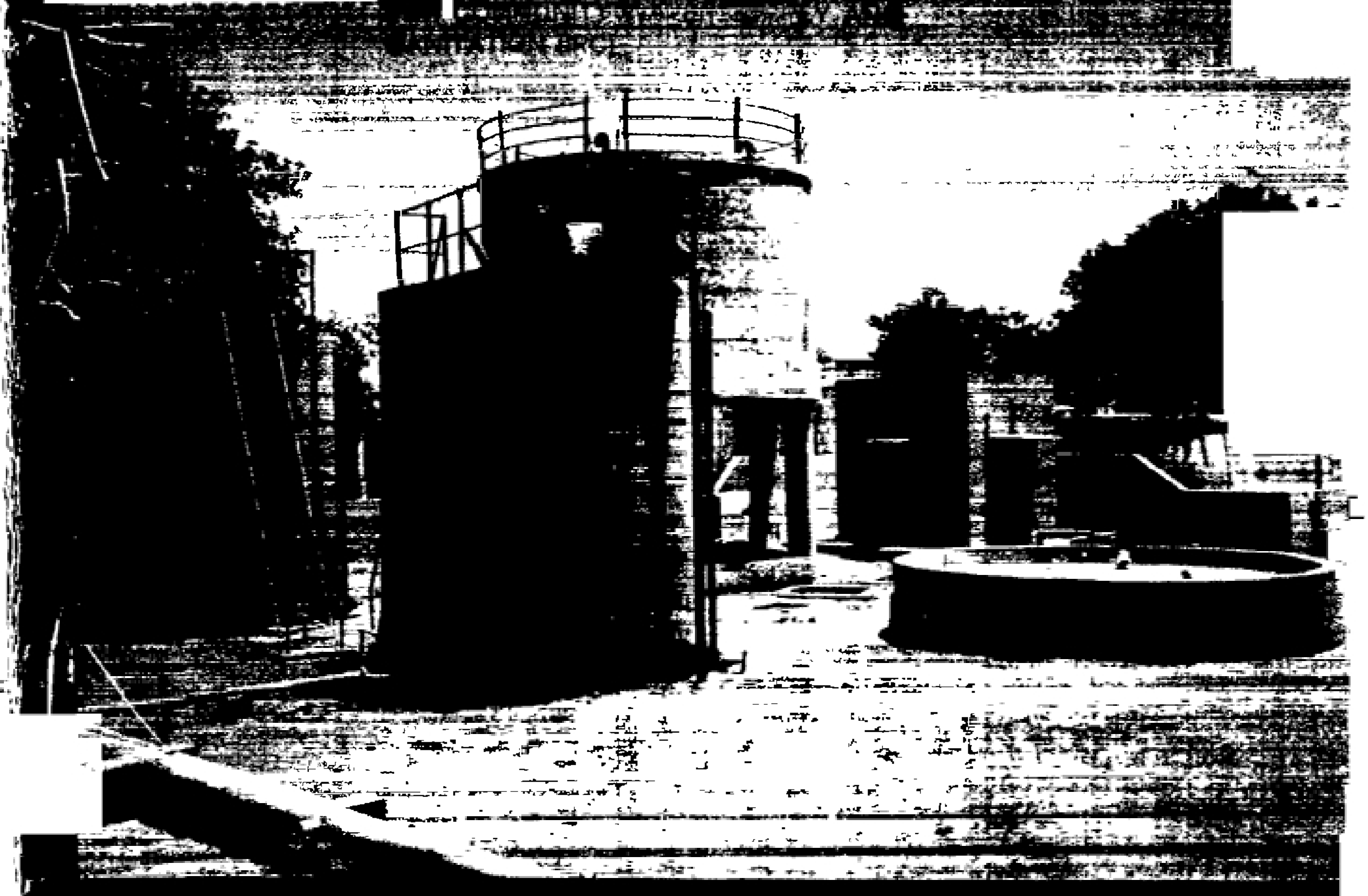

# DEFLUORIDATION

National Environmental
Engineering Research Institute
Nehru Marg, Nagpur - 440 020

October, 1992

# DEFLUORIDATION

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October, 1992

# FOREWORD

National Environmental Engineering Research Institute (NEERI) has conducted extensive R&D on Defluoridation since 1961 The Institute has tested many materials for defluoridation of water and developed a simple and cost effective process for defluoridation, known as Nalgonda Technique.

The Nalgonda Technique has been recommended by the Government of India for its application to remove excess fluoride from drinking water The State Governments have installed several defluoridation plants based on this technique. The Institute installed seven fill-and-draw defluoridation plants for rural water supply in Andhra Pradesh, Haryana and Gujarat under Water Mission programme of the Government of India during 1988-90.

Technology Information Package on Defluoridation was prepared by the Institute in September, 1987 for Water Mission incorporating salient features of Nalgonda Technique, design considerations for rural water supply, and specifications of units for population range of 500 to 5000. The experience of the Institute in the operation and maintenance of the defluoridation plants necessitated revision of this Package. This revised version incorporates the role of fluoride on human health, water quality testing for defluoridation, details of Nalgonda Technique, and design details on community defluoridation plants.

The Institute is indebted to the Water Mission, and State Governments of Andhra Pradesh, Gujarat and Haryana for their financial contribution and technical cooperation in the implementation of Defluoridation Schemes for Water Treatment by Nalgonda Technique.

The Institute is sanguine that the revised Technology Information Package on Defluoridation of drinking water will be useful to engineers, scientists and technicians in various departments charged with the responsibility of public water supply

Kanna

(P Khanna)

NEERI, Nagpur
October, 1992

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# 1. ROLE OF FLUORIDE ON HUMAN HEALTH

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

## 1.1 Dental Fluorosis

The assessment of dental fluorosis (Plate 1) 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 semi-vitriform type of structure. The surface is smooth, glossy and usually of a pale, creamy white powder.

*Questionable*: The enamel discloses slight aberrations from translucency of normal enamel, ranging from a 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 than 1-2 mm of white opacity at the tip of the cusps of the premolars or second molars.

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

*Moderate*: All enamel surfaces are affected and surface to attrition show marked wear. Brown stain is frequently a disfiguring feature.

*Severe*: All enamel surface is affected by hypoplasia and 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.

## 1.2 Skeletal Fluorosis

Ingestion of 20-80 mg F or more through water over a period results in crippling and severe osteosclerosis. Calcification of certain liaments is usually associated with at least 10 mg/L of fluoride in drinking water, which renders the movements of the joints difficult.

Symptoms of Skeletal Fluorosis* (Plate 2) are:

- Severe pain in the back bone
- Severe pain in the joints
- Severe pain in the hip region (pelvic girdle)
- Stiffness of the back bone
- Immobile/stiff joints
- Constriction of vertebral canal and inter-vertebral foramen- pressure on nerves
- X-ray : Increased girth/thickening and density of bone besides calcification of ligaments
- Paralysis

### 1.3 Non-Skeletal Fluorosis*

This aspect of fluorosis is often overlooked because of the notion prevailing that fluoride will only affect bone and teeth. Fluoride when consumed in excess can cause several ailments besides skeletal and dental fluorosis as given below:

1. *Neurological Manifestation* : Nervousness, depression, tingling sensation of fingers and toes, excessive thirst and tendency to urinate more frequently.
2. *Muscular Manifestation* : Muscle weakness, stiffness, pain in muscle and loss of muscle power.
3. *Allegric Manifestation* : Very painful skin rashes, which are perivascular inflammation prevalent in women and children, pinkish red or bluish-red spots on the skin that fade and clear up in 7-10 days round or oval shape.
4. *Gastro-intestinal Problems* : Actue abdominal pain, diarrhoea, constipation, blood in stools, bloated feelings (gas), tenderness in stomach, feeling of nausea (flu-like symptoms) and mouth sores.
5. *Urinary Tract Manifestation* : Urine may be much less in volume - yellow red in colour and its itching in the region.
6. *Headache*

It should not be misunderstood that the above mentioned complaints are always due to fluoride toxicity. Fluoride is one of the factors which can cause such manifestations.

---

* Dr. A.K. Susheela. "Technical information on Training Camp on Prevention and Control of Fluorosis," December 21-22, 1987, Mehsana, Gujarat.

Plate 1. Dental Fluorosis

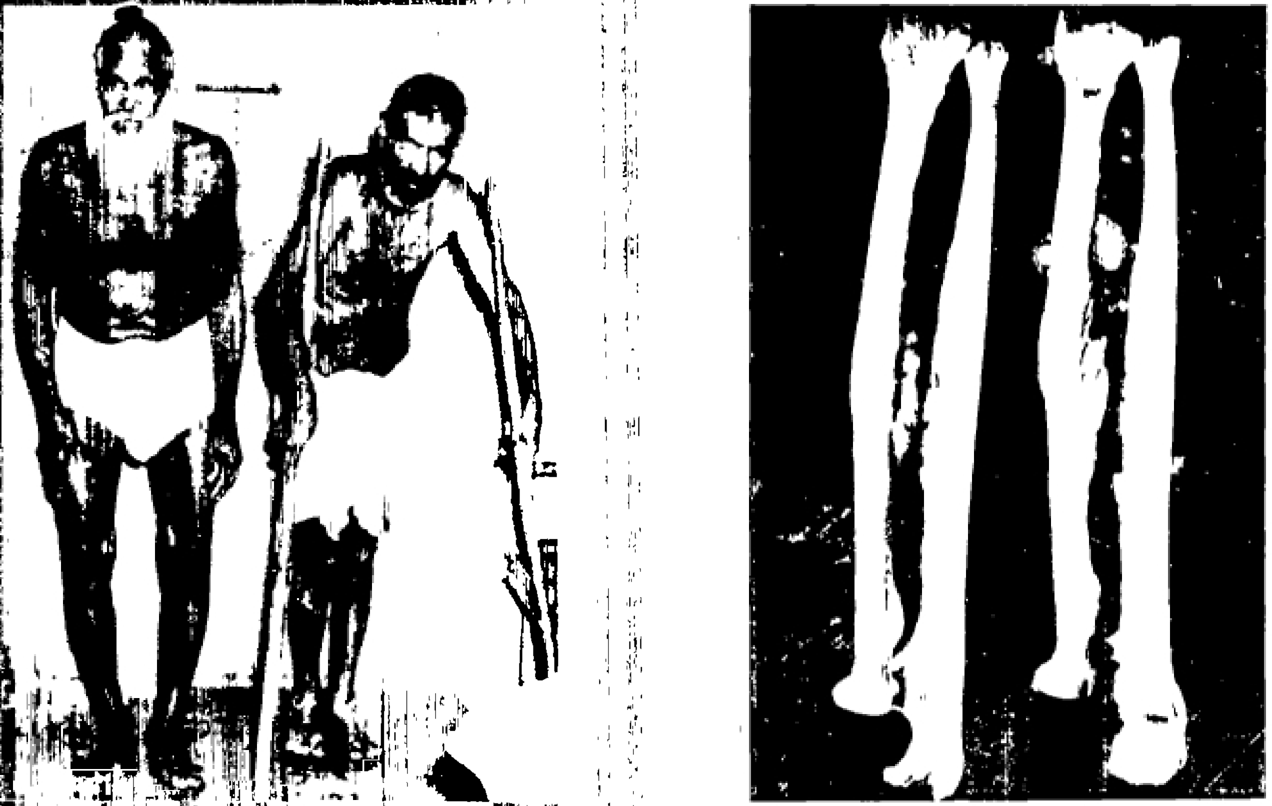


Plate 2. Skeletal Fluorosis

# 2. INCIDENCE OF FLUORIDE IN WATERS

Excess fluoride in ground waters is encountered in Afghanisthan, Algeria, China, Egypt, India, Iran, Iraq, Jordan, Kenya, Libya, Morocco, Sudan, Tanzania, Thailand and Turky.

In India, it occurs in the states of Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu and Uttar Pradesh.

As per WHO Guidelines for Drinking Water Quality (1984), and Water Technology Mission, Government of India (1986), the excessive limit for fluoride is fixed as 1.5 mg/L, after which the water needs treatment for removal of excess fluoride.

There are 8700 villages in India which have problem of excessive fluoride in water affecting 25 million people. The water quality assessment was undertaken by National Environmental Engineering Research Institute (NEERI) in 1987 and 1988 under Water Technology Mission programme of the Government of India. A total of 4252 water samples were analysed for physico-chemical parameters of which 821 samples contained excess fluoride. Out of these 821 samples, 394 samples contained fluoride above 1.5 mg/L and all other parameters were within drinking water standards. Summarised information on the occurrence of excess fluoride in various parts of India is given in Table 1.

**Table 1 : Information on Occurrence of Excessive Fluoride in Ground Water in India.**

| S. No. | State | District | Total Samples analysed | Total Samples having > 1.5 mg F/L | Total Samples having Fluoride Above 1.5 mg F/L but TDS and Nitrate within Limits |
|---|---|---|---|---|---|
| 1 | Andhra Pradesh | Kurnool | 143 | 82 | 55 |
| 2 | Bihar | Palamu | 191 | 35 | 28 |
| 3. | Bihar | Rohatas | 209 | 9 | 4 |
| 4 | Gujarat | Mehsana | 200 | 116 | 64 |
| 5 | Haryana | Faridabad | 200 | 46 | 28 |
| 6 | Haryana | Gurgaon | 429 | 116 | 68 |
| 7 | Karnataka | Gulbarga | 477 | 163 | 81 |
| 8. | Madhya Pradesh | Jhabua | 55 | 12 | 10 |
| 9. | Maharashtra | Nagpur | 114 | 8 | 7 |
| 10 | Maharashtra | Latur | 221 | 8 | 5 |
| 11 | Maharashtra | Satara | 1001 | 13 | 7 |
| 12 | Maharashtra | Chandrapur | 46 | 17 | 12 |
| 13. | Orissa | Phulbani | 225 | 5 | 5 |
| 14 | Orissa | Koraput | 324 | 8 | 4 |
| 15 | Rajasthan | Barmer | 351 | 180 | 16 |
| 16. | Tamilnadu | Ramnathpuram | 66 | 3 | 0 |
| | | Total | 4252 | 821 | 394 |

# 3. WATER QUALITY TESTING FOR DEFLUORIDATION

## 3.1. Introduction

An initial approach to define a problem in environmental sciences necessitates the use of analytical methods & procedures in the field and laboratory that have been proved to yield reliable results. Once the problem is defined, then only satisfactory solution can be sought out. Numerous analytical methods have been developed to obtain the factual information required to find out a solution of problems as well as to have constant supervision to maintain economical and satisfactory performance of the treatment facilities constructed.

Excess of fluoride in water is one such problem parameter which causes dental and skeletal fluorosis and needs to be removed to permissible limit of 1.0 mg F/L for drinking purposes. The excess of fluoride is removed by Nalgonda Technique developed by NEERI by fill-and-draw or continuous system of defluoridation plant. During operation and maintenance of the defluoridation plant, physico-chemical parameters such as turbidity, conductivity, dissolved solids, pH, alkalinity, hardness, chloride, sulphate and fluoride have to be analysed at regular intervals. Analytical procedures of these parameters are covered with more emphasis under different procedures which are prerequisite for assessment and control of defluoridated water quality.

