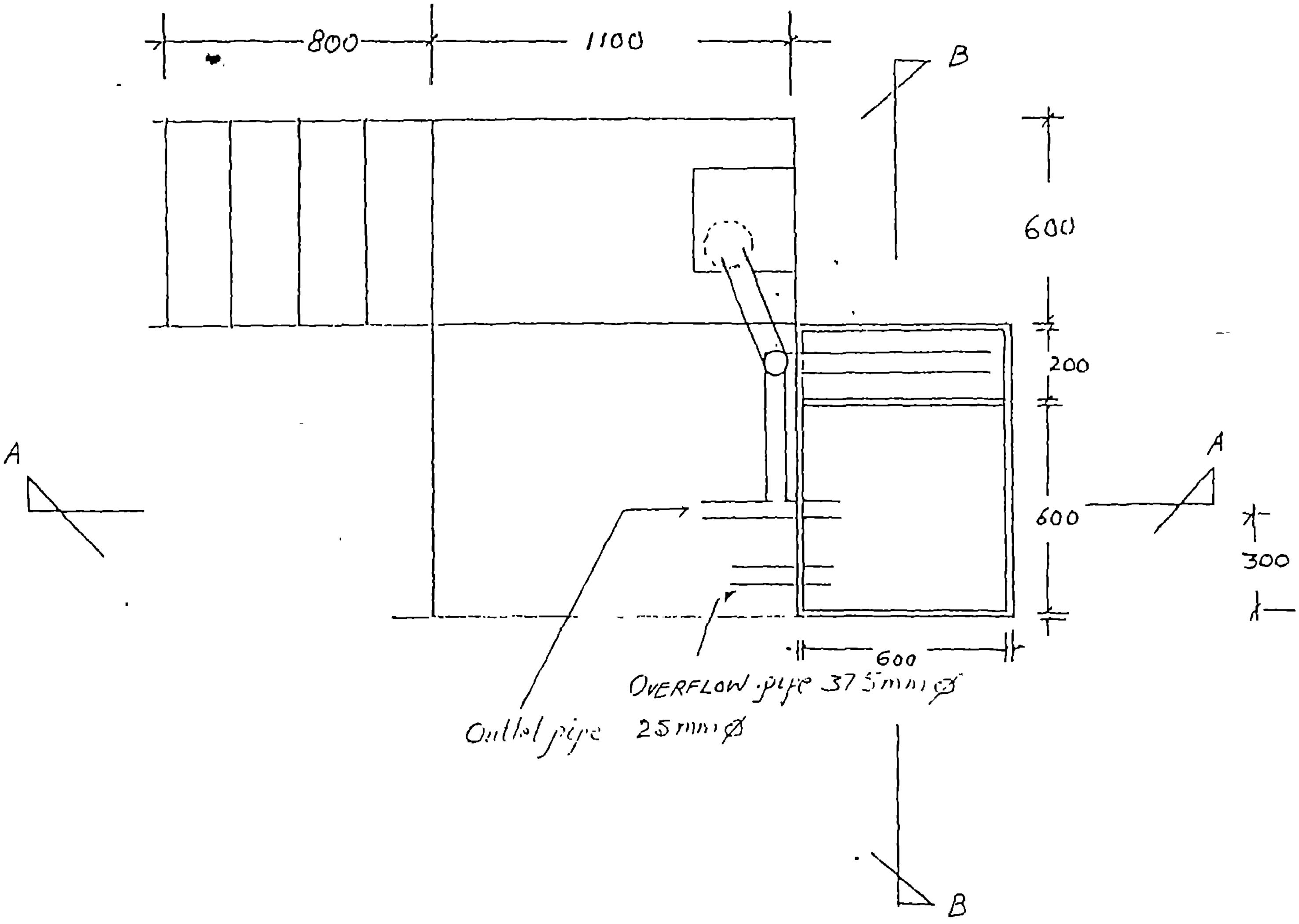


Fig. 13 Plan of proposed unit
Scale 1:20
All dimensions in mm.

