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WATER MISSION
TECHNOLOGY MISSION ON DRINKING WATER
IN VILLAGES AND RELATED WATER MANAGEMENT

TRAINING COURSE MANUAL
ON
FLUORIDE REMOVAL

Course Venue : GANDHINAGAR (Gujarat)
February 20-22, 1989

NATIONAL ENVIRONMENTAL ENGINEERING RESEARCH INSTITUTE
NAGPUR-440 020.

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FOREWORD

I am pleased to write this foreword to this manual on Nalgonda Technique for defluoridation of drinking water supplies.

Many states in India have reported excessive amount of fluoride in their underground waters especially in rural areas, and the harm these do to the health of human beings and the cattle. Gujarat is one of these states with prevalence of dental fluorosis among the villagers and cattle who have no other sources of water to drink other than from the wells.

The Technology Mission of the Government of India has launched a programme of defluoridation of waters in such villages to save the human beings and cattle from this calamity - after first carrying out a comprehensive survey of the quality of the drinking water supplies. This manual has been carefully prepared by Scientists and Engineers of National Environmental Engineering Research Institute, Nagpur, after carrying out detailed analysis of the quality of these drinking waters and suggests different methods to be adopted for defluoridation of these water supplies, depending on whether the supplies are to be treated for individual houses or for a small community or for a rural water supply scheme on a small or large scale. The methods of treatment to be adopted are different for different qualities and quantities of waters. The chemical analysis of water, the quantities of chemicals to be used for treatment, as well as equipment needed for the treatment are all described in this manual. The institute has carried out case studies in a few villages of Gujarat. The operational schedule has also been given, and very clear layout plans have been prepared and described in this manual, so as to facilitate the installation of such treatment plants in the villages. It also gives the details of operation and maintenance of these treatment plants. This is a most important part in these manual. I am quite certain that this manual would be most useful to the operators for the maintenance of the plants. The rough estimates for the capital cost of installation of the plants as well as operational cost of treatment are also given and would be most useful to the authorities. No cost of operation is too much if one takes into account the misery of the people and the severe hardships to animals consuming water containing excessive amount of fluorides.

This disease has plagued the population for many years and now that the remedies are available after extensive Research and Development, its early adoption is recommended.

February 1, 1989

R S Mehta

Ramesh S. Mehta
Ex - Director
N.E.E.R.I.
&
Ex - Chairman
Gujarat Water & Air
Pollution Control Board

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1. OCCURRENCE OF FLUORIDE :

Fluorine is so highly reactive that it is never encountered in its elemental gaseous state except in some industrial processes. It is the 17th most abundant element in the earth crust. It occurs notably as fluorspar CaF_2; Cryolite, Na_3AlF_6; fluorapatite, $3Ca(PO_4)_2$ $Ca(F, Cl)_2$.

As fluorspar it is found in sedimentary rocks (limestone and sandstone) and cryolite in igneous rocks (granite). These fluoride minerals are nearly insoluble in water and are present in ground water only when conditions favour their solution.

Occurrence of fluoride bearing waters have been reported in Andhra Pradesh, Rajasthan, Gujarat, Punjab & Haryana, Maharashtra, Tamil Nadu, Karnataka, Madhya Pradesh and Uttar Pradesh. The survey, conducted under the Water Technology Mission launched by the Govt. of India, has identified 8700 villages in India which have a problem of excessive fluoride in water, affecting about 25 million people. The mission has 3600 villages for the implementation of Defluoridation Programme in its first phase. Out of these 3600 villages, 250 villages are proposed to be covered in Gujarat.

2. HEALTH RELATED ASPECTS OF FLUORIDE :

Most natural waters contain traces of fluoride and in some cases, the amounts are comparatively large.

Fluoride although beneficial when present in concentrations of 0.8 - 1.0 mg/1, has been associated with mottled enamel of the teeth when present in potable waters in concentration in excess of 1.5 mg/1. Skeletal fluorosis has been observed at concentrations beyond 3 mg/1.

Dental Fluorosis :
The assessment of dental fluorosis is particularly important in areas where the natural fluoride content of the water supply is high. The most widely used criteria for the assessment is that developed by Dean (1934).

Normal :
The enamel presents the usual translucent semivitriform type of structure. The surface is smooth, glossy and usually of a pale, creamy white colour.

Questionable :
The enamel discloses slight aberrations from translucancy of normal enamel, ranging from a few white flecks to occasional white spots, with a tendency to form horizontal striations. This classification is used where a definite diagnosis of the mildest form of fluorosis is not warranted but classification of "normal" is not justified.

Very Mild :
Small, opaque, paper-white areas scattered irregularly over the tooth but involving less than about 25% of the tooth surface. Frequently included in this classification are teeth showing no more that 1 - 2 mm of white opacity at the tip of the cusps of the premolons or second molars.

Mild :
The white opaque areas in the enamel of the teeth are more extensive, but still involve less than 50% of the tooth.

Moderate :
All enamel surfaces of the teeth are affected, and surfaces subject to attrition show marked wear. Brown stain is frequently a disfiguring feature.

Severe :
All enamel surfaces are affected and hypoplasia is so marked that the general form of the tooth may be affected. The major diagnostic sign of this classification is the discrete or confluent pitting. Brown stains are widespread and teeth often present a corroded appearance.

Skeletal Fluorosis :
Ingestion of 20-80 mg F per day or more through water over a period of 10 - 20 years results in crippling and severe osteosclerosis. Calcification of certain ligaments is usually associated with at least 10 mg/1 of fluoride in drinking water, which renders the movement of the joints difficult.

3. ESTIMATION OF FLUORIDE :

Among the methods suggested for the determination of fluoride ion in water, the colorimetric method (SPADNS) and the Ion Selective Electrode method are the most satisfactory and applicable to variety of samples. As all the colorimetric methods are subject to errors due to presence of interferring ions, it may be necessary to distill the sample before making the fluoride estimation while addition of the prescribed buffer frees the electrode method from the interference caused by such relatively common ions such as aluminium, hexametaphosphate and orthophosphate which adversely affect the colorimetric methods. However samples containing fluoroborate ion ($B4_4$) must be subject to preliminary distillation step in either of the methods. Both the methods and the preliminary distillation step are discussed later.

Collection & Preservation of Sample :
Glass bottles are satisfactory for samples, provided precautions are taken to prevent the use of containers which previously contained high fluoride solutions. The usual precaution of rinsing the bottle with a portion of the sample should be observed.

The sample should be collected in polyethylene bottle and must be refrigerated at 4° Cfor preservation. The sample should be analysed within 7 days after collection.

3.1 SPADNS Method :

Principle : Under acidic condition fluorides (HF) react with zirconium-SPADNS solution reagent and the 'Lake' (colour of SPADNS reagent) gets bleached due to formation of ZrF_6. Since bleaching is a function of fluoride ions, it is directly proportional to the concentration of F^-. It obeys Beer's law in a reverse manner.

Interference : Alkalinity 5000 mg/1, Aluminium 0.1 mg/1, Chlorides 7000 mg/1, Fe 10 mg/1, PO_4 16 mg/1, SO_4 200 mg/1, and Hexametaphosphate 1.0 mg/1 interfere in the bleaching action. In presence of interfering radicals distillation of sample is recommended.