### 3.1.1 General Information

Collect the sample along with the suspended matter in clean polythene bottle. Shaking may be required before taking an aliquot for analysis.

Calibrate all the glass-wares.

Use A.R. grade reagent.

Express the results as milligrams of parameter per litre of sample. Round off the digits which are not significant.

Statistical analysis of the data should be done before any conclusion is drawn.

For the benefit of the readers, general information is given in subsequent sections about the sampling of water samples.

## 3.2 Sampling

### 3.2.1 Introduction

The collection of water samples may seem a relatively simple task. However, to obtain representative water samples and to preserve their integrity until they are analysed in the laboratory requires a series of steps, procedures and practices A representative sample can easily be obtained from rivers and lakes which are relatively homogenous, whereas many water-bodies have significant spatial and temporal variations and the collection of a representative sample becomes much more complex.

The objective of the sampling is to collect a portion of material small enough in volume to be conveniently transported to and handled in the laboratory while still accurately representing the material being sampled This implies, first, that the relative portions of the concentrations of all pertinent components must be the same in the samples as in the material being sampled and second, that the sample must be handled in such a way that no significant changes in composition occurs before the tests are performed. The analysis is generally intended to reveal the composition of the waters at the time or over the period of sampling. Consequently, errors are introduced if changes take place between taking of the sample and analysis being carried out. There is infact, a strong likelyhood that such changes will occur in most of the waters The arrangement should be such that these are prevented or at least minimised.

### 3.2.2 Planning of Sampling

The monitoring of water quality to give reliable and usable data requires that analytical and other resources are employed to the best advantage. The first step in the planning of water monitoring is to decide what data is needed and how it is useful. The type of investigation, purpose of study and anticipated variations are other points to be considered The first stage of planning of the sampling programme is the selection of the most suitable site to provide the required data.

### 3.2.3 Site Selection

The objectives of water quality monitoring system are

1) To assess the impact of activities by man upon the quality of water and its suitability for required uses

2) To determine the quality of water in its natural state which might be available to meet the future needs and

3) To keep under observation the sources and path way of specified hazardous substances

The selection of sampling site is decided by the various uses of the water and by their location, relative magnitude and importance. The chances of accidental pollution is also an important factor and should be considered. The location of a river used down stream of large urban or industrial area imposes greater risk and requires more supervision than similar uses located upstream.

### 3.2.4 Type of Samples

### 3.2.4.1 Grab or Catch Samples

A sample collected at a particular time and place can represent only the composition of the source at that time and place. However, when a source is known to be fairly constant in composition over a considerable period of time or over substantial distances in all directions, then the sample may be said to represent a larger time period or larger volume or both than the specific point at which it was collected. In such circumstances, same source may be quite well represented by single grab smaples. When a source is known to vary with time, grab samples collected at suitable intervals can be of great value in documenting the extent, frequency, and duration of these variations. In case the composition of a source varies in space rather than in time, a set of samples collected from appropriate locations with less emphasis on timing may provide the most useful information.

### 3.2.4.2 Composite Samples

The term composite refers to a mixture of grab samples collected at the same sampling point at different time. Sometimes the term time composite is used when it is necessary to distinguish this type of sample from other. Time composite samples are most useful for observing average concentrations, as an alternative to the separate analysis of a large number of samples, followed by computation of average and total results. A composite sample of 24 hr. period is considered standard for most determinations. Composite samples can not be used for determinations, of components or characteristics subject to significant and unavoidable changes on storage.

### 3.2.4.3 Integrated Samples

Mixture of grab samples collected from different points simultaneously or as nearly as possible is called integrated sample. Such samples are useful for river or stream that varies in composition across its width and depth. The need for integrated samples also may exist if combined treatment is proposed for several separate waste water stream. The preparation of integrated samples requires special equipment to collect samples from a known depth, without contamination by over lying water. Prior knowledge about volume, movement and composition of the various parameters of the water being sampled is also required.

### 3.2.5 Sampling Frequency

Water samples should be collected at intervals so that no change in quality could pass unnoticed. The quality of water in various water bodies is rarely constant in time but is subjected to change.

The larger the number of samples from which the mean is derived, the narrower will be the limits of the probable difference between observed and true values. However, the sampling schedule is a compromise between accuracy and the funds, personnel for the work.

### 3.2.6 Number of Samples

Number of samples and how often should samples be collected, are calculated by statistical considerations. The following frequencies of sampling may be adopted provisionally.

a) Weekly samples for one year
b) Daily samples for 7 days consecutively (4 times/year)
c) Round the hour sampling for 24 hours
d) 4-hourly samples for 7 days and 4 times/year

The parameters may be limited during these samplings but should be pertinent to the source/ sampling station.

The analytical data collected as per the above procedure will help to lay proper emphasis on parameters of relative importance; their ranges, interferences, and frequencies of their occurrence.

### 3.2.7 Sample Containers

It is advantageous to measure the quantity of water in situ by means of sensors which are lowered into position rather than by withdrawing samples. However, it is not always possible. Water samples are, therefore, collected in suitable containers. A sample container must satisfy the following requirements.

1. It should easily be freed from contamination.
2. It should not change the relevant water characteristics.
3. It should have adequate capacity for storing the samples.
4. It should be resistant to impact and to internal pressure which is increased by expansion of water or by release of dissolved gases at elevated temperature on storage.

The quantity required for chemical examination will vary according to the information required. For most purposes 2 litres are advisable, allowing a margin for contingencies. The ordinary dust free stoppered winchester bottles of colourless or pale green glass holds this quantity and serves well. Dark coloured bottles are to be avoided except, perhaps, for samples for residual chlorine estimations which should be collected separately in amber-coloured glass bottles so that direct access to light is prevented from altering the chlorine content of the sample.

Strong colourless polythene bottles of two sizes, 1-litre and 2-litre capacity, are generally useful. The bottles should not be used for any other purposes.

The specific situation will determine the use of the borosilicate glass bottle or polyethylene container. The bottles should be rinsed with chromic acid solution (35 ml saturated $Na_2Cr_2O_7$ in 1 L conc $H_2SO_4$) followed by tap and distilled water and then be inverted to dry.

For carrying a bottle and sending by rail, strong wicker-work cases or wooden boxes lined with felt, in which the bottles stand upright, are the safest and best. These can easily be made so as to be secured easily with a padlock if desired. Polythene bottles have obvious advantages for carriage of samples by road, rail and air.

Where large quantities of water are required for experimental purposes, well cleaned acid carbuoys to hold about 50 litres are very useful

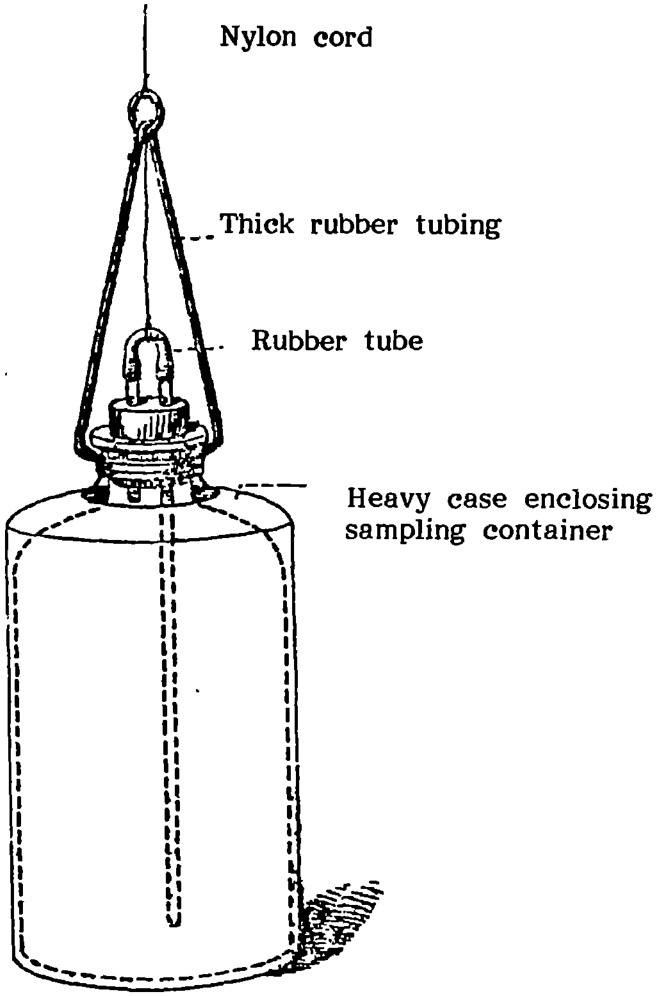
Wherever possible the container should be rinsed out two or three times with the water to be examined before being finally filled. If this cannot be done, the container should be well drained. The stopper or cap of the container should not be laid down, but kept contained in its covering in the hand before being reinserted. Unless it is absolutely unavoidable, no funnel or jug should be used in filling the container, and the container should be so held that the water does not come in contact with hand before entering.

In taking a sample from a tap or pump, the nozzle should be first examined to see that it appears clean. If not, it should be cleaned and then preferably rinsed thoroughly with the same water Water should then be allowed to run to waste for a few minutes before filling the container, unless it is desired to ascertain whether the water is affected by standing in the mains or pump pipe If such is the case, it is best to take the sample first time in the morning, before any water has been drawn for other purposes.

In taking samples from rivulets and springs, it is often necessary to make an excavation sufficiently large to hold the hand and the container and allow sufficient time for all matter disturbed to be washed away before taking the sample. Where the sample is be taken by immersing the container, as in ponds, cisterns, reservoirs, rivers, many wells, etc., it is generally quite satisfactory if the container is weighted by a weight or casing and sunk rapidly to the required depth. When sampling from the sides of river and streams, the container may be clamped to a stout, rigid metal rod which is extended into the main stream of the water

The apparatus illustrated in Diagram is very easily put together, and can be used with equal facility for obtaining water from a considerable depth in a bore tube or deep well, and from an open tank or running stream.

A stoppered bottle of any size can be used, provided the weighted cylinder, partially closed in at the top, will go over it. The stopper is removed, and a rubber cork with two perforations inserted in its place. Through one perforation passes a piece of glass tubing about 5 cm long, and through the other longer piece of tubing reaching to near the bottom of the container, and projecting about 3 cm above the rubber stopper. The projecting tubes are connected by a piece of rubber tubing about 5-6 cm long. The container is suspended by means of a stout band of rubber about 30 cm long, the free ends being secured tightly to the neck of the container by cord. A metal loop or swivel connects the rubber



Apparatus for water sampling from wells

suspender with the nylon cord used for lowering the bottle into the water. The loop or the swivel is connected with the short piece of rubber tubing uniting the two glass tubes by a piece of string of such length that, when the container is suspended, there is no pull upon the rubber tube, which, however, can easily be jerked off when a sharp pull is given to the suspending nylon cord. The apparatus, having been arranged, is lowered to the required depth; a sharp jerk is then given to the suspending nylon cord, when the rubber tube is detatched Water enters through the longer tube and the air is expelled through the shorter tube. Bubbles of air can be seen or heard rising through the water until the bottle is full, or until only a little compressed air remains in the neck of the container. As the apparatus is raised, the air thus imprisoned expands and prevents entering water from nearer the surface. Nylon cord for suspending the apparatus is marked off in meters, so that the depth to which the container has descended is known.

The points requiring chief attention are to see that the rubber stopper is tightly inserted, and that the small piece of rubber tubing can be easily detatched by a slight jerk.

The apparatus is useful, when a smaple has to be taken from a depth of not exceeding 100 meter below the surface of the water. This serves the purpose.

There are commercial depth samplers available in market and these can also be used wherever possible.

### 3.2.8 Sampling Procedure

The first matter to consider is the selection of the sampling point, and great care and discretion are necessary in this selection in order that the sample shall represent as fairly as possible the source desired to be examined.

The suitability of the sampling point having been decided, the hand pump should be allowed to run for several minutes and the water from the sampling point allowed to run to waste for five minutes in order to free the sampling point from stagnant water before the sample is collected with care and expediency. The container should be completely filled with water and the stopper/cap replaced. The container after labelling is replaced in the sampling box for immediate despatch to the laboratory for analysis.

The period of time elapsing between the collection of the sample and its receipt at the laboratory should be as short as possible.

For the collection of the samples at Defluoridation plants, it is desirable to install sampling taps on appropriate points. Such taps could well be installed at various selected points as ‘official sampling points’ and thus avoid a good deal of the unnecessary annoyance and wasted effort which result from the collection of the samples from unsuitable sampling point.

Sampling from reactors, sumpwell and service reservoirs can be made by experienced persons with knowledge of sample collection by means of a jug attached to a metallic chain. Greatest care is required in transferring the water to the sample container. The best material for the jug is stainless steel.

Specimen of the label which is suggested for water samples is shown below:

---

**SAMPLE OF WATER**

**Submitted for physico-chemical examination**

by......................................................................................................................................................

(Name of Authority or person requiring the examination)

of.... ..................................................................................... ..................................................

( Address of the Authority or person)

Taken from.................................................................. ..........................................................................

(State point and place where sample was taken, together with site specific particulars)

.................... ..... ... ........................................ ....................................... ... .......................

....................................................... ...........................................................................

....................................................... ... . ........................................... ......................................

at.................... ..............................................on.........................................................................

(Time of sampling) (Date)

by ... .... ........................ .......... ..... ........................................................... .............................

(Name of person taking sample)

in the presence of .................................... .. .. ... ........................................ .... ..............................

signed....... .... ................................... ........................................................ .... ..............................

(Despatch *sample* as soon as possible after collection)

---

### 3.2.9 Recording of Information

Care should be taken to record at the site of collection every detail which may have any bearing upon the results of the analyses to be undertaken, or which may be of importance in connection with the taking of the sample, or be of general scientific interest.

In taking the sample from a river or stream, the following points should be recorded:

1. Date and time when sample is taken and dispatched
2. In whose presence
3. Exact point marked on map
4. Whether at or near middle or side, and which side

5. Depth below surface
6. Weather at the time and particulars of any recent rainfall or flood condition
7 Whether the level of the water is above or below average
8. Observations with reference to any possible source of pollution in the vicinity and approximate distance of the same from the sampling point
9. Temperature of water
10. Signature of the person taking sample

If a single sample only is being taken, it should be collected from beneath the surface near the middle of the stream.

In taking samples from a well, record 1, 2, 3 as above, and, in addition

4. Approximate ground surface level
5. Depth from ground level to surface of water (rest level)
6. Depth of water in well and depth at which sample is taken
7 The mode of construction of the well, including its covering
8. Whether the appearance of water is affected by heavy rains
9. Any indication of pollution, discoloration of sides, or other visible indication of pollution
10. Characteristics of the surroundings, proximity to drains, sewers, cess pools, stables, dustbins, or other possible sources of pollution, and distance from the well
11 When available, a section or drawing of the well together with its general surrounding
12. Yield of water and effect of pumping
13. Nature and depth of subsoil, impervious layer and water bearing stratum
14 Temperature of water

As the character of the water in open wells often varies at different depths, it is best to lower the container rather rapidly under the surface of the water, so that it may, when filled, contain water from all parts of the well.