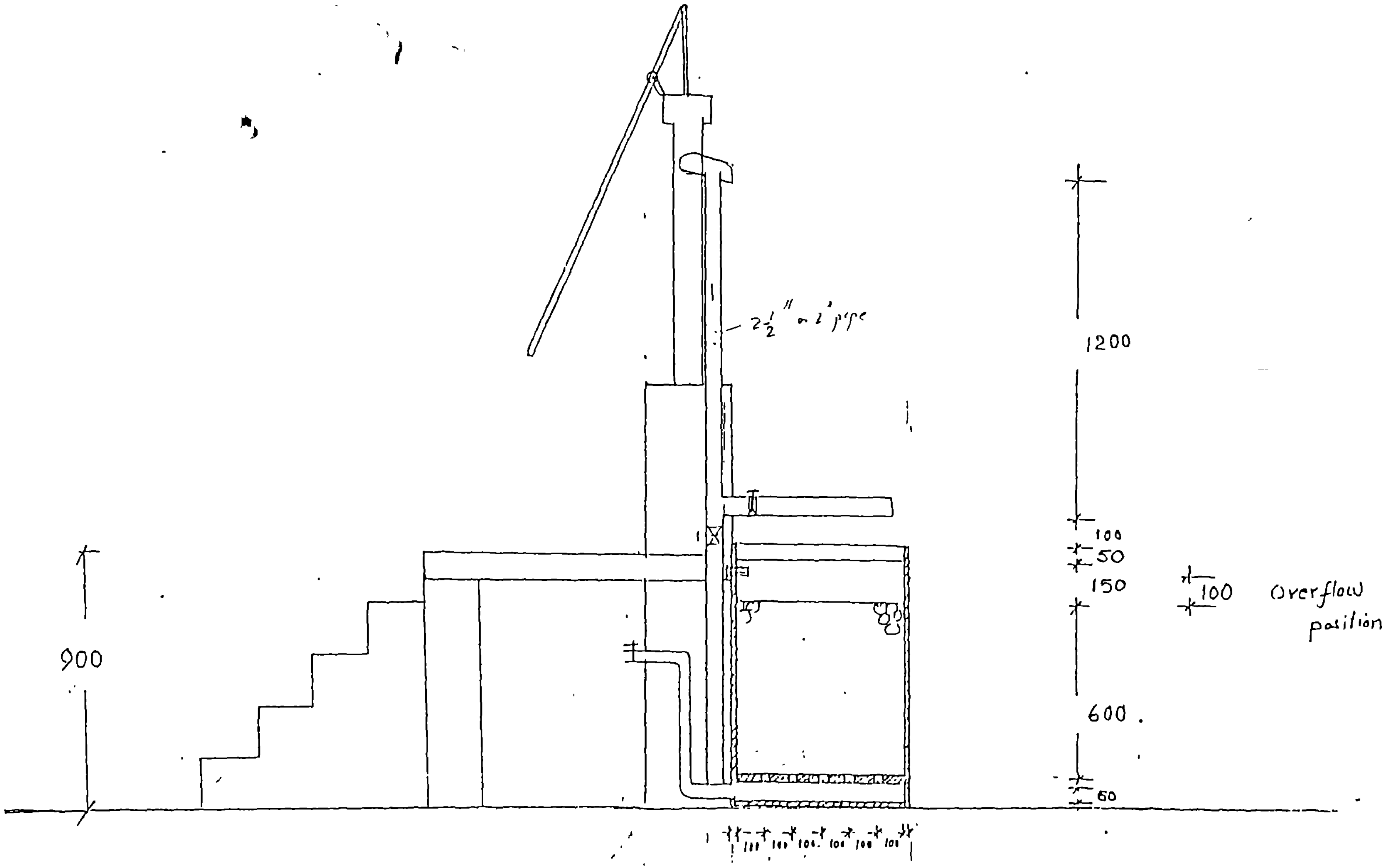


Fig. A4 SECTION AT A-A (Section of proposed unit)