Apparatus :

1. Distillation apparatus (as shown in the Fig. 1)
2. Colorimeter for use at 570 nm.
3. Nessler's tubes cap, 100 ml.

Reagents :

1. Sulphuric acid H_2So_4conc.
2. Silver sulphate Ag_2So_4crystals
3. SPADNS solution : Dissolve 958 mg SPADNS and dilute to 500 ml.
4. Zirconyl acid reagent: Dissolve 133 mg $ZrOCl_2 . 8H_2 0$ in 25 ml water. Add 350 ml conc. HCl and dilute to 500 ml.
5. Mix equal volumes of 3 and 4 to produce a single reagent. Protect from direct light.
6. Reference solution : Add 10 ml SPADNS solution to 100 ml distilled water. Dilute 7 ml conc. HCl to 10 ml and add to diluted SPADNS solution.
7. Sodium arsenite solution: Dissolve 5.0 g $NaAs0_2$ and dilute to 1000 ml.
8. Stock F^- solution: Dissolve 221.0 mg anhydrous NaF and dilute to 1000 ml. 1 ml = 100 µg F^-.
9. Standard F^- : Dilute stock solution 10 times to obtain 1 ml = 10 µg F^-

Preliminary Distillation Step : Place 400 ml distilled water in the distilling flask and carefully add 200 ml conc. H_2SO_4. Swirl until the flask contents are homogenous, add 25 to 30 glass beads and connect the apparatus as shown in Fig.1. Begin heating slowly at first and then rapidly until the temperature of the flask reaches exactly 180° C . Discard the distillate. The process removes fluoride contamination and adjusts the acid-water ratio for subsequent distillations.

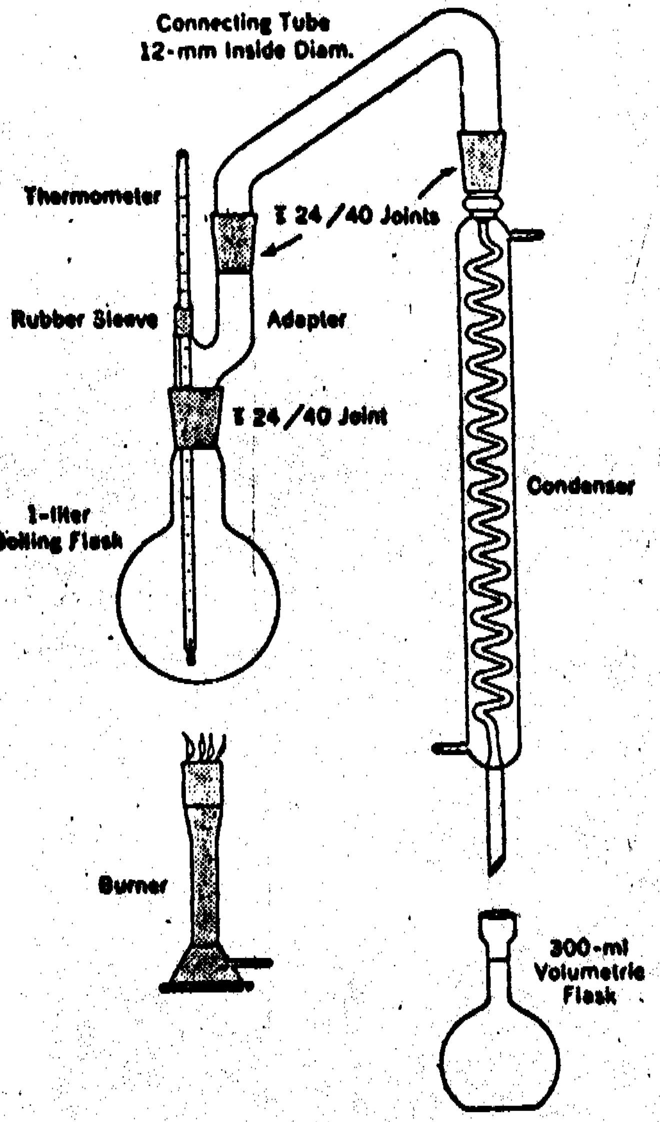


FIG. 1 Direct Distillation Assembly for Fluoride

After cooling, the acid mixture remaining after the above step or previous distillation cooled to 120° C and below, add 300 ml of sample, mix thoroughly, and distill as before until the temperature reaches 180° C. Do not heat above 180 C° to prevent sulphate carryover.

Add Ag_2So_4 to distilling flask at the rate of 5 mg/mg $C1^-$ when high chloride samples are distilled. Use the sulphuric acid solution in the flask repeatedly until the contaminants from the samples accumulate to such an extent that recovery is affected or interferences appear in the distillate. After the distillation of high fluoride samples, flush the still with 300 ml distilled water and combine the two fluoride distillates. After period of inactivity, similarly flush the still, discard the distillate.

Procedure :

1. Prepare standard curve in the range 0.0 to 1.40 mg/1 by diluting appropriate volume of standard F^- solution to 50 ml in Nessler's tubes.

2. Add 10 ml mixed reagent prepared as in 5 above to all the samples, mix well and read optical density of bleached colour at 570 nm using reference solution for setting zero absorbance.

3. Plot concentration vs percent transmission or absorbance.

4. If sample contains residual chlorine remove it by adding 1 drop (0.05 ml) $NaAsO_2$ solution per 0.1 mg Cl_2 and mix. $NaAsO_2$ concentration should not exceed 1300 mg/1 to avoid error due to $NaAsO_2$. Take suitable aliquot & dilute it to 50 ml.

5. Add acid Zirconyl - SPADNS reagent 10 ml; mix well and read % transmision or absorbance.

6. Take suitable aliquots of sample either direct or after distillation in Nessler's tubes. Follow the step 5.

7. Calculate the mg F^- present in the sample using standard curve.

3.2 Ion Selective Electrode Method :

Principle : The fluoride sensitive electrode is of the solid state type, consisting of a lanthanum fluoride crystal; in use it forms a cell in combination with a reference electrode, normally the calomel electrode. The crystal contacts the sample solution at one face and an internal reference solution at the other. A potential is established by the presence of fluoride ions across the crystal which is measured by a device called ion meter or by any modern pH meter having an expanded millivolt scale. The fluoride ion selective electrode can be used to measure the activity or concentration of fluoride in aqueous samples by use of an appropriate calibration curve.

However fluoride activity depends on the total ionic strength of the sample. The electrode does not respond to bound or complexed fluoride. Addition of buffer solution of high total ionic strength containing a chelate to complex aluminium preferentially overcomes these difficulties.

Interference : Polyvalent cations such as Al(III), Fe(III), and Si(IV) will complex fluoride ions. However the addition of CDTA (cyclohexylene diamine tetra acetic acid) or sodium citrate preferentially will complex concentrations of aluminium up to 5 mg/1. Hydrogen ion forms complex with fluoride while hydroxide ion interferes with electrode response. By adusting the pH in between 5 and 5.5 no interference occurs.

Apparatus :

1. Ion meter (field/laboratory model) or pH/mV meter for precision laboratory measurements.
2. Reference electrode (calomel electrode)
3. Fluoride sensitive electrode
4. Magnetic stirrer
5. Plastic labware (samples and standards should always be stored in plastic containers as fluoride reacts with glass).

Reagents :

1. Standard fluoride solution prepared as directed in SPADNS method.
2. Total Ionic Strength Adjustment Buffer (TISAB)

Place approximately 500 ml distilled water in a 1 - L beaker, add 57 ml glacial acetic acid, 58 gm NaCl and 4.0 gm 1, 2 cyclohexylene diaminetetraacetic acid. (Or 12 gm. sodium citrate dihydrate, Na C_6H_5 O $2H_2$ O). Stir to dissolve. Place beaker in a cool water bath and add slowly 6 N NaOH (about 125 ml) with stirring, until pH is between 5 and 5.5 Transfer to a 1 - L volumetric flask and make up the volume to the mark.