In taking samples from a large Reservoir, it is best to use a boat and depth-sampling apparatus. Samples also should be taken near the point of entry, and near the exit of the waters. If only one sample is to be collected, it is best to take it from beneath the surface, just over or very near the mouth of the trunk main or conduit.

When taking a sample from a house tap connected with a public supply, it should always be noted whether the tap is directly connected with the main or with a cistern. If the latter, the cistern should be examined and particulars thereof recorded The position of the main should also be noted, and the possibility of a dead end ascertained if possible.

When samples of water are received for analysis and there is any doubt about the way in which they have been collected or about the cleanliness of the containers used or when the samples are sent in container with unclean stoppers, it is best to communicate with the sender and offer to dispatch suitable containers for fresh samples together with instructions on how to collect them.

In taking the samples from the tube well, the following information is to be furnished by the owner of the tube well, which in turn must have been obtained by the owner from the Drilling agency.

Agency drilling the tube well ........................................
Location of the tube well ........................................
Method of drilling adopted ........................................
Date of starting ........................................
Date of completion ........................................
Pilot hole or test hole .................... Bit size .................... Bit type ....................
Hours .................... From .................... to ....................
Coring done .................... Bit size .................... Bit type .................... Hours ..........
Recovery .................... From .................... to ....................
Reaming .................... Bit size .................... Bit type .................... Hours ..........
From .................... to ....................
Lithological date

| From | To | Formations |
|---|---|---|
| .................... | .................... | .................... |
| .................... | .................... | .................... |

Assembly of production well .................... Size .................... Length .................... Type ....................
Perforation per metre ........................................
Housing pipe ........................................
Blind pipe ........................................
Strainer ........................................
Bail plug ........................................
Top of tube well above/below ground level ........................................
Size of gravel .................... Quantity used before development ....................
Quantity used during development ........................................
Total hours of testing ........................................
Further details appended:

a) Samples of strata, neatly packed in sample bags
b) Chart of pipe assembly lowered
c) Results of mechanical analysis of samples of unconsolidated strata.

Remarks:

Owner .................... Driller ....................

### 3.2.10 Field Measured Parameters

A number of parameters including pH, conductivity, dissolved oxygen, ammonia, $CO_2$, temperature, turbidity and residual chlorine should be measured at the sampling site immediately after collection of sample. However, in situ, measurements of these parameters are recommended.

## 3.3 Physico-chemical Analysis

Physico-chemical analysis is the prime consideration to assess the quality of water for best usage say for drinking, bathing, industrial processing and so on, while for waste water either domestic or industrial to know the pollutional strength and its effect on the ecology.

River water often necessitates examination of water samples from different points and under varying conditions to find out the extent of pollution and purification that takes place in the water.

Well waters are examined to locate the potable source of water as well as to study the effect of pumping in coastal areas, or in saline water.

Waters are also examined to test the samples to ascertain their suitability for potability or a particular trade, e.g. paper making, tanning, steam raising, dying, dairying etc. In such case, a particular parameter assumes importance, e g. for steam raising water should be checked for hardness and dissolved oxygen, water used in textiles should be checked for iron and hardness.

Similarly, domestic and industrial waste waters are also analysed for various parameters to decide upon what physical, chemical or biological treatment should be given to make them suitable for discharge either on land for irrigation or in other water bodies.

Comparatively this analysis, for example, determination of pH, temperature, DO, can be done quick enough to be adopted by regulatory agencies to monitor and control the ecological balance of nature.

Physico-chemical parameters such as turbidity, conductivity, pH, alkalinity, hardness, chloride, sulphate and fluoride are monitored when the defluoridation plants based on Nalgonda Technique are operated and maintained for rural water supply.

## 3.4 Conductivity

Conductivity is a capacity of water to carry an electrical current and varies both with the number and types of ions the solution contains, which, in turn, is related to the concentration of ionized substances in the water Most dissolved inorganic substances in water are in the ionised form and hence contribute to conductance. Rough estimation of dissolved ionic contents of water sample can be done by multiplying specific conductance (in u Siemens/cm) by an emperical factor which may vary from 0.55 to 0.9 depending on the soluble components of water and on the temperature of measurement. Conductivity measurement gives rapid and practical estimate of the variations in the dissolved mineral contents of a water supply

### Procedure

Conductivity measurement is affected by :

1. The nature of the various ions, their relative concentration and the ionic strength of water.

2. Dissolved $CO_2$.
3. Turbidity
4. Temperature (For precise work, the conductivity must be determined at $25^0C$)

Most of the instruments commercially available for measurement of conductivity consist of

i) A source of alternating current.
ii) A wheat-stone bridge, a null indicator, and,
iii) A conductivity cell consisting of a pair of rigidly mounted electrodes. Each conductivity cell has its own cell constant depending on its shape, size and the position of the electrodes. Either the cell constant is mentioned by the supplier or can be determined by using standard solution of KCl (0.01 M), alternatively by comparison with a cell of known cell constant Other instruments measure the ratio of alternating current through the cell to voltage across it and have advantage of linear reading of conductance. Portable battery operated instruments for both pH and conductivity are also available for field studies.

Conductivity can be measured as per the instruction manual supplied with the instrument and the results may be expressed as u Siemens/cm at temperature say $25^0C$ at which measurement was made. With reasonable care, conductivity meter needs very little maintenance and gives accurate results. However, few important points in this respect are.

1. Adherent coating formation of the sample substances on the electrodes should be avoided which requires thorough washing of cell with distilled water at the end of each measurement.

2. Keep the eletrode immersed in distilled water

3. Organic material coating can be removed with alcohol or acetone followed by washing with distilled water.

### 3.5 Turbidity

Suspension of particles in water interfering with passage of light is called turbidity Turbidity is caused by wide variety of suspended matter which ranges in size from colloidal to coarse dispersions depending upon the degree of turbulance and also ranges from pure inorganic substances to those that are highly organic in nature. Turbid waters are undesirable from aesthetic point of view in drinking water supplies and may also affect products in industries. Turbidity is measured to evaluate the performance of water treatment plant Turbidity in the defluoridated water is a measure of the aluminium remaining and hence an essential parameter. In well settled defluoridated water the turbidity is <1 N.T.U. with the corresponding aluminium concentration < 20 microgram/L.

#### Principle

Turbidity can be measured either by its effect on the transmission of light which is termed as Turbidimetry or by its effect on the scattering of light which is termed as Nephelometry. Turbidimeter can be used for sample with moderate turbidity and nephelometer for samples with low turbidity. Higher the intensity of scattered light higher the turbidity.

### Interference

Colour is the main source of interference in the measurement of turbidity.

### Apparatus

Turbidimeter or Nephelometer.

### Reagents

1. **Solution I :** Dissolve 1.0 gm Hydrazine sulphate and dilute to 100 ml.

2. **Solution II:** Dissolve 10.0 gm hexamethylene tetramine and dilute to 100 ml.

3. **Solution III:** Mix 5 ml of I with 5 ml of II. Allow to stand for 24 hrs. at $25 \pm 30^0$C and dilute to 100 ml. This solution will have turbidity of 400 units (N.T.U.)

4. **Solution IV - Standard turbidity suspension :** Dilute 10 ml of solution III as prepared above to 100 ml to have solution of the turbidity of 40 units (N.T.U.)

### Procedure

1. Prepare calibration curve in the range of 0-400 units by carrying out appropriate dilutions of solutions III and IV above taking readings on turbidimeter.

2. Take sample or a suitably diluted aliquot and determine its turbidity either by visual comparison with the diluted standards or by reading on turbidimeter.

3. Read turbidity from the standard curves and apply correction due to dilution, if necessary.

4. Report the readings in turbidity units.

### 3.6 Total Dissolved (Filtrable) Solids

The dissolved (filtrable) solids can be determined from the difference between the residue on evaporation and total suspended solids; but if the dissolved solids content is low and the suspended solids high, a direct determination is better. It is preferable to adopt the centrifugal method of separating suspended matter in order that a sufficiently large volume of separated liquid is available for the determination.

### Principle

A known volume of filtered sample is evaporated and dried in a weighed dish at $105^{0}C$ to constant weight. The increase in weight over the empty dish represents the dissolved solids.

### Apparatus

1. Evaporating dishes, 50, 100 ml capacity (Preferable porcelain or silica)
2. Pipettes 25, 50 ml capacity
3. Water bath & oven
4. Balance to weigh up to 4th decimal

### Procedure

Take the known volume (V) of filtered sample in a previously ignited and weighed basin (W1). Evaporate to dryness on a steam bath and further dry at $105^{0}C$ for one or two hours in an oven. Cool in dessicator and weigh ($W_2$). Repeat by further heating for 15 minutes and cooling until successive results do not differ by more than about 0.4 mg.

### Calculation

$$\text{Dissolved solids mg/L} = \frac{(W_2 - W_1) \times 1000}{V}$$

## 3.7 pH

For most practical purposes the pH of aqueous solutions can be taken as negative logarithm of hydrogen ion activity. pH values from 0 to 7 are diminishingly acidic, 7 to 14 increasingly alkaline and 7 is neutral.

The pH of natural water usually lies in the range of 4.4 to 8.5. Its value is governed largely by the carbon dioxide/ bicarbonate/ carbonate equilibrium. It may be affected by humic substances by changes in the carbonate equilibria due to the bioactivity of plants and in some cases by hydrolyzable salts. The effect of pH on the chemical and biological properties of liquids makes its determination very important. It is used in several calculations in analytical work and its adjustment is necessary for some analytical procedures.

The determination of pH by conventional chemical means is not practicable and the equilibria which are involved depend to some extent on temperature. The precise accepted scale of pH must therefore be based on an agreed primary standard. The *colorimetric indicator methods can be used* only if approximate pH values are required.

The pH determination is usually done by electrometric method which is the most accurate method and free of interferences.

### 3.7.1 Electrometric Method

The pH is determined by measurement of the electromotive force of a cell comprising an indicator electrode (an electrode responsive to hydrogen ions such as glass electrode) immersed in the test solution and a reference electrode (usually a mercury calomel electrode) contact between the test solution and the reference electrode is usually achieved by means of a liquid junction, which forms a part of the reference electrode. The emf of this cell is measured with pH meter. This is a high impedance electrometer calibrated in terms of pH.

### Apparatus

**Glass Electrode** : This must be compatible with the pH meter used and must be suitable for the particular application. Special electrodes are available for pH values greater than 10 and for use at temperature greater than 60$^0$C. Combined glass/reference electrodes are also available and are convenient to use

**Reference Electrode** · The mercury/calomel electrode is widely used but the silver/silver chloride electrode may be preferable on account of it being more reproducible and more reliable. Less concentrated solutions of KCl (e.g. 3.5 M KCl) are more satisfactory as filling solutions than the saturated solution often used because problems due to clogging of the electrode or the liquid junction will be avoided To prevent dissolution of the silver chloride film the potassium chloride filling solution of Ag/AgCl electrodes should be saturated with AgCl

**pH Meter** : Both mains and battery operated models are available, the later type can be used for field measurements. The most accurate pH meters can be read to better than ±0.005 pH unit.

### Reagents

1. **Buffer solution for pH 4.0** : Dissolve 10.12 gm potassium dihydrogen phthalate dried at 110$^0$C in freshly distilled water and dilute to one litre at 25$^0$C

2. **Buffer solution for pH 6.8** : Dissolve 3.388 gm anhydrous $KH_2PO_4$ and 3.533 gm $Na_2HPO_4$ both of which have been dried overnight at between 110$^0$C and 130$^0$C in water and dilute to 1 litre at 25$^0$C. The distilled water should be freshly boiled, cooled and free from $CO_2$.

3. **Buffer solution for pH 9.2 :** Dissolve 3 80 gm $Na_2B_4O_7.10\,H_2O$ in water and dilute to 1 litre at 25$^0$C.

**NOTE** : In general, analytical reagent grade chemicals are satisfactory for the preparation of these solutions. Commercial buffer tablets are available in the market for the preparation of solution of above pH value (each tablet dissolved in 100 ml gives the buffer solution of required pH).

### Procedure

1 Standardize the pH meter according to the manufacturer's instructions.
2. Select a standard buffer solution with a pH value close to that of the water to be treated.
3. Set the temperature control to the temperature of the buffer.
4. Set the meter to the pH of the buffer at that temperature.
5 Check the electrode response by measuring a second standard buffer solution of different pH.
6. Wash the electrode thoroughly first with distilled water and then with the sample.
7. Set the temperature control to the temperature of the sample.
8. Immerse electrodes in the sample and record the pH after stabilising the system.

**NOTE** : Between measurements, the electrodes are kept in distilled water. New or dried out glass electrodes should be prepared for the use by soaking in 0.1 N HCl for 8 hours or according to the maker's instructions

## 3.8 Alkalinity

The alkalinity of water is a measure of its capacity to neutralise acids. The alkalinity of natural water is due to the salts of carbonate, bicarbonate, borates, silicates and phosphates along with the hydroxyl ions in free state. However, the major portion of the alkalinity in natural waters is caused by hydroxide, carbonate and bicarbonates which may be ranked in order of their association with high pH values. Alkalinity values provide guidance in applying proper doses of aluminium sulphate or aluminium chloride or both in water and wastewater to be defluoridated. To achieve complete hydrolysis of aluminium salts added, it is essential to ensure a residual alkalinity of 1-2 meq/L in the defluoridated water

### Principle

Alkalinity of a sample can be estimated by titrating with standard sulphuric acid Titration to pH 8.3 or decolourisation of phenolphthalein indicator will indicate complete neutralisation of OH and 1/2 of $CO_3$ while to pH 4.5 or sharp change from yellow to pink of methyl orange indicator will indicate total alkalinity (complete neutralisation of OH, $CO_3$, $HCO_3$).

### Reagents

1. **Standard $H_2SO_4$(0.02 N)** : Prepare 0.1 N $H_2SO_4$ by diluting 3 0 ml conc. $H_2SO_4$ to 1000 ml. Standardise it against standard 0.1 N $Na_2CO_3$. Dilute appropriate volume of $H_2SO_4$ (approx. 0.1 N) to 1000 ml to obtain standard 0.02 N $H_2SO_4$.

2. **Phenolphthalein indicator :** Dissolve 5 gm in 500 ml 95% ethyl alcohol Add 500 ml distilled water. Add dropwise 0.02 N NaOH till faint pink colour appears.

3. **Methyl orange indicator :** Dissolve 0.5 gm and dilute to 1000 ml with $CO_2$ free distilled water.

**Procedure**

1. Take 25 or 50 ml sample in a conical flask and add 2-3 drops of phenolphthalein indicator.

2. If pink colour develops, titrate with 0.02 N $H_2SO_4$ till it disappears or pH is 8.3. Note the volume of $H_2SO_4$ required. ...............A

3. Add 2-3 drops methyl orange to the same flask, and continue titration till pH comes down to 4.4 or orange colour changes to pink.

   Note the vol. of $H_2SO_4$ added. ................ B

4. In case pink colour does not appear after addition of phenolphthalein, continue as in 3 above.

5. Calculate Total (T), phenolphthalein (P) and methyl orange alkalinity as follows and express in mg/L as $CaCO_3$.

P - Alkalinity, mg/L as $CaCO_3$ = A x 1000/ml sample.