SCALE 1:20

ALL DIMENSIONS IN MM

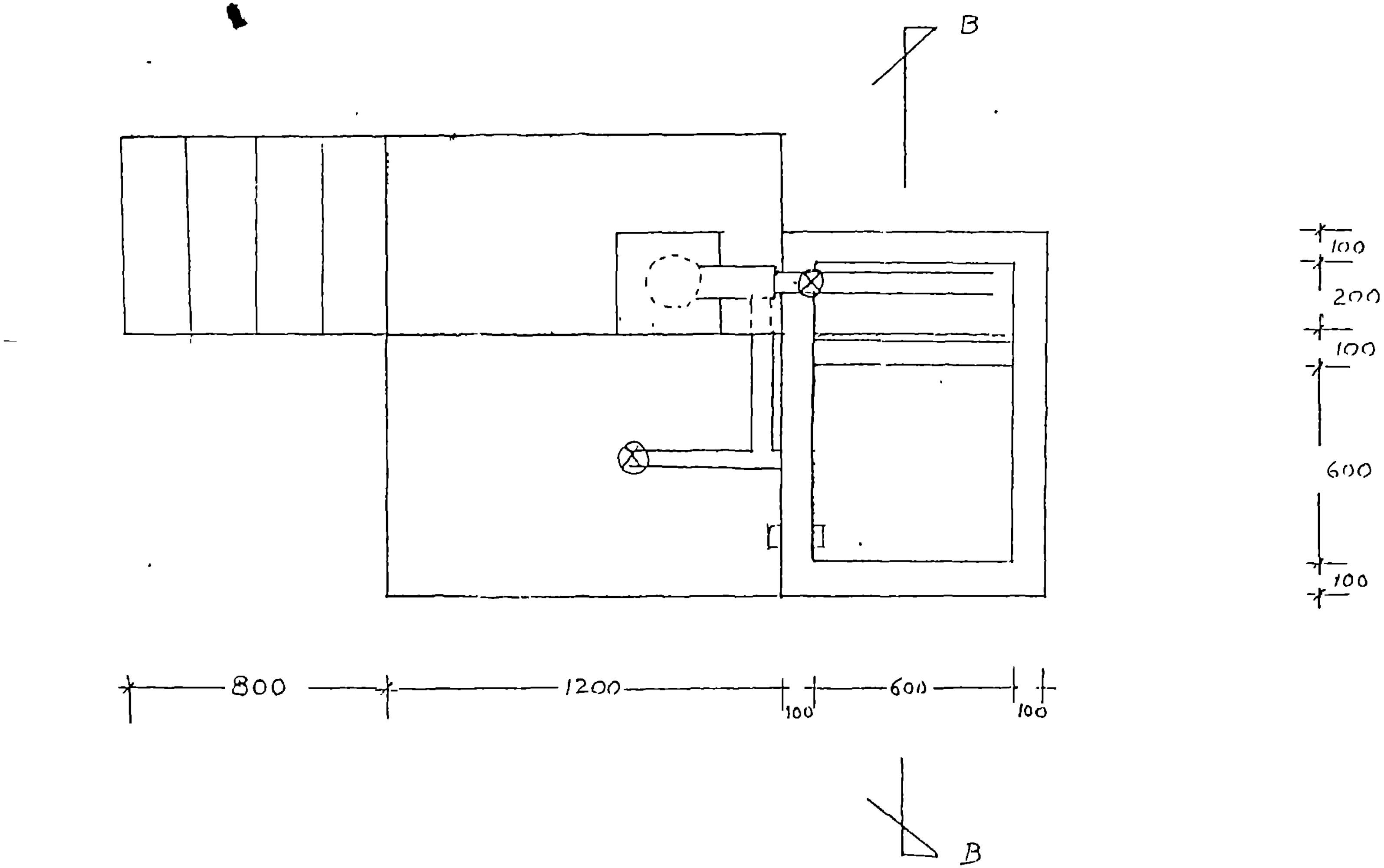


Fig. A5 Proposed masonry filtering unit
(All dim. [illegible] in mm)

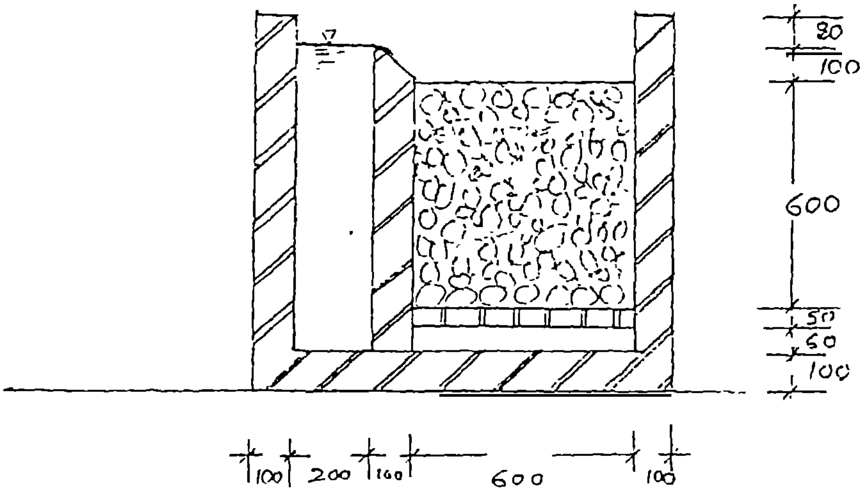


Fig A6 Section at B-B
(All dimensions in mm)