Procedure :

1. For connecting the electrodes to meters, and for further operation of the instrument, follow the instruction manual supplied by the manufacturer.
2. Check the electrode slope with the ionmeter (59.16 mV for monovalent ions and 29.58 mV for divalent ions at 25° C)
3. Take 50 ml of each 1 ppm and 10 ppm fluoride standard. Add 50 ml TISAB (or 5 ml if conc. TISAB is used) and calibrate the instrument.
4. Transfer 50 to 100 ml of sample to a 150 ml plastic beaker. Add TISAB as mentioned in (3).
5. Rinse electrode, blot dry and place in the sample. Stir thoroughly and note down the steady reading on the meter.
6. Recalibrate every 1 or 2 hours.
7. Direct measurement is a simple procedure for measuring a large number of samples. The temperature of samples and standard should be the same and the ionic strength of standard and samples should be made the same by addition of TISAB to all solutions.

8. Direct measurement results can be verified by a known addition procedure. The known addition procedure involves adding a standard of known concentration to a sample solution. From the change in electrode potential before and after addition, the original sample concentration is determined.

4. REMOVAL OF FLUORIDE - NALGONDA TECHNIQUE :

Removal of excessive fluoride from public water supply is a sound economic investment when related to the increased cost of dental care, loss of teeth and other health hazards. Keeping in view the associated health problems and sufferings of the millions in the country, NEERI being cognizant of the problem has developed a simple technique known as Nalgonda Technique for the removal of excess fluoride from water.

The technical method for the removal of excessive fluoride at domestic, community and rural water supply levels using precipitation by aluminium salts is known as Nalgonda Technique. The sequence of treatment is precipitation, settling and filtration.

4.1 Mechanism of fluoride removal :

The Nalgonda Technique is a combination of several unit operations and processes incorporating rapid mixing, chemical interaction, flocculation, sedimentation, filtration, disinfection and sludge concentration (to recover water and aluminium salts).

Rapid Mix : It enables thorough mixing of alkali, aluminium salts and bleaching powder with the water. This is achieved by providing an agitator which is started as soon as the tank is filled. After a short while the chemicals are added to ensure instantaneous dispersion of alum.

Flocculation : Consequently the gentle stirring allows the flocs to be formed. The flocculation period should be adequate enough to allow close contact between the fluoride in water and polyalumenic species formed in the system. The interaction between fluoride and aluminium species attains equilibrium.

The chemical reaction between fluoride and the aluminium species is a complex one. It is a combination of polyhydroxy aluminium species complexation with fluoride and their adsorption on polymeric alumina hydroxides (Floc).

Lime or sodium carbonate ensures adequate alkalinity for effective hydrolysis of aluminium salts, so that the residual aluminium does not remain in the treated water. It also weightens the floc and accelerates the settling.

Bleaching powder is then added for disinfection and it also keeps the system free from undesirable biological growths.

In addition to the removal of fluoride, turbidity, colour, odour, pesticides and organics are also removed. All these are by adsorption on the floc.

Sedimentation : It permits the floc which is loaded with fluoride, turbidity, bacteria etc. to settle and thus reduce the concentration of suspended solids that must be removed by filters.

Filtration : Rapid gravity sand filters are suggested to receive coagulated and settled water in these filters and unsettled gelatinous floc is retained. Residual fluoride and bacteria are adsorbed on the gelatinous floc retained on the filter bed.

Disinfection and distribution : The filtered water collected in the storage tank is rechlorinated with bleaching powder and distributed as per adoptable water supply practice.

4.2 Based on the volume of water to be treated the techniques can be applied at the following levels :

i. Domestic for individual houses.
ii. Fill & Draw type for small communities.
iii. Fill & Draw type for Rural W/S schemes.
iv. Continuous flow type for larger W/S schemes.

4.2.1 *Domestic Treatment :*

I. Precipitation, settling and filtration.

Here the treatment is carried out in a container/bucket of 60 1 capacity with a tap 3 - 5 cm above the bottom for the withdrawal of treated water after precipitation and settling. The bucket is filled with the raw water, mixed with adequate amounts of alum, lime or sodium carbonate and bleaching powder, depending upon its alkalinity and fluoride content. Lime or sodium carbonate solution is added first and mixed well with water. Alum solution is then added to the water, stirred slowly for 10 mins and allowed to settle for nearly one hour. The supernatent which contains permissible amount of fluoride is withdrawn through the tap for consumption. The settled sludge is discarded. The process is illustrated in Fig. 2.

Approximate volume of alum solution (millilitre) required to be added in 40 litres test water to obtain permissive limit (1 mg. F/L) of fluoride in water at various alkalinity and fluoride levels is given below in a Table.

Test water Fluoride mg. F/L	Test Water Alkalinity, mg. $CaCO_3$ /L							
	125	200	300	400	500	600	800	1000
2	60	90	110	125	140	160	190	210
3	90	120	140	160	205	210	235	310
4		160	165	190	225	240	275	375
5			205	240	275	290	355	405
6			245	285	315	375	425	485
8					395	450	520	570
10							605	675