MO- Alkalinity, mg/L as $CaCO_3$ = B x 1000/ml sample.

T - Alkalinity, mg/L as $CaCO_3$ = (A+B) x 1000/ml sample.

In case $H_2SO_4$ is not 0.02 N, apply the following formula:

$$\text{Alkalinity, mg/L as } CaCO_3 = \frac{A \times N \times 50000}{\text{ml Sample}}$$

where N = Normality of $H_2SO_4$ used.

Once the phenolphthalein and total alkalinity is determined, then three types of alkalinities, i e. hydroxide, carbonate and bicarbonate are easily calculated from the table given below.

| **Values of P&T** | OH | $CO_3$ | $HCO_3$ |
|---|---|---|---|
| P = 0 | 0 | 0 | T |
| P < 1/2 T | 0 | 2P | T-2P |
| P = 1/2 T | 0 | 2P | 0 |
| P > 1/2 T | 2P-T | 2(T-P) | 0 |
| P = T | T | 0 | 0 |

## 3.9 Hardness

Water hardness is the traditional measure of the capacity of water to react with soap, hard water requiring a considerable amount of soap to produce a lather. Hardness of water is not a specific constituent but a variable and complex mixture of cations and anions. The principal hardness causing ions are calcium and magnesium. Internationally, the degree of hardness of drinking water has been classified in terms of the equivalent $CaCO_3$ concentration as follows:

| | | |
|---|---|---|
| Soft | : | 0-60 mg/L |
| Medium | : | 60-120 mg/L |
| Hard | : | 120-180 mg/L |
| Very hard | : | >180 mg/L |

The degree of hardness of drinking water has been classified by BIS in terms of the equivalent $CaCO_3$ concentration as follows:

| | | |
|---|---|---|
| Desirable requirement | : | 300 mg/L |
| Permissible limit | : | 600 mg/L |

The permissible limit is applied in the absence of alternate sources of water.

Fluoride removal by Nalgonda Technique is not affected by Hardness. However, hardness values > 300 mg/L affects the taste of the treated water. Public acceptability of the degree of hardness may vary considerably from community, depending on local conditions.

Hardness may also be discussed in terms of Carbonate (temporary) and Non-carbonate (permanent) Hardness. Carbonate hardness can be removed or precipitated by boiling. This type of hardness is responsible for the deposition of scale in hot water pipes and kettles. Non-carbonate hardness is caused by the association of the hardness causing cations with sulphate, chloride or nitrate. It cannot be removed by boiling. Public acceptability of the degree of hardness may vary considerably from community to community, depending on local conditions.

### 3.9.1 EDTA Titrimetric Method

**Principle**

In alkaline condition EDTA reacts with Ca and Mg to form a soluble chelated complex. Ca and Mg ions develop wine red colour with Eriochrome Black - T under alkaline condition. When EDTA is added as a titrant the Ca and Mg divalent ions get complexed resulting in sharp change from wine red to blue which indicates end point of the titration. The pH for this titration has to be maintained at $10.0 \pm 0.1$. At a high pH, i e. about 12.0, Mg ion precipitates and only $Ca^{++}$ ion remains in solution. At this pH, Murexide indicator forms a pink colour with $Ca^{++}$. When EDTA is added, $Ca^{++}$ gets complexed resulting in a change of colour from pink to purple which indicates the end point of the reaction.

**Interference**

Metal ions do interfere but can be overcome by addition of inhibitors.

**Reagents**

1. **Buffer Solution :** Dissolve 16.9 gm. $NH_4Cl$ in 143 ml $NH_4OH$. Add 1.25 gm. magnesium salt of EDTA to obtain sharp change in indicator and dilute to 250 ml. If magnesium salt of EDTA is not available, dissolve 1.179 gm. disodium salt of EDTA (AR grade) and 780 mg $MgSO_4.7H_2O$ or 644 mg $MgCl_2.6H_2O$ in 50 ml distilled water. Add to above solution of $NH_4Cl$ in $NH_4OH$ and dilute to 250 ml.

2. **Inhibitor :** Dissolve 4.5 gm hydroxyl-amine hydrochloride in 100 ml 95% ethyl alcohol or isopropyl-alcohol.

3. **Eriochrome Black T indicator :** Mix 0.5 gm. dye with 100 gm. NaCl to prepare dry powder.

4. **Murexide indicator :** Prepare a ground mixture of 200 mg of murexide (ammonium purpurate) with 100 gm of solid NaCl.

5. **Sodium hydroxide 2 N :** Dissolve 80 gm NaOH and dilute to 1000 ml.

6. **Standard EDTA solution 0.01 M :** Dissolve 3.723 gm EDTA sodium salt and dilute to 1000 ml. Standardize against standard calcium solution, 1 ml = 1 mg $CaCO_3$.

7. **Standard calcium solution :** Weigh accurately 1.0 gm AR grade $CaCO_3$ and transfer to 250 ml conical flask. Place a funnel in the neck of a flask and add 1+1 HCl till $CaCO_3$ dissolves completely. Add 200 ml distilled water and boil for 20-30 min. to expel $CO_2$. Cool and add methyl red indicator. Add 3N $NH_4OH$ dorpwise till intermediate orange colour develops. Dilute to 1000 ml to obtain 1 ml = 1 mg $CaCO_3$.

**Procedure**

### 3.9.2 Total Hardness

1. Take 25 or 50 ml well mixed sample in porcelain dish or conical flask.

2. Add 1-2 ml buffer solution followed by 1 ml inhibitor.

3. Add a pinch of Eriochrome Black T and titrate with standard EDTA (0.01 M) till wine red colour changes to blue. Note down the volume of EDTA required (A)

4. Run a reagent blank. Note the volume of EDTA (B)

5. Calculate volume of EDTA required by sample, from volume of EDTA required in steps 3 & 4 (C)

$$C = (A - B)$$

6. Calculate as follows :

$$\text{Total hardness as } CaCO_3 \text{ mg/L} = \frac{C \times D \times 1000}{\text{ml sample}}$$

Where C = Vol. of EDTA required by sample
D = mg $CaCO_3$ per 1.0 ml. EDTA (0.01 M) used as titrant

### 3.9.3 Calcium Hardness

1. Take 25 or 50 ml sample in porcelain dish.

2. Add 1 ml NaOH to raise pH to 12.0 and a pinch of murexide indicator.

3. Titrate immediately with EDTA till pink colour changes to purple. Note the vol. of EDTA used (A').

4. Run a reagent blank. Note the volume of EDTA (B') required and keep it aside to compare end points of sample titrations.

5. Calculate as follows:

$$\text{Calcium Hardness as } CaCO_3 \text{ mg/L} = \frac{C' \times D' \times 1000}{\text{ml sample}}$$

Where C' = volume of EDTA used by sample (A'-B')
D' = mg $CaCO_3$ per 1.0 ml EDTA (0.01 M) used for titration

### 3.9.4 **Magnesium Hardness** as $CaCO_3$ mg/L

Magnesium Hardness = Total Hardness - Ca Hardness

### 3.9.5 Alkaline (Carbonate) Hardness and Non alkaline (Non carbonate) Hardness.

These types of hardness can be calculated from total hardness and total alkalinity data as follows:

If Total Hardness as $CaCO_3$ > Total Alkalinity as $CaCO_3$,

1. Alkaline Hardness = Total Alkalinity.

2. Non-alkaline Hardness = Total Hardness - Total Alkalinity

If Total Hardness as $CaCO_3$ < Total Alkalinity as $CaCO_3$,

I. Alkaline Hardness = Total hardness

II. Non-alkaline Hardness = Nil.

## 3.10 Chloride

Chloride ion is generally present in natural waters. The presence of chloride in natural waters can be attributed to dissolution of salt deposits, discharges of effluents from chemical industries, irrigation drainage, contamination from refuge leachates and sea water intrusion in coastal areas. The salty taste produced by chloride depends on the chemical composition of the water. The BIS prescribed the desirable requirement of chlorides as 250 mg/L from taste considerations. The permissible limit in the absence of alternate sources is 1000 mg/L, a cause for rejection of waer source.

A combination of aluminium sulphate and aluminium chloride is necessary for waters with fluorides > 12 mg/L to achieve a value < 1 mg F/L in the defluoridated water. Chloride determination is, therefore, necessary as routine. The change in the chloride concentration is a measure of the quantity of aluminium chloride added to the water for defluoridation.

### Principle

Chloride is determined in a neutral or slightly alkaline solution by titration with standard silver nitrate, using potassium chromate as an indicator. Silver chloride is quantitatively precipitated before red silver chromate is formed.

### Interference

If the sample is too coloured or turbid to allow the end point to be readily detected, this interference may be reduced by alum flocculating followed by filtration prior to the estimation of chloride.

### Reagents

1. **Potassium chromate indicator:** Dissolve 50 g $K_2CrO_4$ in distilled water. Add $AgNO_3$ till definite red precipitate is formed. Allow to stand for 12 hrs. Filter and dilute to 1000 ml.

2. **Silver nitrate (0.0141 N) :** Dissolve 2 395 gm $AgNO_3$ and dilute to 1000 ml. Standardize against 0.0141 N NaCl. 1 ml of 0.0141 N $AgNO_3$ = 0.5 mg Cl.

3. **Sodium chloride (0.0141) N :** Dissolve 824.1 mg NaCl dried at $140^0$C and dilute to 1000 ml. 1 ml = 0.5 mg Cl.

4. **Special reagent to remove colour and turbidity:** Dissolve 125 g $AlK(SO_4)_2.12\ H_2O$ or $AlNH_4(SO_4)_2.12H_2O$ and dilute to 1000 ml. Warm to 60$^0$C and add 55 ml conc. $NH_4OH$ slowly. Allow to stand for 1 hr Solution should be free from Cl.

**Procedure**

1 Take 100 ml sample and adjust the pH between 7.0 and 8.0
2. Take 50 ml well mixed sample adjusted to pH 7.0 - 8.0 and add 1.0 ml $K_2CrO_4$
3. Titrate with standard $AgNO_3$ solution till $AgCrO_4$ starts precipitating
4. Standardize $AgNO_3$ against standard NaCl.
5 For better accuracy titrate distilled water (50 ml) in the same way to establish reagent blank
6. Calculate as follows:

$$\text{Chloride mg/L} = \frac{(A-B) \times N \times 35.45 \times 1000}{\text{ml sample}}$$

Where, A = ml $AgNO_3$ required for sample; B = ml $AgNO_3$ required for blank and
N = Normality of $AgNO_3$ used.

### 3.11 Sulphate

Sulphate ions usually occur in natural water Many sulphate compounds are readily soluble in water. Most of them originate from the oxidation of sulphite ores, the solution of gypsum and anhydrite, the presence of shales, particularly those rich in organic compounds. Atmospheric sulphurdioxide formed by the combustion of fossil fuels and emitted by the metallurgical roasting processes may also contribute to the sulphate compounds of water. Sulphate bearing minerals are common in most sedimentary rocks. In the weathering process gypsum ($CaSO_4$) is dissolved and sulphide minerals are partly oxidised, giving rise to a soluble form of sulphate that is carried away by water. Sulphates cause a problem of scaling in industrial water supplies, and problems of odor and corrosion in waste water treatment due its reduction to $H_2S$ Ingestion of water containing high concentration of sulphate can have a laxative effect, which is enhanced when sulphate is consumed in combination with magnesium. The BIS prescribed 400 mg/L as permissible limit in the absence of alternate sources.

Aluminium sulphate added to the water for removal of fluorides contributes sulphate ions to the defluoridated water. The change in the concentration of sulphate is a measure of the aluminium sulphate dose applied.

**Turbidimetric Method**

**Principle**

Sulphate ions are precipitated as $BaSO_4$ in acidic media (HCl) with Barium chloride. The absorption of light by this precipitated suspension is measured by spectrophotometer at 420 nm or scattered light by Nephelometer.

### Interference

Colour, turbidity and silica in the concentration of 500 ppm interfere in this estimation. Fltration is adopted to remove colour and turbidity.

### Apparatus

1. Magnetic stirrer
2. Colorimeter for use at 420 nm
3. Stopwatch
4. Nessler's tubes, cap 100 ml
5. Measuring spoon cap - 0.2 to 0.3 ml

### Reagents

1. **Conditioning reagent:** Mix 50 ml glycerol with a solution containing 30 ml concentrated HCl, 300 ml distilled water, 100 ml 95% ethyl or isopropyl alcohol and 75 g NaCl.

2. **Barium chloride Crystals :** 20-30 mesh.

3. **Standard sulphate solution** : Dissolve 147.9 mg anhydrous $Na_2SO_4$ and dilute to 1000 ml.
   1 ml = 100 ug $SO_4$.

### Procedure

1. Take suitable vol. of sample in 250 ml conical flask and dilute to 100 ml.

2. Add 5.0 ml conditioning reagent accurately. Mix well.

3. Keep the flask constantly stirred with the help of stirrer. Add $BaCl_2$ crystals while stirring. Continue stirring for 1 min. after addition of $BaCl_2$.

4. Measure the turbidity developed after every 30 sec. for 4 min. on colorimeter at 420 nm. After 2 min. stirring, reading will remain constant. Note this reading for calculation purpose.

5. Prepare standard curve by carrying standard sulphate solution through entire procedure. Space standards at 5 mg/L increment in the 0 to 40 mg/L range.

6. Read mg $SO_4$ present in the sample from the standard curve.

7. Calculate as follows:

$$\text{mg/L } SO_4 = \frac{\text{mg } SO_4 \times 1000}{\text{ml Sample}}$$

## 3.12 Fluorides

Fluoride ions have dual significance in water supplies. High concentration of $F^-$ causes dental fluorosis (Disfigurement of the teeth). At the same time, a concentration less than 0.8 mg/l results in 'dental caries'. Hence, it is essential to maintain the $F^-$ conc. between 0.8 to 1.0 mg/L in drinking water. The BIS mentions the desirable requiremenet as 1 mg F/L. Further BIS mentions that fluoride may be kept as 1.5 mg/L.

Among the many methods suggested for the determination of fluoride ion in water, the colorimetric method (SPADNS) & the ion selective electrode method are the most satisfactory and applicable to variety of samples. Because all of the colorimetric methods are subject to errors due to presence of interfering 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 as aluminium, hexametaphosphate, and orthophosphate which adversely affect the colorimetric methods. However, samples containing fluoroborate ion ($BF_4$) must be subject to preliminary distillation step in either of the methods. Both the methods and the preliminary distillation step are discussed below.

### 3.12.1 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 homogeneous, 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 $180^0$C. Discard the distillate. This process removes fluoride contamination and adjusts the acid-water ratio for subsequent distillations.

After cooling the acid mixture remaining after above step or previous distillation to $120^0$C or below, add 300 ml of sample, mix thoroughly, and distill as before until the temperature reaches $180^0$C. Do not heat above $180^0$C to prevent sulphate carryover.

Add $Ag_2SO_4$ to distilling flask at the rate of 5 mg/mg Cl 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 periods of inactivity, similarly flush the still, discard the distillate.

### 3.12.2 SPADNS Method

#### Principle

Under acid condition fluorides (HF) react with zirconium SPADNS solution and the 'Lake' (colour of SPADNS reagent) gets bleached due to formation of $ZrF^{-2}$. 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.