DEFLUORIDATION AT DOMESTIC LEVEL

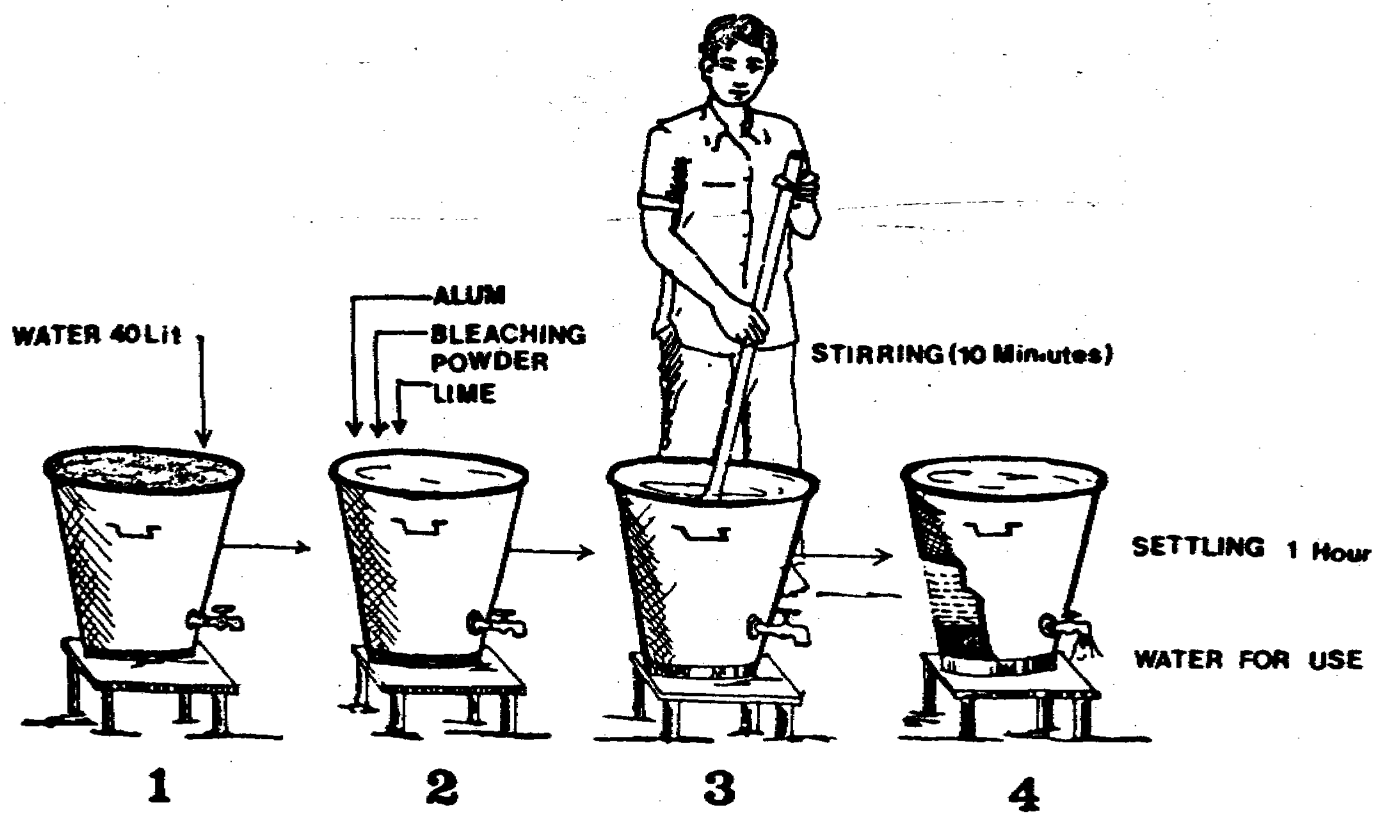


FIG. 2

II. Precipitation, Floatation and filtration

Domestic treatment is achieved using a 100 l capacity batch type dissolved air floatation cell with hand operated pressure pump. The pump and cell form a compact dissolved air floatation defluoridation system.

Raw water in the cell is mixed with alkali and aluminium salts. A small quantity of air-water mixture from the pressure pump is allowed into the cell. The precipitate with fluoride lifts to the top and floats. The treated water is collected in a bucket filtered through a sand filter. Using this cell, 100 L water is available for use in 20 minutes.

The same principle of floatation is extended to a 500 l capacity dissolved air floatation cell to obtain nearly lm^3 treated water per hour for small communities.

4.2.2 Fill and Draw Type for Small Community (Precipitation Settling and Filtration)

This is also a batch method for communities upto 200 population. The plant comprises a hopper-bottom cylindrical tank with a depth of 2 m equipped with a hand-operated or power driven stirring mechanism. Raw water is pumped or poured into the tank and the required amounts of bleaching powder, lime or sodium carbonate and alum added with stirring. The contents are stirred slowly for ten minutes and allowed to settle for two hours. The defluoridated supernatant water is withdrawn to be supplied through standposts and the settled sludge is discarded. A typical fill and Draw type Defluoridation plant is shown in fig. 3.

Fill and Draw Type Defluoridation Plant

Plant diameter (metres) for populations upto 200 on the basis of 40 lpcd defluoridated water through standposts,

Water depth	-	1.5 m
Free Board	-	0.3 m
Depth of sludge cone	-	D/10
Shaft diameter	-	50 mm

Population	Water volume (m^3)	Plant diameter (m)	Suggested H.P. for motor
50	2	1.30	1.0
100	4	1.85	2.0
200	8	2.60	2.0

Alum required to be added per each batch of treatment (grams, alumina ferric, IS : 299 - 1962)
= (Water volume, m^3) (Alum dose for that particular water, mg/1).
Fresh Bleaching Powder (grams per batch) = 3 x (Water volume, m^3).

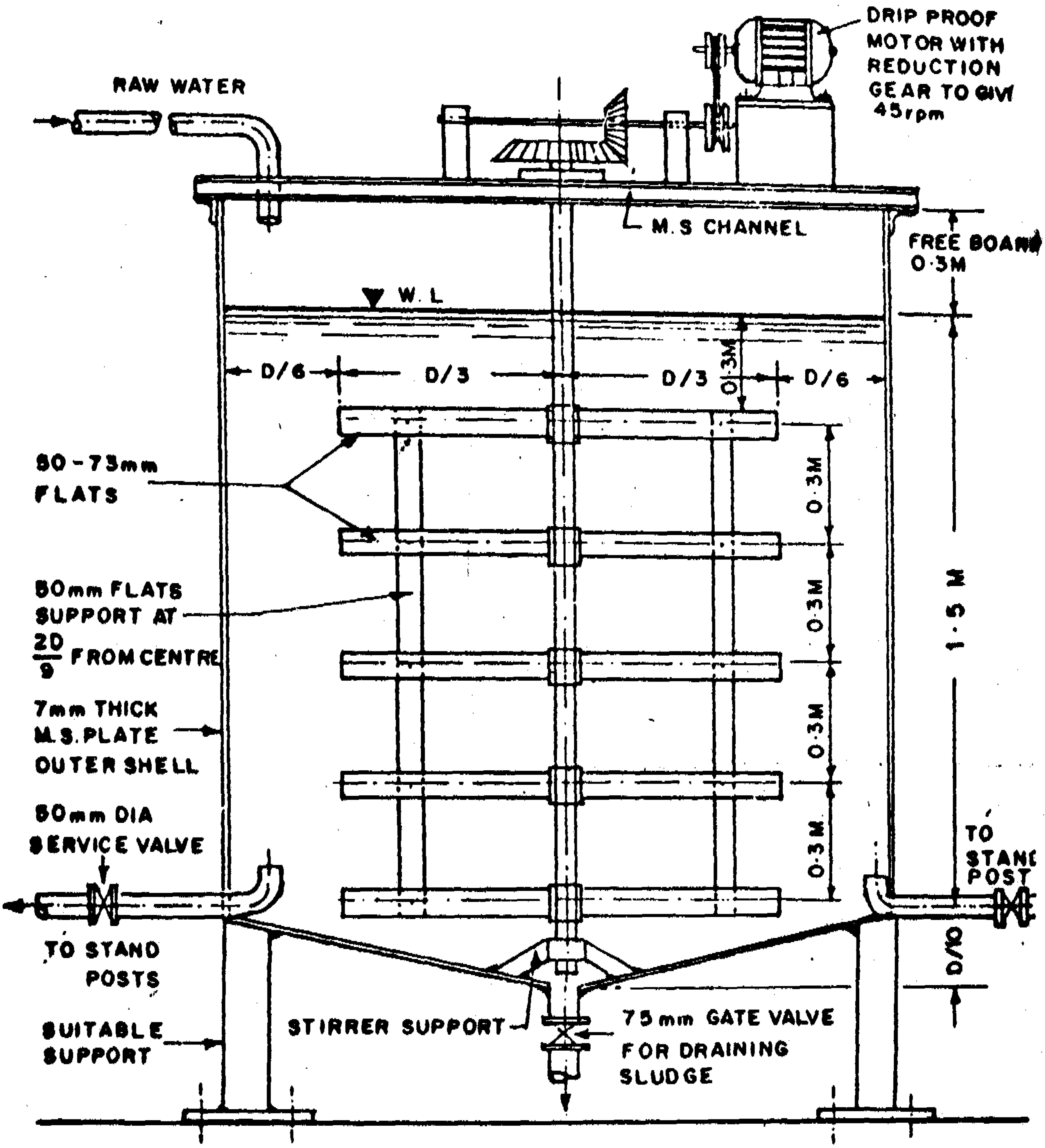


FIG. 3 FILL AND DRAW TYPE DEFLUORIDATION PLANT
BASIS : 40 lpcd DOMESTIC WATER
(FOR POPULATION UPTO 200)

D = DIAMETER OF PLANT

The notable features are :

(i) With a pump of adequate capacity the entire operation is completed in 2-3 hours and a number of batches of defluoridated water can be obtained in a day.