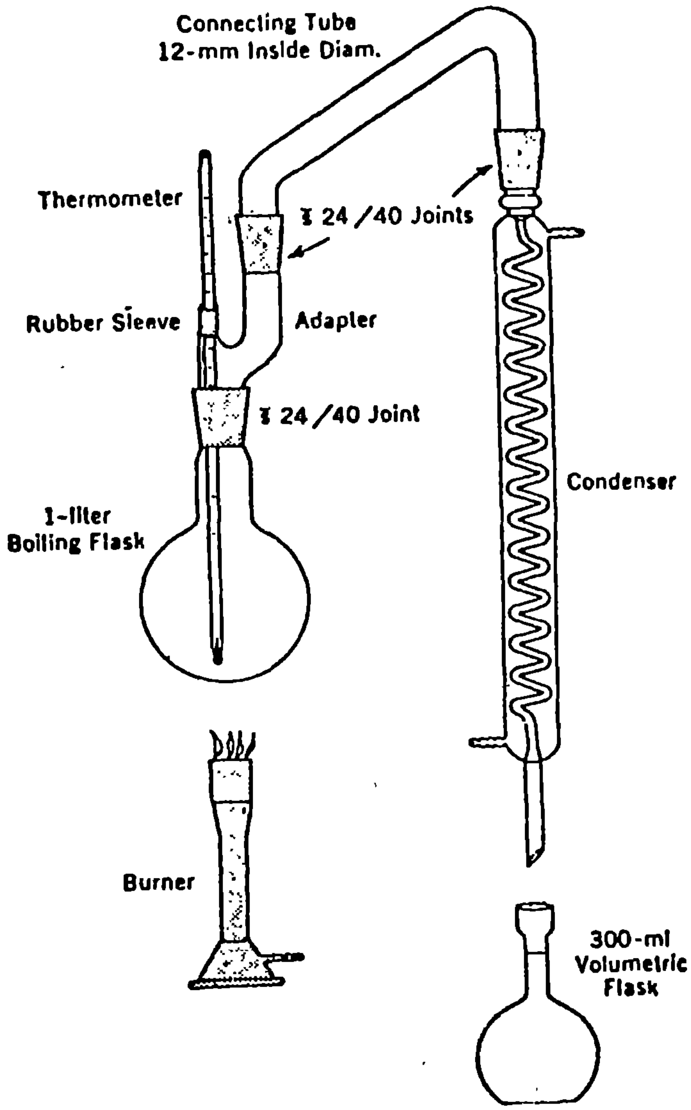


Fig. 1 - Direct Distillation Assembly for Fluoride

### Interference

Alkalinity 5000 mg/l, aluminium 0 1 mg/L, chlorides 7000 mg/L, Fe 10 mg/L, $PO_4$ 16 mg/L, $SO_4$ 200 mg/L, and hexametaphosphate 1.0 mg/L 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, $H_2SO_4$, conc.**

2. **Silver sulphate, $Ag_2SO_4$, crystals.**

3. **SPADNS solution :** Dissolve 958 mg SPADNS and dilute to 500 ml.

4. **Zirconyl acid reagent :** Dissove 133 mg $ZrOCl_2$ $8H_2O$ in 25 ml water. Add 350 ml conc. HCl and dilute to 500 ml

5. **Mixed reagent:** 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 arsenic solution :** Dissolve 5.0 g $NaAsO_2$ and dilute to 1000 ml

8. **Stock F solution :** Dissolve 221.0 mg anhydrous NaF and dilute to 1000 ml. 1 ml = 100 ug F.

9. **Standard F :** Dilute stock solution 10 times to obtain 1 ml = 10 ug F.

### Procedure

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

2. Add 10.0 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 % 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. $NaAsO_2$ concn. should not exceed 1300 mg/l to avoid error due to $NaAsO_2$. Take suitable aliquot & dilute it to 50 ml.

5. Add 10 ml acid Zirconyl - SPADNS reagent. Mix well and read % transmission 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.

### 3.12.3 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 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 sample 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 a 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) preferentially will complex concentrations of aluminium up to 5 mg/L. Hydrogen ion forms complex with fluoride while hydroxide ion interferes with electrode response. By adusting the pH in between 5 to 8 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 labwares (Samples and standards should always be *stored in plastic containers as fluoride* reacts with glass)

## Reagents

1. **Standard fluoride solution:** Prepare as directed in SPADNS method

2. **Total Ionic strength adjustment buffer (TISAB):** Place approximately 500 ml distilled water in 1 L beaker add 57 ml glacial acetic acid, 58 gm NaCl and 4.0 gm 1,2 cyclohexylene diamine tetraacetic acid. 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 electrode to meter, 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 $25^{0}$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 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 standards should be the same and the ionic strength of standards 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. DEFLUORIDATION

- It is removal of excess fluorides from water
- Removal is achievable either by fixed bed regeneratable media or by precipitation and complexation process
- Recommended defluoridation method - Nalgonda Technique

## 4.1 Nalgonda Technique

After extensivly testing many materials and processes since 1961, NEERI has evolved an economical and simple process for removal of fluoride which is referred as Nalgonda Technique.

Nalgonda Technique developed by NEERI involves addition of aluminium salt, lime and bleaching powder followed by rapid mixing, flocculation, sedimentation, filtration and disinfection (Fig. 2) Aluminium salt may be added as aluminium sulphate or aluminium chloride or combination of these two. Aluminium salt is only responsible for removal of fluoride from water. The dose of aluminium salt increases with increase in the fluoride and alkalinity levels of the raw water. The selection of either aluminium sulphate or aluminium chloride also depends on sulphate and chloride contents of the raw water to avoid exceeding their permissible limits. The dose of lime is emperically 1/20th that of the dose of aluminium salt. Lime facilitates forming denser floc or rapid settling. Bleaching powder is added to the raw water at the rate of 3 mg/L for disinfection Approximate doses of alum required to obtain permissive limit (1 mg F/L) in water at various fluoride and alkalinity levels are given in the Table 2.

**Table 2 : Approximate Alum Dose (mg/L) Required to Obtain Permissive Limit (1 mg F/L) of Fluoride in Water at Various Alkalinity and Fluoride Levels**

| Test Water Fluorides, mg F/L | Test Water Alkalinity, mg CaCO$_3$/L | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 125 | 200 | 300 | 400 | 500 | 600 | 800 | 1000 |
| 2 | 145 | 220 | 275 | 310 | 350 | 405 | 470 | 520 |
| 3 | 220 | 300 | 350 | 405 | 510 | 520 | 585 | 765 |
| 4 | * | 400 | 415 | 470 | 560 | 600 | 690 | 935 |
| 5 | * | * | 510 | 600 | 690 | 715 | 885 | 1010 |
| 6 | * | * | 610 | 715 | 780 | 935 | 1065 | 1210 |
| 8 | * | * | * | * | 990 | 1120 | 1300 | 1430 |
| 10 | * | * | * | * | * | * | 1510 | 1690 |

* To be treated after increasing the alkalinity with lime or sodium carbonate

## 4.2 Mechanism of Defluoridation by Nalgonda Technique

Nalgonda Technique is a combination of several unit operations and processes incorporating rapid

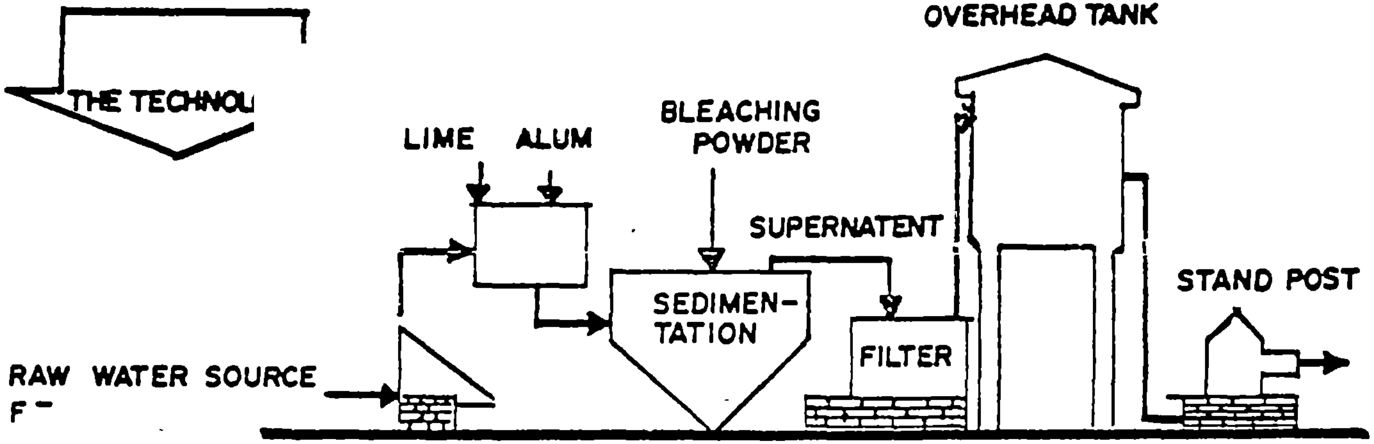


Fig. 2 - Layout Plan of the Nalgonda Technique

mixing, chemical interaction, flocculation, sedimentation, filtration, disinfection and sludge concentration to recover water and aluminium salts.

Rapid Mix : Provides thorough mixing of alkali, aluminium salts and bleaching powder with the water. The chemicals are added just when the water enters the system.

*Flocculation* : Flocculators provide subsequent gentle agitation before entry to the sedimentation tank. The flocculation period permits 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 involving fluorides and aluminium species is complex. It is a combination of polyhydroxy aluminium species complexation with fluorides and their adsorption on polymeric alumino hydroxides (floc). Besides fluorides, turbidity, colour, odour, pesticides and organics are also removed. The bacterial load is also reduced significantly. All these are by adsorption on the floc.

Sodium carbonate or sodium bicarbonate ensures adequate alkalinity for effective hydrolysis of aluminium salts, so that residual aluminium does not remain in the treated water.

The reactions are depending upon the nature of alkalinity. The reactions are:

1) $3\ Al_2(SO_4)_3.18\ H_2O + NaF + 9\ Na_2CO_3$ ----> $[5\ Al(OH)_3.\ Al(OH)_2F] + 9\ Na_2SO_4 + NaHCO_3 + 8\ CO_2 + 45\ H_2O$

2) $3\ Al_2(SO_4)_3.18\ H_2O + NaF + 17\ NaHCO_3$ ----> $[5\ Al(OH)_3.Al(OH)_2F] + 9\ Na_2SO_4 + 17\ CO_2 + 18\ H_2O$

*Sedimentation* : Permits settleable floc loaded with fluorides, turbidity, bacteria, and other impurities to be deposited and thus reduces concentration of suspended solids that must be removed by filters. Sedimentation theory is complex and of little avail, because floc is not uniform and hence its basic sedimentation properties cannot be given quantitative values and because the influence of eddy currents cannot be predicted. Hence, various factors which influence sedimentation in relation to design and operation rely largly on experience.

*Filtration* : Rapid gravity sand filters are suggested to receive coagulated and settled water in those fiters and unsettled gelatinous floc is retained. Residual fluorides and bacteria are absorbed on the gelatinous floc retained on the filter bed.

*Disinfection and Distribution* : The filtered water collected in the storage water tank is rechlorinated with bleaching powder before distribution.

### 4.3 Salient Features of Nalgonda Technique

- No regeneration of media
- No handling of caustic acids and alkalies

- Readily available chemicals used in conventional municipal water treatment are only required
- Adoptable to domestic use
- Flexible upto several thousands $m^3/d$
- Applicable in batch as well as in continuous operation to suit needs
- Simplicity of design, construction, operation and maintenance
- Local skills could be readily employed
- Highly efficient removal of fluorides from 2 to 20 mg F/L to desirable levels
- Simulateneous removal of colour, odour, turbidity, bacteria and organic contaminants
- Normally, associated alkalinity ensures fluoride removal efficiency
- Sludge generated is convertible to alum for use elsewhere
- Little wastage of water and least disposal problem
- Needs minimum of mechanical and electrical equipment
- No energy except muscle power for domestic equipment
- Economical-annual cost of defluoridation of water at 40 lpcd works out to Rs. 20/- for domestic treatment and Rs. 85/- for community treatment using fill-and-draw system based on 5000 population for water with 5 mg F/L and 400 mg/L alkalinity which requires 600 mg/L alum dose
- Provides defluoridated water of uniform acceptable quality

## 4.4 When to Adapt Nalgonda Technique

- Absence of acceptable alternate low fluoride source
- Dissolved solids are below 1500 mg/L
- Total hardness is below 250 mg/L
- Alkalinity of the water is sufficient
- Raw water fluorides ranging from 2 to 20 mg F/L

Nalgonda Technique is a simple and economical process which can be adapted by a common man. It can be adapted at domestic as well as community level. Both fill-and-draw and continuous operation systems can be installed for defluoridation of water for community water supply. Nalgonda Technique is effective even when the fluoride is above 20 mgF/L, the dissolved solids above 1500 mg/L and hardness above 250 mg/L.

# 5. DOMESTIC DEFLUORIDATION

Defluoridation at domestic level can be carried out in a container (bucket) of 60 L capacity with a tap 3 - 5 cm above the bottom of the container for the withdrawal of treated water after precipitation and settling. The raw water taken in the container, is mixed with adequate amount of aluminium sulphate solution (alum), lime or sodium carbonate and bleaching powder depending upon its alkalinity and fluoride content. Alum solution is added first and mixed well with water. Lime or sodium carbonate solution then added and the water stirred slowly for 20 minutes and allowed to settle for nearly one hour and is withdrawn (Fig. 3). The supernatant which contains permissible amount of fluoride is withdrawn through the tap for consumption. The settled sludge is discarded. Approximate volumes of alum solution for defluoridation of 40 L of water are given in Table 3.

*Preparation of Alum Solution* : Weigh 1000 g Alumina ferric (commercial alum - IS:299-1962) and dissolve in water to make it 10 L solution in a plastic carboy. One mL of this solution contains approximately 100 mg alum. Keep the solution stoppered to prevent evaporation of water.

*Preparation of Lime Solution* Weigh 100 g quick lime, slake in water and prepare slurry by diluting to 10 L in a plastic corboy. One mL of the slurry contains about 10 mg lime. Keep the solution stoppered.

*Bleaching Powder (fresh quality)* : approx. 120 mg per 40 L water.

**Table 3 : Domestic Defluoridation 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**

| Test Water Fluorides, 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 |

A fill-and-draw type domestic defluoridation unit of 200 L capacity is developed by NEERI. It consists of a cylindrical vessel of 1 m depth equipped with a hand operated stirring mechanism. The unit is filled with raw water and similar defluoridation operation is performed as in bucket. The settled sludge is withdrawn through the valve at the bottom of the unit. All unit operations of mixing, flocculation and sedimentation are performed in the same unit (Fig. 4).