(ii) The accessories needed are few and these are easily available (these include 16 1 buckets for dissolving alum, preparation of lime slurry or sodium carbonate solution, bleaching powder and a weighing balance).

(iii) The plant can be located in the open with precautions to cover the motor.

(iv) Semi-skilled labour can perform the function independently.

4.2.3 *Fill and draw Type for Rural Water Supply*

The fill-and-Draw Type vertical unit comprises cylindrical tank of 10m capacity with dished bottom, inlet, outlet and sludge drain. The cylindrical tank will have sturdy railings, etc. Each tank is fitted with an agitator assembly consisting of : (i) 5 HP drip proof electric motor; 50 Hz; 1440 RPM with 415 V $\pm$6% voltage fluctuation, and (ii) gear box for 1440 RPM input speed with reduction ratio 60:1 to attain an output speed of 24 RPM, complete with downward shaft to hold the agitator paddles. The agitator is fixed to the bottom of the vessel by sturdy, suitable stainless steel supporting bushings.

The scheme comprises tanks of $10m^3$ capacity each, a sump well and an overhead reservoir. A system with two units in parallel for treating water for 1500 population at the rate of 40 lpcd is shown in the layout (Figure 4.) Raw water is pumped into the units and treated by Nalgonda Technique. The treated water collected in a sump is pumped to an overhead tank, from where the water is supplied through stand posts.

4.2.4 *Continuous Flow System for Rural Water Suply :*

The scheme intends to treat the raw water for villages and includes channel mixer, pebble bed flocculator, sedimentation tank and constant rate sand filters. The design of entire water facilities are available for 500, 1000, 2000, and 5000 population. The scheme is gravity operated except the filling of the overhead tank and delivery from treated water sump. Channel mixer is provided for mixing lime slurry or sodium carbonate solution and aluminium salts with the raw water. Pebble bed flocculation is used in place of conventional flocculation in order to avoid the dependence on electrical power supply. The scheme envisages power supply for 2 hours each during morning and evening for filling the over head tank and for supply of treated water. The basis of design of various units are given below :

(i)	water consumption	70 lpcd
(ii)	flash mixing-detention period velocity to be maintained	30 second

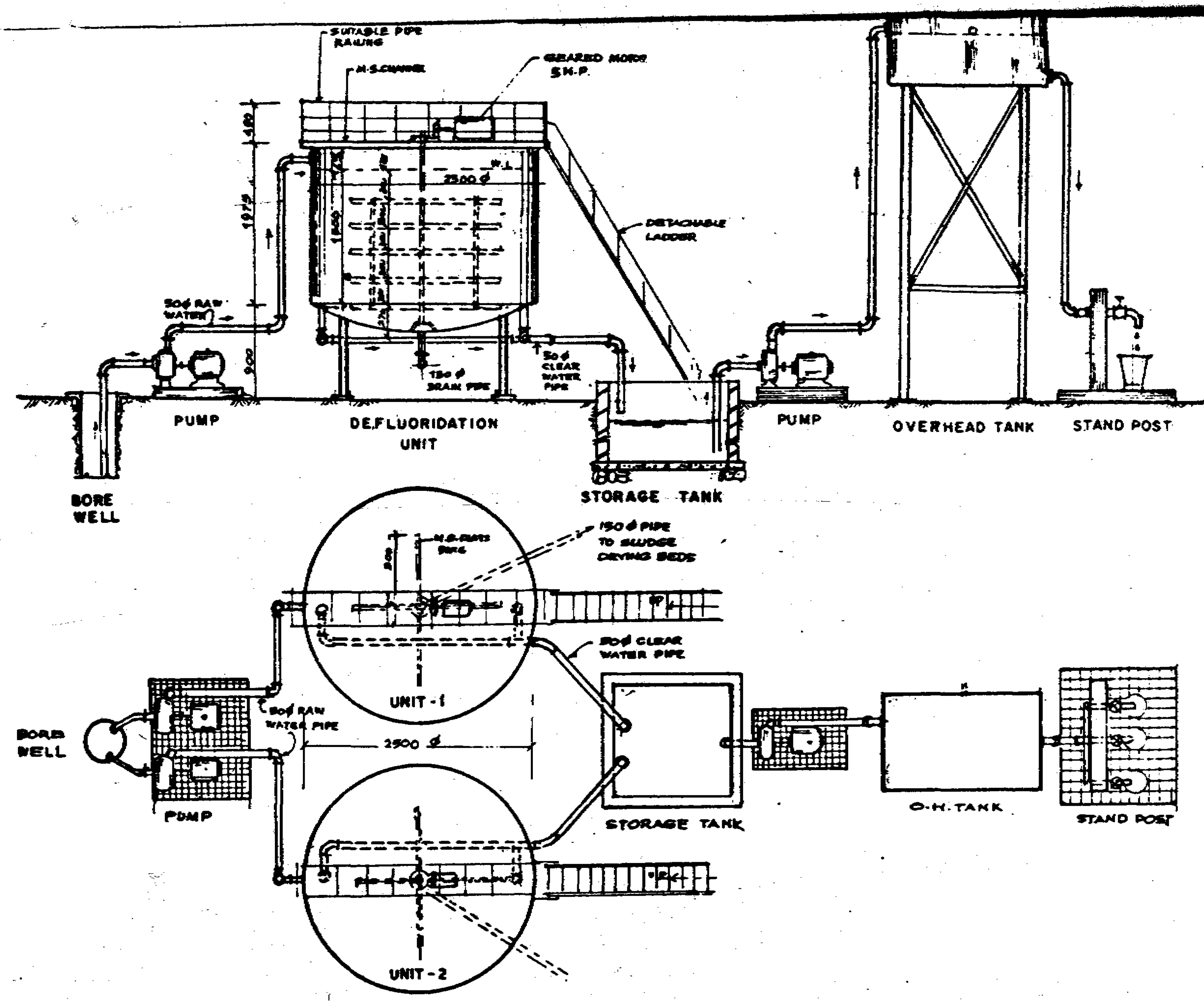


FIG. 4 FILL & DRAW DEFLUORIDATION SYSTEM FOR RURAL WATER SUPPLY

(iii) pebble bed flocculator :

* detention period (considering 50% voids)	30 minutes
* size of media	20 - 40 mm
* depth of media	1.2 m
* rate of backwash	0.5 m/min.