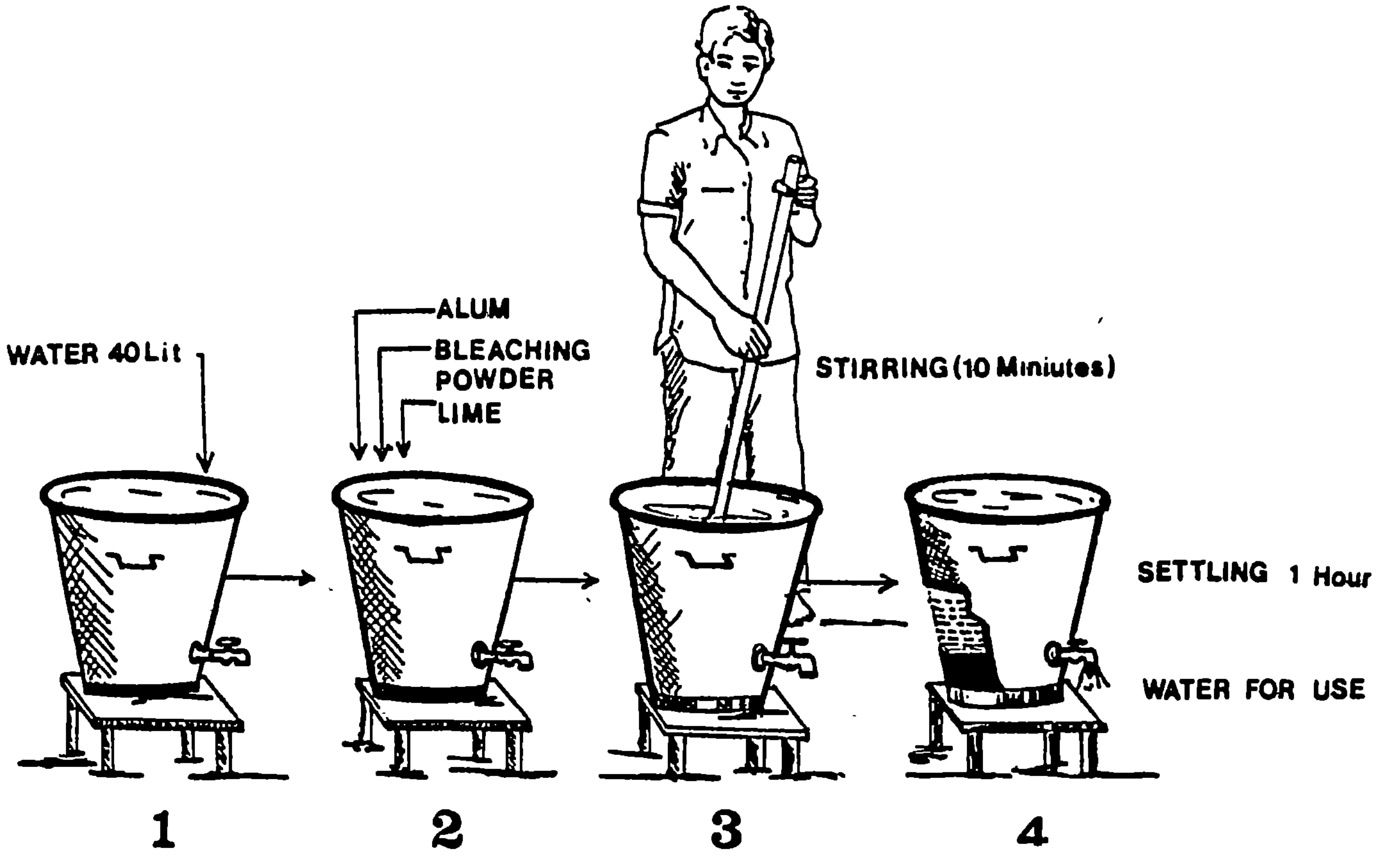


Fig.3. Defluoridation at Domestic Level

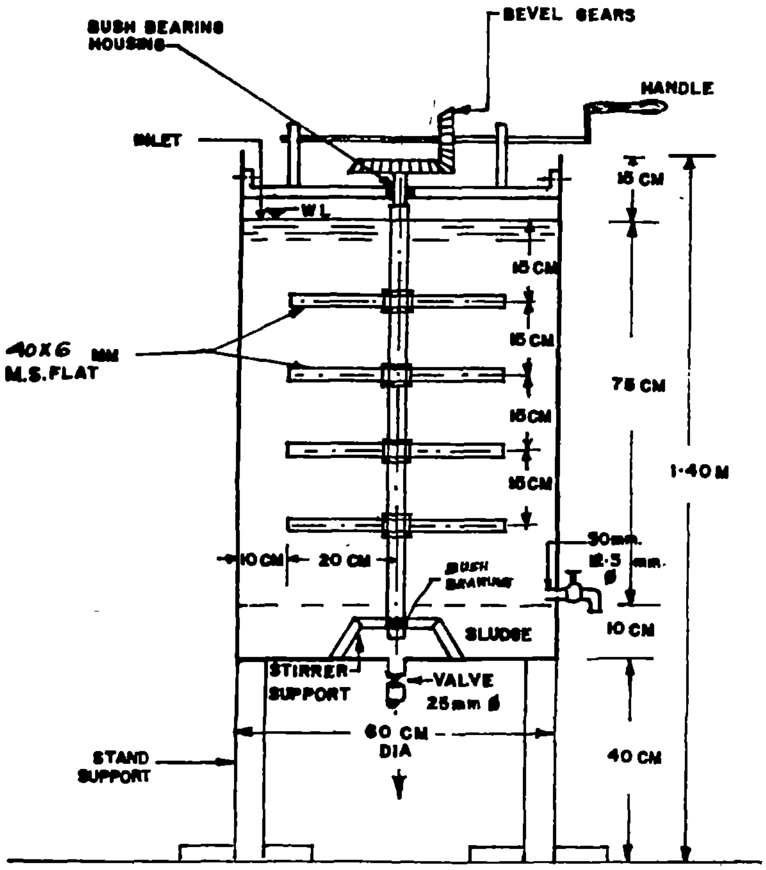


Fig.4. Fill-and-Draw Domestic Defluoridation Unit

# 6. FILL-AND-DRAW DEFLUORIDATION PLANT FOR SMALL COMMUNITY

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 (Fig. 5). Raw water is pumped or poured into the tank and the required amounts of alum, lime or sodium carbonate and bleaching powder added with stirring. The contents are stirred slowly for ten minutes and allowed to settle for two hours. The defluoridated supernatant water is withdrawn and supplied through standposts. The settled sludge is discarded. Plant dimensions for various populations are given in Table 4.

**Table 4 : Plant Diameter for Populations upto 200 on the Basis of 40 lpcd Defluoridated Water**

| Population m$^3$ | Water Volume m | Plant Diameter for Motor | Suggested H P |
|---|---|---|---|
| 050 | 2 | 1 30 | 1.0 |
| 100 | 4 | 1 85 | 2 0 |
| 200 | 8 | 2 60 | 2 0 |

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

Fresh Bleaching Powder (grams per batch) = 3 x (water volume, m$^3$)

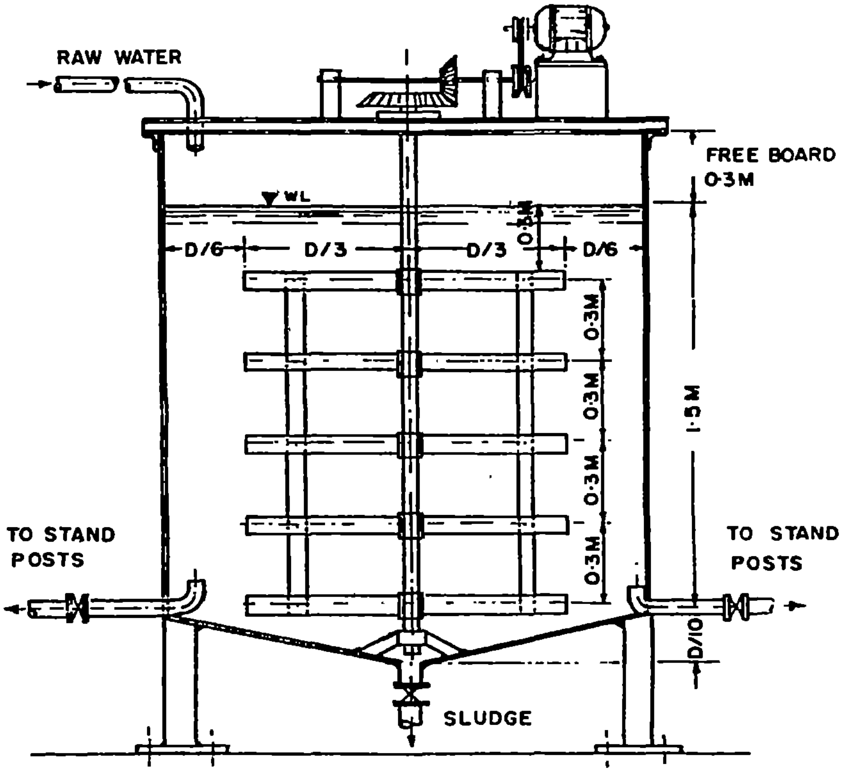
The notable features are:

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 a few and these are easily available (these include 16 L 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.



**BASIS : 40 lpcd DOMESTIC WATER**
**(FOR POPULATION UPTO 200)**

**D = DIAMETER OF PLANT**

**Water Depth = 1·5 M**
**Depth of sludge cone = D/10**
**Shaft Diameter = 50 mm**
**Free Board = 0·3 M**

Fig. 5 - Fill-and-Draw Domestic Defluoridation Plant for Small Community

# 7. FILL-AND-DRAW DEFLUORIDATION PLANT TECHNOLOGY FOR RURAL WATER SUPPLY

Fill-and-draw defluoridation plant technology based on Nalgonda Technique is designed for removal of excess fluoride from water, which is most suitable for Rural Water Supply.

## 7.1 Components of Fill-and-Draw Defluoridation Plant (Fig. 6)

- reactor(s);it is reaction-cum-sedimentation tank equipped with power driven agitator assembly
- sump well
- sludge drying beds
- elevated service reservoir
- electric panel room
- chemical store house

## 7.2 Design Considerations

- The plant capacities are based on one to four operations in each reactor per day,subject to availability of electricity.
- Each reactor will be of 10, 20 or 30 $m^3$ capacity.
- The capacity of raw water pump will be sufficient to fill up the reactors within an hour.
- The defluoridated water from the sump well will be pumped to the elevated service reservoir and distributed by gravity through stand posts and house connections.
- The capacity of the sump well will be equal to the total capacity of the reactor/s.
- The capacity of the elevated service reservoir will be half of the capacity of the sump well.

## 7.3 Reactors

The raw water from the source is pumped to the reaction-cum-sedimentation tank which is referred to as reactor (Fig. 7). The reactors are of HDPE, Ferro-cement or RCC, circular in shape with dished bottom and epoxy coating (in case of RCC). The top portion of the reactor is covered with a sturdy lid. A manhole with a lid is provided for inspection and to pour chemicals into the reactor. An operation platform is raised on girders 10 cm above the top of the reactor. The stirring mechanism consisting of motor, reduction gear, paddles, and shaft is mounted on the platform A ladder with a pipe railing