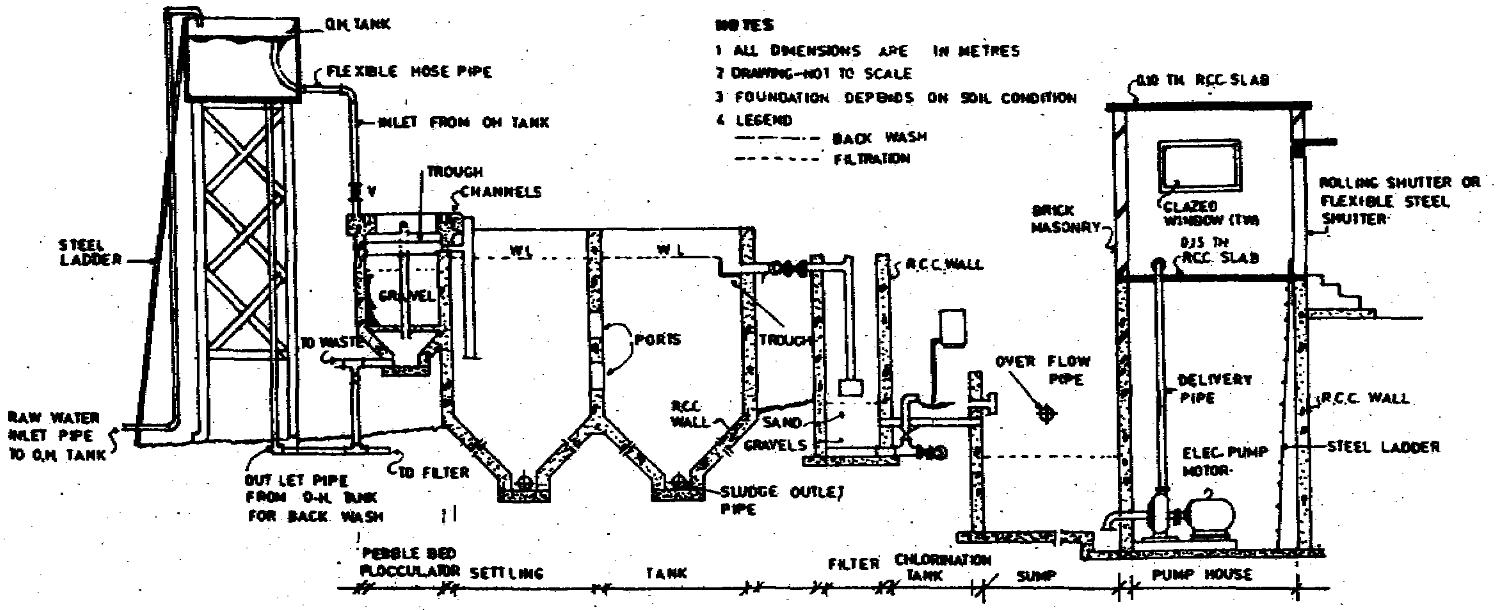
(iv) sedimentation :

* vertical depth	3 m
* weir loading rate	<300 $m^3/m/d$
* surface overloading rate	<20 $m^3/m^2/d$

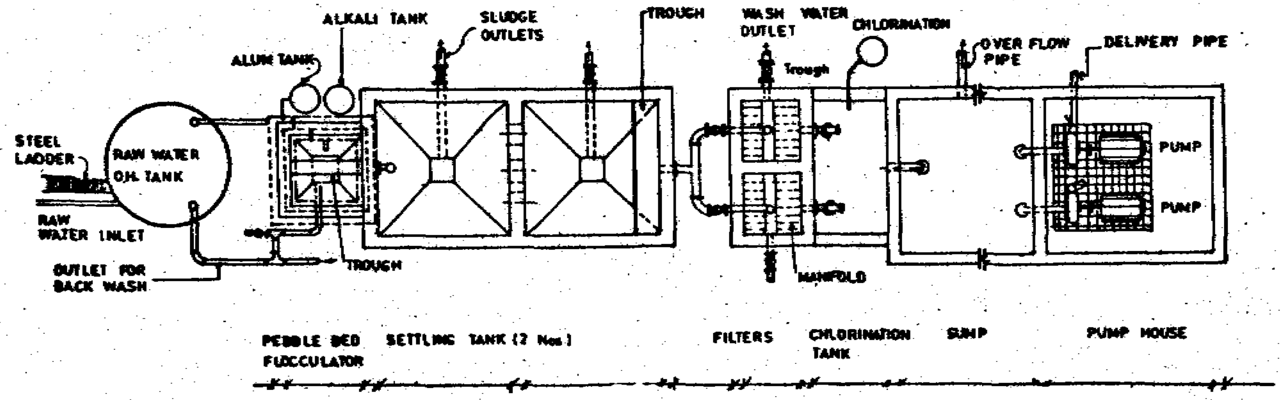
(v) sand gravity filter :

* total head above the sand	2 m
* rate of filtration	4.88 $m^3/m^2/h$
* total head for backwashing filter	12 m
* minimum backwash rate	0.73 $m^3/m^2/m$
* sand depth	1.00m.
* gravel depth	0.45 m.
* effective size of sand	0.6 mm to o.8 mm

The sizes of all units, viz., overhead tank, channel mixer, pebble bed flocculator, sedimentation tank, and filter and underground treated water storage tank are based on these design considerations for populations 500, 1000, 2000 and 5000. The layout plan and sectional elevation of this system is shown in Fig. 5.



SECTIONAL ELEVATION



LAYOUT PLAN

FIG. 5 CONTINUOUS FLOW SYSTEM FOR RURAL WATER SUPPLY

5. INSTALLATION OF D F PLANTS (FILL & DRAW TYPE) FOR RURAL WATER SUPPLY SCHEMES IN GUJARAT : CASE STUDIES

In view of the problem of excessive fluoride in the villages of Gujarat a systematic programme to fight this menace is envisaged. A defluoridation Camp was held at Mehsana and water quality survey in some villages was conducted. Out of the 200 water samples collected from various villages in Mehsana district, 92 villages have the fluoride concentration less than 1.6 mg/1, 69 villages have fluoride in the range of 1.6 to 2.5 mg/1, 32 villages have 2.6 to 3.5 mg/1 and 7 have fluoride concentration between 3.6 and 5.6 mg/1. On the basis of fluroide concentrations it was decided in consultation with GWSSB to install two Fill & Draw Type DF Plants at Tavadia (Sidhpur Taluka) and Badarpur (Kheralu Taluka) villages respectively. The fluoride concentrations in these Villages was observed to be 3.8 mg/1 and 3.2 mg/1 respectively. The site specific data and the physicochemical characteristics of raw water are shown below.

Table 1

Parameters	Site Specific Data	
	Village Tavadia	Village Badarpur
Population (1981 Census)	1286	2633
Population (Design - projected for the year 1991)	1740	3500
Estimated Water Demand	77 m^3/d	144 m^3/d
Water Source	Tube Well	Tube Well
Scheme	Pump & tank	Pump & tank
Power availability per day	12 hrs.	12 hrs.
Fluoride level	3.8 mg/1	3.2 mg/1
Approachability	Kuccha road	Tar road
Nearest Town and distance	Sidhpur, 8 km	Vadnagar, 5 km
Height above MSL (Noted from nearest railway station)	132 m	154.24 m
Educational Facilities	Primary School	Primary & High School
Medical Facilities	Health Worker, 1	Health Workers, 2
Communication Facilities	Post Office and Telephone	Post Office and Telephone

Table 2

Parameters		Physicochemical Characteristics of raw water Village Tavadia	Village Badarpur
pH		8.1	8.4
Turbidity (NTU)		0.5	1
Conductivity (µS/cm)		1533	1640
Alkalinity	(as $caco_3$)	370	780
Total Hardness	- do -	128	88
Ca. Hardness	- do -	72	36
Mg. Hardness	- do -	56	52
Chloride	(as Cl^-)	250	180
Sulphate	(as SO_4^{--})	122	72
Fluoride	(as F^-)	3.8	3.2
TDS		900	940

All parameters except pH, Turbidity & conductivity are in mg/l.

Laboratory treatability studies (Jar test experiments) were carried out with varying doses of alum and lime (depending on the Fluoride concentration and natural alkalinity of water). Based on this the alum dose required to bring down the fluoride level to 1 mg/1 was worked out. The results of the treatability studies for the water samples of the villages Tavadia & Badarpur are shown below in Table 3

Table 3

Alum dose, mg/l	Laboratory Treatability Studies (Jar Test) Village Tavadia	Village Badarpur
300	1.9	–
400	1.4	–
450	1.2	–
500	1.0	–
550	0.9	–
600	0.78	1.1
700	–	0.74

Based on the site data and the fluoride levels observed in respect of the identified villages it was decided to install DF system in these two villages. The defluoridation at Tavadia is achieved through a removable/shiftable HDPE system and a Ferrocement system is installed in Badarpur.