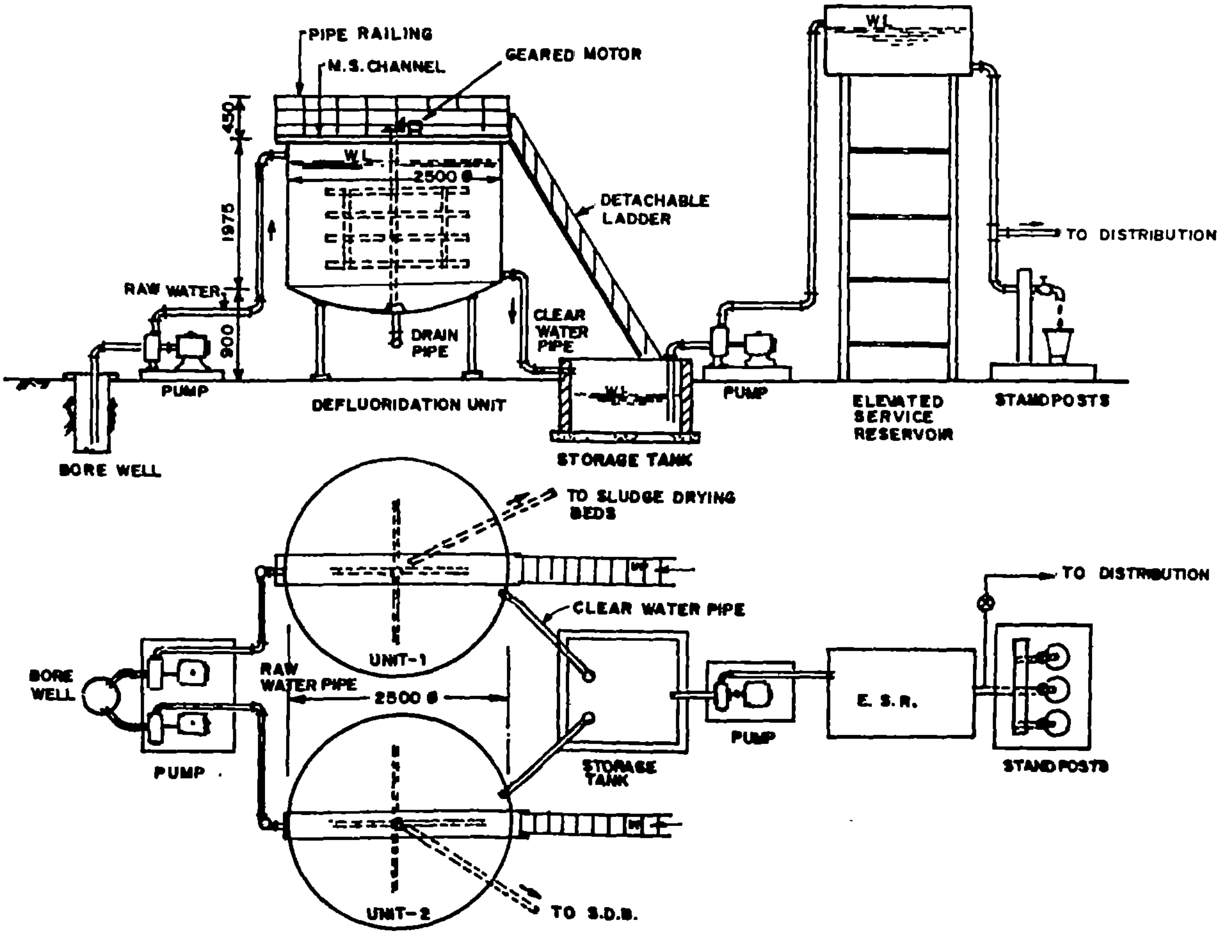


Fig. 6 - Fill-and-Draw Domestic Defluoridation Plant for Rural Water Supply

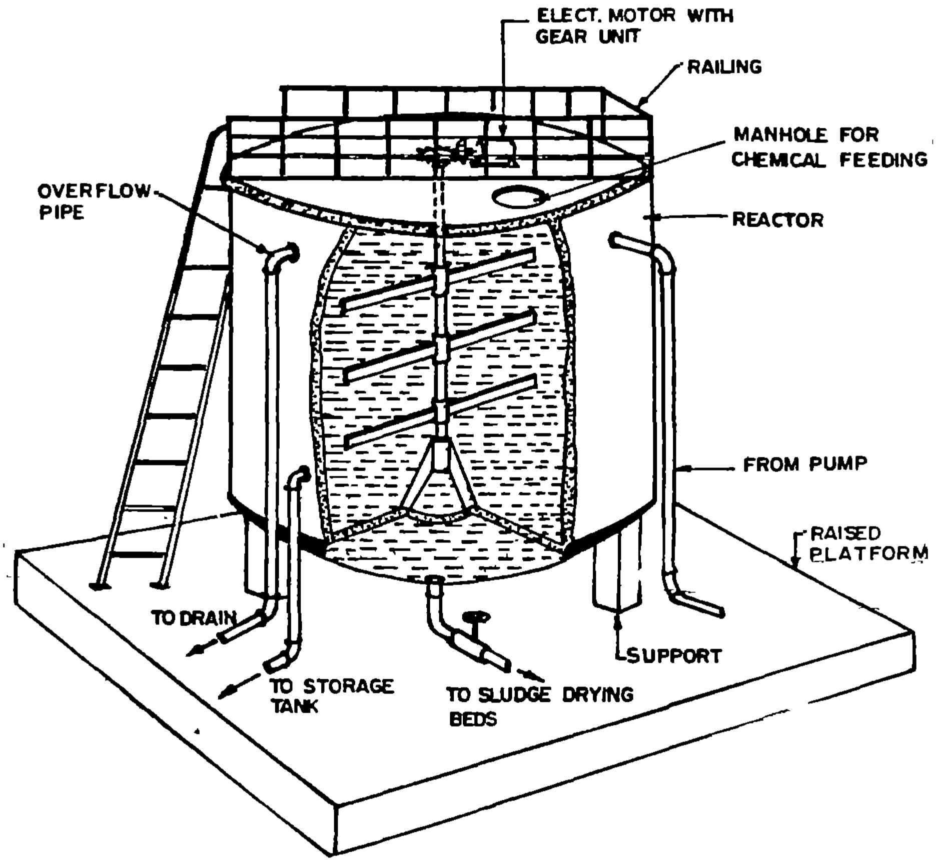


Fig 7 - Reactor for Defluoridation Operation across the platform is provided. The settled water outlet with sluice valve is connected to inlet of sump well. To withdraw the settled sludge once daily and dispose it on to the sludge drying beds, a sludge pipe with sluice valve is provided. The height of the reactor is one meter above the ground level.

### 7.3.1 Design Aspects of Reactor

Material for fabrication - HDPE, Ferro-cement or RCC

Shape - Cylindrical with

- dished bottom
- inlet pipe
- outlet pipe
- sludge drain
- 50 cm dia. or 50 cm x 50 cm manhole for inspection and adding chemicals
- agitator assembly (details given separately).

Dimensions

| | |
|---|---|
| Free board | 0.50 m |
| Water Depth | 2.50 m |
| Depth of the truncated cone | 0.65 m |
| Height of the reinforced platform | 0.45 m |

| Capacity, $m^3$ | Dimeter, m |
|---|---|
| 10 | 2 3 |
| 20 | 3.2 |
| 30 | 3.9 |

Settling time 2 to 4 hours

- Each reactor needs 4-6 hrs for complete operation.
- Each reactor can be operated upto 4 times daily.
- The number of operations depends upon duration of power supply in the village.

### 7.3.2 Design Aspects of Agitator Assembly

The agitator assembly consists of mild steel agitator with anticorrosive epoxy coating, reduction gear box with output speed of 20 RPM, vertical downward shaft with ball bearing housing, flanged coupling and directly coupled to totally enclosed fan cooled induction motor of specified rating, 3 phase, 50 Hz, AC, 1440 RPM with 415 ± 6% voltage fluctuation.

Material of agitating paddles - Mild steel
Width of paddles - 1/3 dia. of the reactor
Shaft diameter - 50 mm for 10 $m^3$ reactor
75 mm for 20 $m^3$ reactor
100 mm for 30 $m^3$ reactor
Type of mixer - Vane type
Material of vanes - Mild steel
Type of mounting - Vertical flanged mounted type

### 7.3.3 Gear Box

* Worm reduction gear box
Input speed - 1440RPM
Output speed - 20RPM
Reduction ratio - 72 : 1 with vertical downward shaft
Rating of motor - 3 HP for 10 $m^3$ reactor
5 HP for 20 $m^3$ reactor
7.5 HP for 30 $m^3$ reactor
Make - Elecon/Radicon

* The gears are hobbed, hardened and lapped.

The output shaft of the gear box can be rotated in either direction.

* The gear box is equipped with

- CI bush intermediate support for agitator shaft
- Input and output cushioned drive type flexible couplings
- Agitator shaft top end coupling with the output of the gear box

### 7.3.4 Platform-cum-Walkway

A suitable study M.S. platform with sturdy railings across the sides supported over horizontal girders is provided at a height of 20 cm above the cover slab. The motor and gear box assembly is to be supported over this platform. It is extended to the full diameter of the tank and can withstand weight of at least 6 adults. Alum and lime solution tanks are kept on this platform for adding into the raw water.

Each reactor is provided with a sturdy ladder with railings at a slope of 45-60 degrees.

## 7.4 Other Plant Components

### 7.4.1 Lime and Alum Solution Tanks

The tanks kept on the reactor are of HDPE to hold 10% (W/V) alum solution and 1% (W/V) lime slurry. The solution tanks are complete with lid, feeding pipe and delivery valve.

### 7.4.2 Sump Well

The capacity of the sump well will be equal to one operation capacity of the reactors. The sump well may be circular or rectangular in shape and 3 m deep and the diameter will vary according to its capacity. Details of sump wells for various plant capacities are given in Table 5.

**Table 5 : Details of Sump Wells for Various Plant Capacities**

| Capcity of the Sump Well $m^3$ | Diameter m | Height m |
|---|---|---|
| 10 | 3.2 | 1.3 |
| 20 | 3.8 | 1.8 |
| 30 | 4.6 | 1.8 |
| 40 | 5.3 | 1.8 |
| 60 | 6.5 | 1.8 |
| 80 | 7.5 | 1.8 |
| 100 | 8.4 | 1.8 |
| 120 | 9.2 | 1.8 |
| 180 | 11.3 | 1.8 |

### 7.4.3 Elevated Service Reservoir

Treated water from sump well is pumped to the elevated service reservoir. It should be a RCC circular

**Table 6 : Dimensions of Elevated Service Reservoir for Various Capacities**

| Capacity of Elevated Service Reservoir $m^3$ | Diameter m | Height of tank m | Height of Dome m |
|---|---|---|---|
| 10 | 2.1 | 3.0 | 0.5 |
| 20 | 3.0 | 3.0 | 0.7 |
| 30 | 3.6 | 3.0 | 0.8 |
| 40 | 4.2 | 3.0 | 1.0 |
| 60 | 4.7 | 3.5 | 1.1 |
| 80 | 5.4 | 3.5 | 1.3 |
| 100 | 5.7 | 4.0 | 1.4 |
| 120 | 6.2 | 4.0 | 1.5 |
| 180 | 7.6 | 4.0 | 1.8 |

tank with a dome at the top supported over RCC columns provided with inlet pipe from sump well and outlet piping arrangement including overflow pipe and wash water outlet. The capacity of the reservoir should be half of the capacity of reactor per operation limited to minimum of 10 $m^3$. Design details are shown in Table 6.

### 7.4.4 Sludge Drying Beds

After decantation of defluoridated water, the settled sludge with about 1% (W/V) solids is discharged once every day over sludge drying beds. The number and size of beds for various plant capacities are given in Table 7.

**Table 7 : Sizes of Sludge Drying Beds**

| Total Capacity of the Plant $m^3/d$ | Size of Bed m | No. of Beds |
|---|---|---|
| 10 | 2.5 x 2.5 | 2 |
| 20 | 2.5 x 2.5 | 2 |
| 30 | 3.2 x 3.2 | 2 |
| 40 | 4.5 x 4.5 | 2 |
| 60 | 4.5 x 4.5 | 2 |
| 80 | 5.5 x 5.5 | 2 |
| 100 | 5.5 x 5.5 | 2 |
| 120 | 4.5 x 4.5 | 4 |
| 180 | 5.5 x 5.5 | 4 |

### 7.4.5 Electric Panel Room

The electric panel room, 2.5 m x 3.0 m x 3.0 m, is of brick masonary with RCC slab to house the pumps and electrical controls of reactors (Table 8).

**Table 8. : Capacities of Raw Water Pumps in Electric Panel Room**

| Capacity of Plant, $m^3/d$ | Capacity of Pumps (horse power) | No. of Raw Water Pumps |
|---|---|---|
| 10 | 1.5 | 2 |
| 20 | 3.0 | 2 |
| 30 | 3.0 | 2 |
| 40 | 5.0 | 2 |
| 60 | 7.5 | 2 |
| 80 | 10.0 | 2 |
| 100 | 12.5 | 2 |
| 120 | 15.0 | 2 |

### 7.4.6 Chemical Store House

This is adjacent to Electric Panel Room and of brick masonary with RCC slab to store lime, alum and bleaching powder sufficient for 100 days operation of the plant at the capacity indicated in Table 9. A ram with big door is provided to unload material from a truck.

**Table 9. : Sizes of Chemical Store Houses for Various Plant Capacities**

| Capacity of Plant, $m^3/d$ | Quantity of Chemicals (kg) | | | Area Required for Storage of Chemicals, $m^2$** | Size of Chemical House, l x b x h,m |
|---|---|---|---|---|---|
| | Alum* | Lime | Bleaching Powder | | |
| 10 | 1000 | 100 | 5 | 1 | 3 0 x 3 0 x 3.0 |
| 20 | 2000 | 200 | 10 | 2 | 3 0 x 3 0 x 3 0 |
| 30 | 3000 | 300 | 15 | 3 | 3.0 x 3 0 x 3 0 |
| 40 | 4000 | 400 | 20 | 4 | 3 0 x 3 0 x 3 0 |
| 60 | 6000 | 600 | 30 | 6 | 3 0 x 3 0 x 3 0 |
| 80 | 8000 | 800 | 40 | 8 | 3 0 x 3 0 x 3 0 |
| 100 | 10000 | 1000 | 50 | 10 | 3 0 x 3.0 x 3 0 |
| 120 | 12000 | 1200 | 60 | 12 | 4.0 x 4 0 x 4.0 |
| 180 | 18000 | 1800 | 90 | 18 | 4.0 x 4 0 x 4 0 |

* 50 kg alum per bag , six bags kept one above the other in one heap,

** includes area for passage, weigh balance and minor stores

### 7.5 Configuration of Reactors

The configuration of reactors depends upon water demand, size of reactors, number of reactors and

**Table 10. : Configuration of Reactors of the Defluoridation Plant and Personnel for Operation and Maintenance**

| Water Demand $m^3$/day | Configuration of Reactors | | | Personnel | | |
|---|---|---|---|---|---|---|
| | Capacity $m^3$ | Number of Reactors | Number of Operations | Supervisor | Chemist | Helpers |
| 10 | 10 | 1 | 1 | Nil | 1 | 2 |
| 20 | 10 | 1 | 2 | Nil | 1 | 2 |
| 40 | 20 | 1 | 2 | Nil | 1 | 2 |
| 60 | 20 | 1 | 3 | Nil | 1 | 4 |
| 80 | 20 | 2 | 2 | Nil | 1 | 4 |
| 120 | 20 | 2 | 3 | 1 | 1 | 6 |
| 180 | 30 | 2 | 3 | 1 | 1 | 6 |
| 180 | 20 | 3 | 3 | 1 | 1 | 6 |
| 240 | 20 | 4 | 3 | 1 | 1 | 6 |
| 360 | 30 | 4 | 3 | 1 | 1 | 8 |
| 480 | 30 | 4 | 4 | 1 | 1 | 8 |

number of operations per day. The optimal configurations for various water demands are given in Table 10.

### 7.6 Cost Estimations

Cost estimates are made for various plant capacities per day at the rate of 40 lpcd on the basis of configuration of reactors, which includes capacity of the reactors, number of reactors and number of operations in a day. Capacities of sump well and elevated service reservoir are fixed on the basis of plant capacity for one operation. Skilled personnel are required for systematic operation and maintenance of the plant. Table 23 shows configuration of reactors and personnel depending upon the amount of water to be treated daily upto 480 $m^3$/d for RCC and upto 180 $m^3$/day for HDPE rectors. The total estimates also include pump house-cum-chemical house, treated water pumps, chemical solution tanks, interconnecting piping, valves and fixtures and electrical items.

Capital costs of defluoridation plants of various capacities were estimated after taking into account the above plant components. Based on these costs, annual depreciation, interest and maintenance costs were estimated. In addition to these, the total annual expenditure includes salaries of the personnel and cost of power and chemicals for estimation of total operational cost. Estimations for running costs include costs of power and chemicals.

The considerations for calculating the costs are as follows:

| | |
|---|---|
| Depreciation | 5% per annum on capital cost |
| Maintenance | 5% per annum on capital cost |
| Interest | 12% per annum on capital cost |
| | |
| Cost of power | Re. 0.50 per unit |
| Cost of alum | Rs. 2.00 per kg |
| Cost of lime | Re. 0.70 per kg |
| Cost of bleaching powder | Rs. 1.50 per kg |

| Salaries of personnel | Rs. per month |
|---|---|
| Supervisor | 2,000 |
| Chemist | 1,500 |
| Helper | 900 |

Table 11 and 12 give capital costs, total operational costs/$m^3$ and running costs/$m^3$ for various capacities per day for RCC and HDPE reactor systems respectively. The cost per $m^3$ decreases as the per day plant capacity increases. There are exceptions to this and these exceptions are due to plant configurations.