The Fill and Draw Type vertical system comprises of two cylindrical tanks of 10 m^3 capacity each with dished bottom, inlet and outlet, and sludge drain. Each tank is fitted with an agitator assembly consisting of

i) 5 HP 'drip proof' electric motor, 3 phase, 50 Hz. 1440 RPM with 415 $\pm$ 6% voltage fluctuation and

ii) Gear box for 1440 RPM input speed with reduction ratio 60 : 1 to give an output speed of 24 RPM complete with down ward shaft to hold the agitator paddles.

The entire scheme was designed on the following considerations :

(i) Water supply @ 40 lpcd for projected population of 1991 (design population)

(ii) Power availability, which is for about 12 hrs. a day in the villages. Hence adequate batches are to be run during this period to meet the daily requirements of the village population.

5.1 Design Example

Population of Tavadia	:	1286 (1981 census)
Projected Population (for the year 1991)	:	1740
Rate of supply	:	40 lpcd
Total daily requirement	:	69600 lit/day ~ 70 m^3 / day
Considering 10% losses	(clarifier bleed etc.)	
Total gross requirement	:	77 m^3 / day
Power availability	:	12 hrs.

Taking 10 - 20 mins for mixing/flocculation and 2 hrs settling,

Duration of each cycle	:	2 1/2 hrs
Number of cycles that can be operated	:	4

The quantity of water treated daily with a system comprising two unit of 10 m^3 each is $2 \times 10 \times 4 = 80$ m^3

To store this water an underground sump of 20 m^3 (diameter 2.55 m and ht 4.5 m). is constructed.

The village has an existing ESR of capacity 25m^3 to which water from the underground sump will be lifted and supplied to the villagers through PSP's and house connections.

5.2 Cost of Treatment

The detailed cost estimates for HDPE/Ferrocement systems at village Tavadia and Badarpur respectively have been prepared based on the population, water demand and items of recurring expenditure like electricity, chemicals, personnel etc and shown below.

		TAVADIA	BADARPUR
Capital Cost (System + civil costs)	:	4,05,000	3,62,000
Running cost per annum			
i) Power (Rs. 1/- per unit)		30,000	30,000
ii) Chemicals Alum (Rs. 1.5/kg.) Lime (Rs. 1/kg.) Bleaching powder (Rs. 0.5/kg.)		25,769	32,777
iii) Personnel One supervisor (Rs.1000/- pm) One chemist (Rs. 800/- pm) Two labourers (Rs. 600/- pm)		36,000	36,000
iv) Depreciation @ 5% per annum		20,250	18,100
v) Maintenance @ 5% per annum		20,250	18,100
Total running cost per annum		1,32,269	1,34,977
- Quantity of water treated per annum @ 80 m^3 / day (4 cycles of operation)		29,200 m^3	29,200 m^3
- Running cost Rs/m^3 treated water		4.53	4.62

Note :

a) Chemicals required per 10 m^3 of water

	Tavadia	Badarpur
Alum	5.5 kg	7.0 kg
Lime	0.55 kg	0.7 kg
Bleaching powder	50 gm	50 gm

b) Cost is exclusive of the minimum needed laboratory instruments viz. pH meter, Turbidimeter, Ion selective meter, Conductivity meter and required Glassware/ Chemicals. Subsidy is expected for these items from the state agency.

c) Once more plants are installed, the supervisory and laboratory staff will be common for 5 - 6 plants and as such reduction in O & M cost could be achieved.

5.3 Operational Data :

Initially trial tests were conducted to check for possible leakage etc. and proper functioning of the system before putting it to regular operation. The schedule followed is as below :

1) Each tank was filled to capacity.

2) Alum solution (10% w/v) was prepared. (10% excess alum was added to account for scaling up factor). Flocculation was carried out for 10 - 15 minutes with alum in one reactor. This was followed with alum in combination with lime (1/10th of alum dose) in the second reactor.

3) Following flocculation, the settlement of the flocs was observed for a period of 2 - 4 hrs.

   It was observed that while flocs formed due to addition of only alum took about 3 to 4 hrs. for settling, the flocs formed as a result of addition of alum in combination with lime took only 2 hrs. to settle properly.

4. Settled water was drawn to an underground sump from where it was lifted to an ESR for distribution to the village.

5. Settled sludge was withdrawn and put on sludge drying beds.

   The results of the trial tests are shown in the Table 4 and the layout plans of the systems are depicted in Fig. 6 & 7.

6. SUGGESTED OPERATIONAL SCHEDULE ;

1. Fill the reactor with raw water.

2. Weigh the alum - preferably in powder form as per requirement arrived at earlier and dissolve it in water to prepare approximate 10% solution in the feeder container. (A 100 lit HDPE/Plastic container should suffice).

   Keep the solution overnight.

3. Start the stirring mechanism.

4. Add the entire quantity of alum solution to the reactor.

5. After 5 minutes of stirring, add 700 gms of powdered lime together with 50 gms of bleaching powder to the reactor.

6. Continue stirring for 15 more minutes.

7. Allow the reactor contents to settle for 2 - 3 hrs.

Table 4 **Operational Data of Defluoridation Plants at Villages Tavadia & Badarpur**

Parameter	TAVADIA							BADARPUR		
	Raw Water	Treated Water		Raw Water	Treated Water			Raw Water	Treated Water	
		I	II		I	II	III		I	II
Alum dose (10% Solution)	–	550	550	–	550	550	550	–	700	700
Lime dose (1% Solution)	–	–	–	–	–	–	55	–	–	–
pH	8.1	7.3	7.3	7.5	6.4	6.4	6.7	8.4	6.5	6.6
Turbidity (NTU)	0.5	0.5	0.5	1.0	0.6	0.6	0.3	1	0.1	0.1
Conductivity (μS/cm)	1533	1558	1559	1310	1480	1480	1480	1640	1650	1650
M. Alklinity (as $CaCO_3$)	370	208	–	370	180	180	220	780	380	380
Total Hardness - do -	128	132	132	176	176	176	216	780	–	–
Ca. Hardness - do -	72	76	76	88	88	88	132	36	–	–
Mg. Hardness - do -	56	56	56	88	88	88	84	52	–	–
Chloride (as Cl^-)	250	250	250	–	270	270	270	180	180	180
Sulphate (as SO_4^{--})	122	504	528	152	516	516	–	72	600	–
Fluoride (as F^-)	3.8	1.2	0.92	3.6	0.9	0.72	0.68	3.2	0.6	0.74

All parameters except pH, Turbidity and Conductivity are in mg/1.

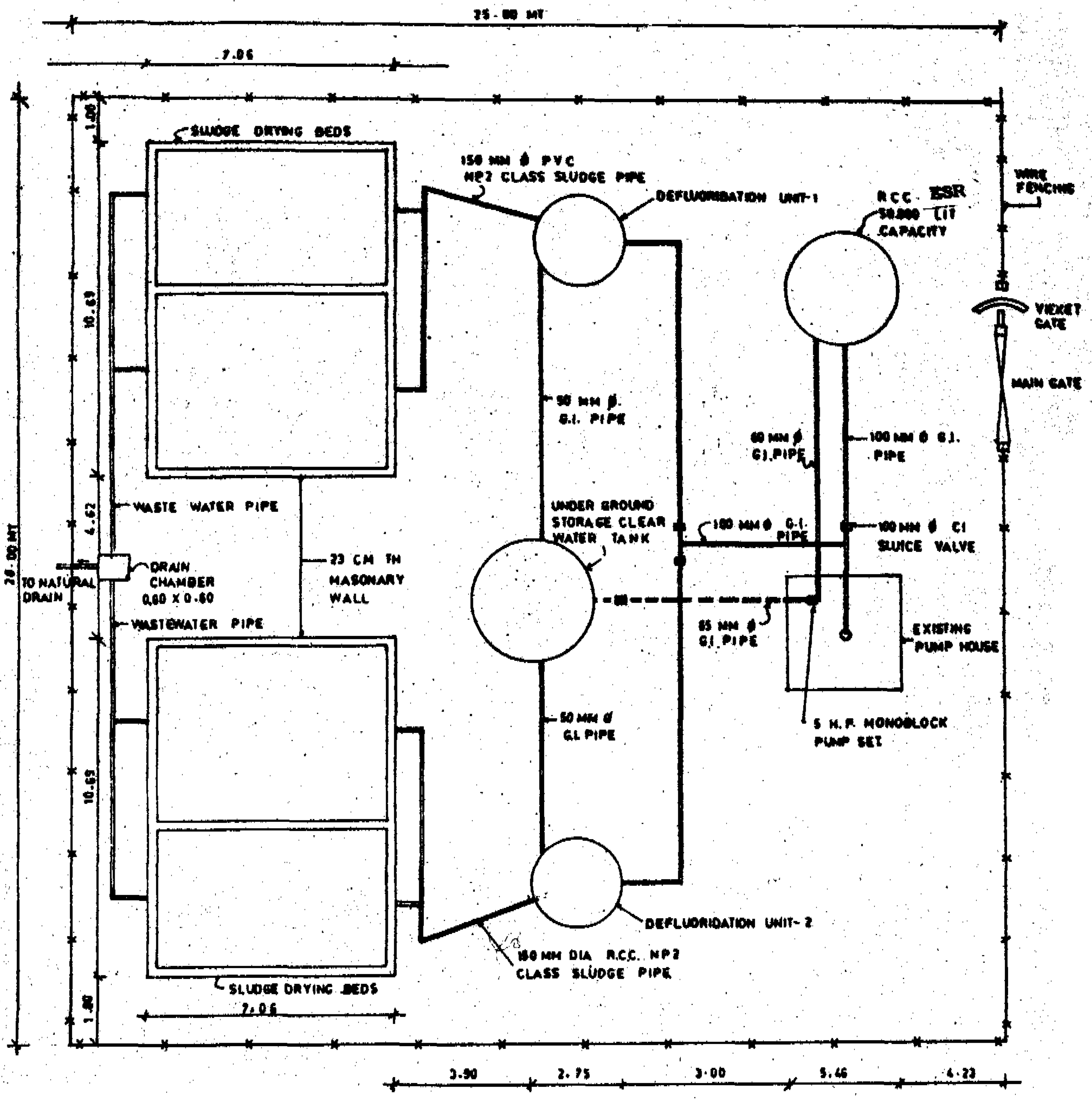
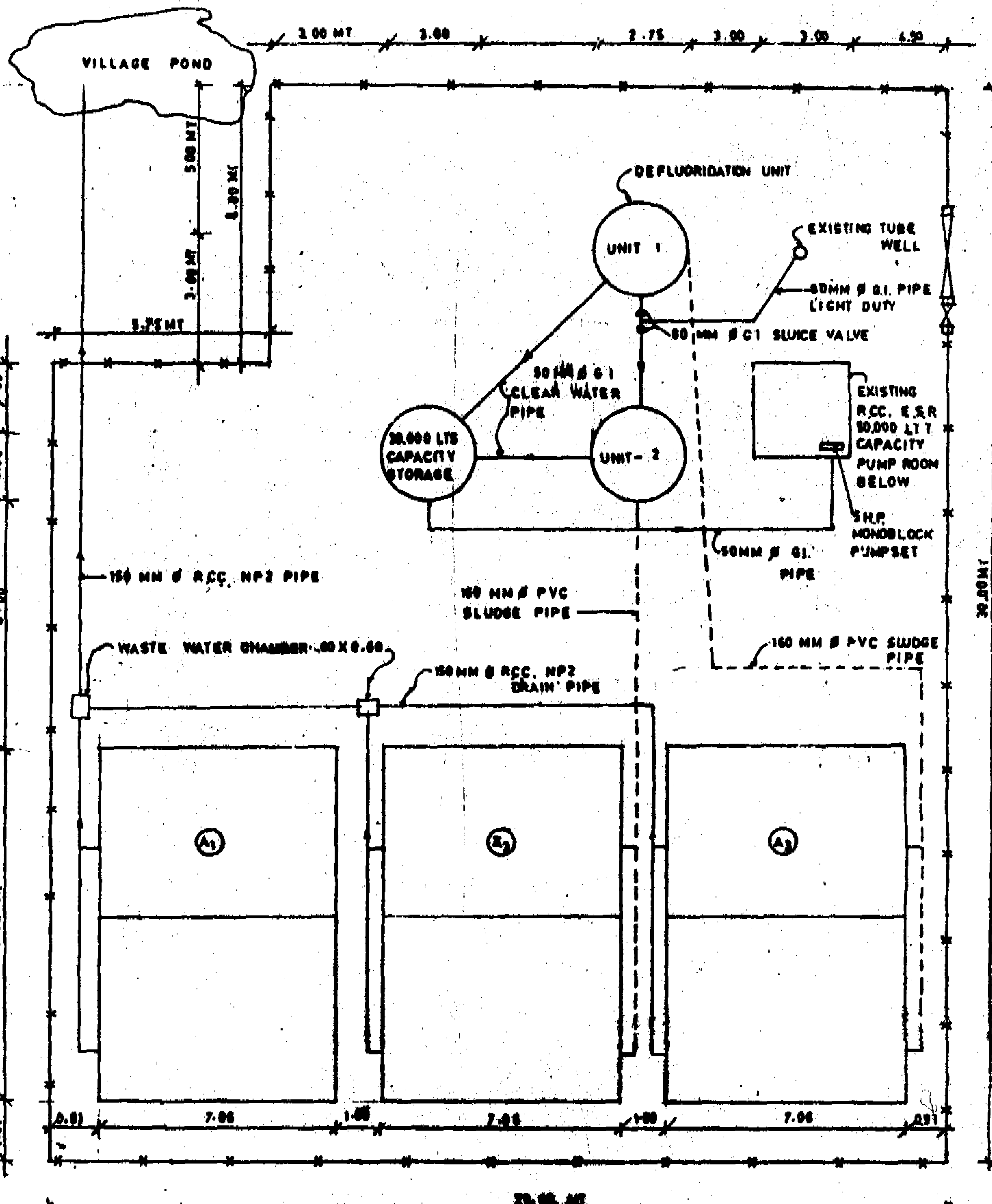


FIG. 6 LAYOUT PLAN

VILLAGE – TAVADIA



A1 A2 A3 SLUDGE DRYING BEDS

LAYOUT PLAN

FIG. 7 VILLAGE SABARPUR

8. Withdraw the supernatent by opening the sluice valve provided at outlet to the underground clear water sump.

9. Open the sludge valve and withdraw the sludge to the sludge drying bed.

10. Pump the clear water to the ESR for distribution to the village through PSP and/ or house connection.

11. Start a new cycle of operation in the similar manner.