## Table 11 : Cost Estimates for RCC Defluoridation Plants of Various Capacities @ 40 lpcd

Raw water fluoride = 5 mg F/L
Raw water alkalinity = 400 mg $CaCO_3$/L

| Plant Capacity $m^3$/day | Capital Cost Rs | Annual Expenditure | | | | Total Annual Cost of Operation Rs. | Total Cost of Operation Rs./$m^3$ | Running Cost of Operation Rs /$m^3$ |
|---|---|---|---|---|---|---|---|---|
| | | Depreciation + Interest + Maintenance Rs | Personnel Rs | Power Rs. | Chemicals Rs | | | |
| 10 | 3,47,000 | 76,340 | 39,600 | 2,510 | 4,550 | 1,22,990 | 33.70 | 1.93 |
| 20 | 3,47,000 | 76,340 | 39,600 | 4,480 | 9,100 | 1,29,540 | 17.75 | 1.86 |
| 40 | 4,21,000 | 92,620 | 39,600 | 5,680 | 18,200 | 1,56,120 | 10.69 | 1.64 |
| 60 | 4,21,000 | 92,620 | 61,200 | 8,250 | 27,300 | 1,89,370 | 8.64 | 1.62 |
| 80 | 6,77,000 | 1,48,940 | 61,200 | 11,000 | 36,400 | 2,57,540 | 8.82 | 1.62 |
| 120 | 6,77,000 | 1,48,940 | 1,06,800 | 16,130 | 54,600 | 3,26,440 | 7.45 | 1.61 |
| 180 | 8,85,000 | 1,94,700 | 1,06,800 | 17,410 | 81,900 | 4,04,650 | 6.16 | 1.57 |
| 240 | 11,20,000 | 2,46,400 | 1,06,800 | 31,890 | 1,09,200 | 4,94,300 | 5.64 | 1.61 |
| 360 | 12,31,000 | 2,70,820 | 1,06,800 | 44,725 | 1,63,800 | 5,86,145 | 4.46 | 1.59 |
| 480 | 15,55,000 | 3,42,100 | 1,28,400 | 59,250 | 2,18,400 | 7,48,150 | 4.27 | 1.58 |

## Table12. : Cost Estimates for HPDE Defluoridation Plants of Various Capacities @ 40 lpcd

Raw water fluoride = 5 mg F/L
Raw water alkalinity = 400 mg $CaCO_3$/L

| Plant Capacity | Capital Cost | Annual Expenditure | | | | Total Annual Cost of Operation | Total Cost of Operation | Running Cost of Operation |
|---|---|---|---|---|---|---|---|---|
| | | Depreciation + Interest + Maintenance | Personnel | Power | Chemicals | | | |
| $m^3$/day | Rs | Rs. | Rs. | Rs | Rs | Rs | Rs./$m^3$ | Rs /$m^3$ |
| 10 | 3,81,000 | 83,820 | 39,600 | 2,510 | 4,550 | 1,30,480 | 37 75 | 1.93 |
| 20 | 3,81,000 | 83,820 | 39,600 | 4,480 | 9,100 | 1,37,000 | 18.77 | 1.86 |
| 40 | 5,79,000 | 1,27,380 | 39,600 | 5,680 | 18,200 | 1,90,860 | 13 07 | 1.64 |
| 60 | 5,79,000 | 1,27,380 | 61,200 | 8,250 | 27,300 | 2,24,130 | 10.23 | 1.62 |
| 80 | 9,48,000 | 2,08,560 | 61,200 | 11,000 | 36,400 | 3,17,160 | 10.86 | 1 62 |
| 120 | 9,48,000 | 2,08,560 | 1,06,800 | 16,130 | 54,600 | 3,86,090 | 8.81 | 1.61 |
| 180 | 13,77,000 | 3,02,940 | 1,06,800 | 17,410 | 81,900 | 5,09,050 | 7.75 | 1.57 |

The total operational cost ranges between Rs. 33.70/$m^3$ and Rs.4.27/$m^3$ for plant capacity ranging between 10 and 480 $m^3$/day for RCC reactor system. The running cost varies between Rs.1.93 and Rs.1.57/$m^3$.

The water demands in arid and semi-arid regions are more, because the cattle population is also taken into account in addition to human population. The people need defluoridated water only for drinking and they use fluoride water for other domestic uses such as bath, washing etc. In such cases the water needed for drinking only is less Considering these variable water demands, capital costs for 10, 20, 40, 70 and 100 lpcd were estimated for various populations and are shown in Table 13.

**Table 13 : Capital Costs (Rs. in lakhs) for Various Populations at Different Rates of Water Supply**

| Population | Rates of Water Supply, $m^3$/day | | | | |
|---|---|---|---|---|---|
| | 10 | 20 | 40 | 70 | 100 |
| 500 | 3.5 | 3.5 | 3.5 | 4.2 | 4.7 |
| 1000 | 3.5 | 3.5 | 4.2 | 5.5 | 7.3 |
| 2000 | 3.5 | 4.2 | 5.5 | 7.3 | 8.8 |
| 4000 | 4.2 | 5.5 | 8.8 | 12.3 | 15.5 |
| 6000 | 4.7 | 7.3 | 11.2 | 15.5 | |

— The calculations are based on the assumption that the plant capacities per day are limited between 10 and 480 $m^3$

## 7.7 Adaption of Fill-and-Draw Defluoridation Technology For Rural Water Supply

Government of India set up a Technology Mission on Drinking Water in Villages and Related Water Management for supplying safe drinking water to rural population. After performing water quality assessments of the rural areas in various states in the country, problem parameters were identified which cause the water unsafe for drinking purposes Fluoride is one of the problem parameters which make the water unsafe.

After collection and compilation of site specific data, the problem villages containing excess fluoride in drinking water sources were identified in the states of Andhra Pradesh, Gujarat, Karnataka and Tamil Nadu. NEERI was entrusted with the job of installation of seven fill-and- draw defluoridation plants at Tartur, Fazilpur, Tavadia, Badarpur, Sheshpur, Ranchodpura and Samadhiyala under Water Technology Mission Programme Site specific information for these villages is given in Table 14. Raw water quality of the sources identified for defluoridation is given in Table 15.

The entrepreneurs were identified for installation of defluoridation plants at these villages. NEERI scientists made frequent visits to the plant sites during various stages of installation work. The defluoridation plants at Tartur, Fazilpur, Tavadia, Badarpur, Sheshpur, Ranchodpura and Samadhiyala are shown in Plates 3, 4, 5, 6, 7, 8 and 9 respectively. The defluoridation plants were evaluated to see their performance under field conditions.

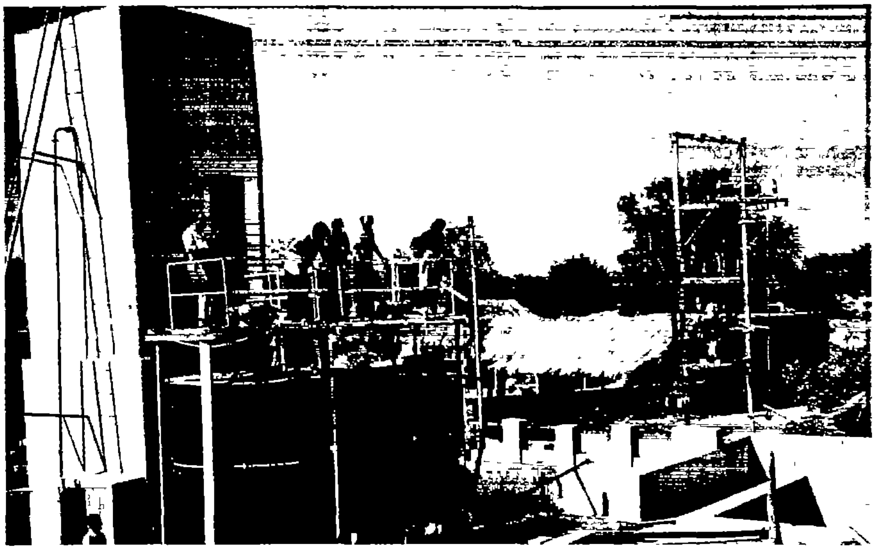


Plate 3. Fill-and-Draw Defluoridation Plant at Tartur, Andhra Pradesh

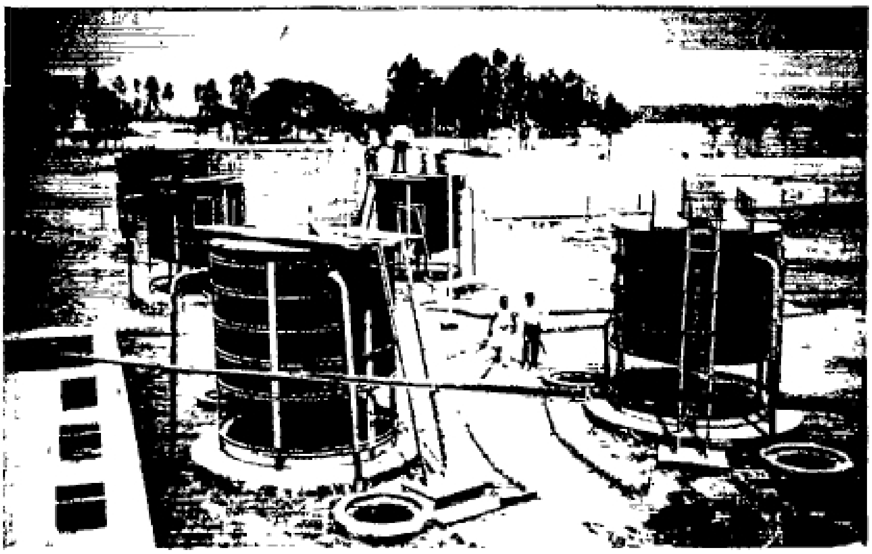


Plate 4. Fill-and-Draw Defluoridation Plant at Fazilpur, Haryana

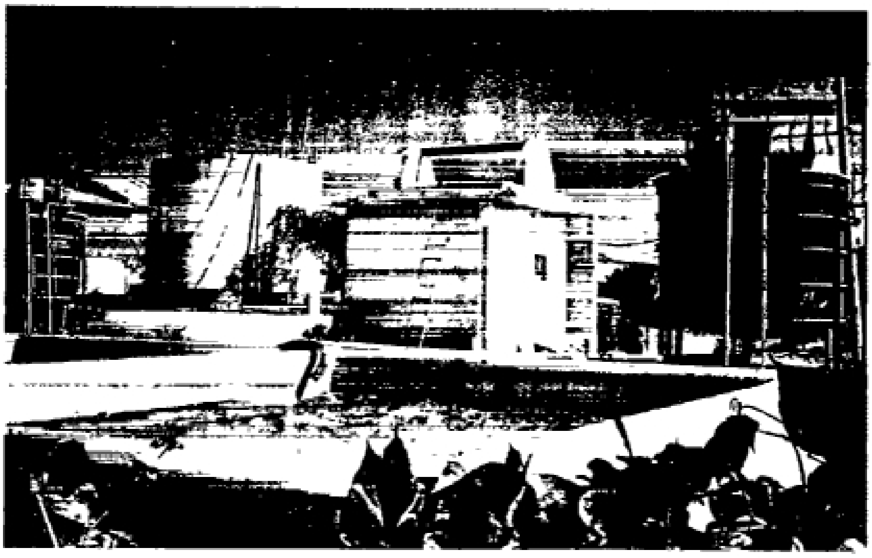


Plate 5. Fill-and-Draw Defluoridation Plant at Tavadia, Gujarat

Plate 6. Fill-and-Draw Defluoridation Plant at Badarpur, Gujarat

**Table 14 : Site Specific Information of Villages Where Defluoridation Plants have been Installed**

| Village | District | Population (1981) | Capacity $m^3/D$ | Configuration of the reactors | |
|---|---|---|---|---|---|
| | | | | Capacity, $m^3$ | Nos. |
| Andhra Pradesh | | | | | |
| 1. Tartur | Kurnool | 1686 | 40 | 10 | 2 |
| Haryana | | | | | |
| 2 Fazilpur | Gurgaon | 1958 | 80 | 10 | 4 |
| Gujarat | | | | | |
| 3. Tavadia | Mehsana | 1286 | 80 | 10 | 2 |
| 4. Badarpur | Mehsana | 2633 | 80 | 10 | 2 |
| 5. Sheshpur | Mehsana | 296 | 20 | 10 | 1 |
| 6. Ranchodpura | Mehsana | 2606 | 180 | 30 | 2 |
| 7 Samadhiyala | Bhavnagar | 1654 | 120 | 20 | 2 |

**Table15 : Raw Water Quality of the Sources Used for Defluoridation**

| S No | Village | Total Dissolved Solids, mg/L | pH | Alkalinity mg $CaCO_3$/L | Chloride mg Cl/L | Sulphate mg $SO_4$/L | Fluoride mg F/L |
|---|---|---|---|---|---|---|---|
| 1 | Tartur | 794 | 7 5 | 380 | | 16 | 3 45 |
| 2. | Fazilpur | 700 | 8.1 | 450 | | 83 | 2.50 |
| 3 | Tavadia | 900 | 8.1 | 370 | 250 | 122 | 3 80 |
| 4 | Badarpur | 940 | 8 1 | 780 | 180 | 72 | 3 20 |
| 5. | Sheshpur | 372 | 8.0 | 200 | 58 | 14 | 6.20 |
| 6 | Ranchodpura | 1386 | 8.3 | 550 | 365 | 70 | 2 70 |
| 7 | Samadhiyala | 850 | 8.2 | 640 | 65 | 15 | 4.00 |

These plants have been commissioned and are in operation. Their performance is satisfactory for supplying safe drinking water to villagers.

## 7.8 Evaluation of Defluoridation Plants

### 7.8.1 Operation of Defluoridation Plants

The reactors were filled with raw water from the source by pumping. During filling operation, alum solution of 10% concentration and 1% lime slurry were prepared in the solution tanks which are placed on the platforms of the reactors for dosing into the reactors after filling with raw water. The agitation motors were switched on, which moved the agitating paddles at 20 RPM. While the paddles were in motion, alum solutions were first added into the reactors for 1 minute. After this, lime slurries were added followed by adding bleaching powder in solution form at the rate of 3 mg/L and agitation continued for 20 minutes. During agitation at 20 RPM, the contents in the raw water formed flocs of polymeric alumino hydroxide and fluorides adsorbed on these flocs. The flocs in the reactors are allowed to settle for 4-6 hours.

The supernatant was withdrawn into the sump well by gravity. The defluoridated water was then pumped into the elevated service reservoir and supplied to the villagers through public stand posts and house connections. The settled sludge from the reactors was withdrawn and spread over the sludge drying beds. The seepage water from the beds was carried away through the drain pipe for disposal This was the complete cycle of operation and the reactors were ready for subsequent operations.

Various doses of alum were applied on the reactors at every defluoridation plant to find out the optimum doses which are effective for removal of fluoride to premissible limit of 1 mg F/L. The lime doses were 1/20th of the alum doses and bleaching powder was applied at the rate of 3 mg/L to achieve disinfection.

Generally, it is observed that, where there is high fluoride, there is also high alkalinity in the water. This alkalinity is sufficient to react with alum during defluoridation operation. But, there is one village, i.e. Sheshpur, where fluoride content of the raw water is 6.2 mg F/L and the alkalinity is 200 mg $CaCO_3$/L. With 400 mg/L alum dose, all the alkalinity was neutralised and the fluoride in treated water was much above 1 0 mg/L. In this case, the alkalinity of raw water was initially increased by adding 250 mg/L lime before applying alum dose.

The optimum doses of alum and lime are given in Table 16.

**Table 16 : Optimum Doses of Alum and Lime**

| S No | Village | Dose of Alum, mg/L | Dose of Lime, mg/L |
|---|---|---|---|
| 1 | Tartur | 500 | 25 |
| 2 | Fazilpur | 300 | 15 |
| 3. | Tavadia | 550 | 27 5 |
| 4 | Badarpur | 600 | 30 |
| 5. | Sheshpur | 900 | 250* + 45 |
| 6 | Ranchodpura | 550 | 27.5 |
| 7 | Samadhiyala | 850 | 42 5 |

* A dose of 250 mg/L lime is added in the raw water to increase the alkalinity before adding alum dose

### 7.8.2 Water Quality of the Defluoridated Water

The water quality of the defluoridated water is given in Table 17. It is observed that the dissolved soilds in the defluoridated waters are within excessive limits except that it is 1525 mg/L, i.e. slight above the

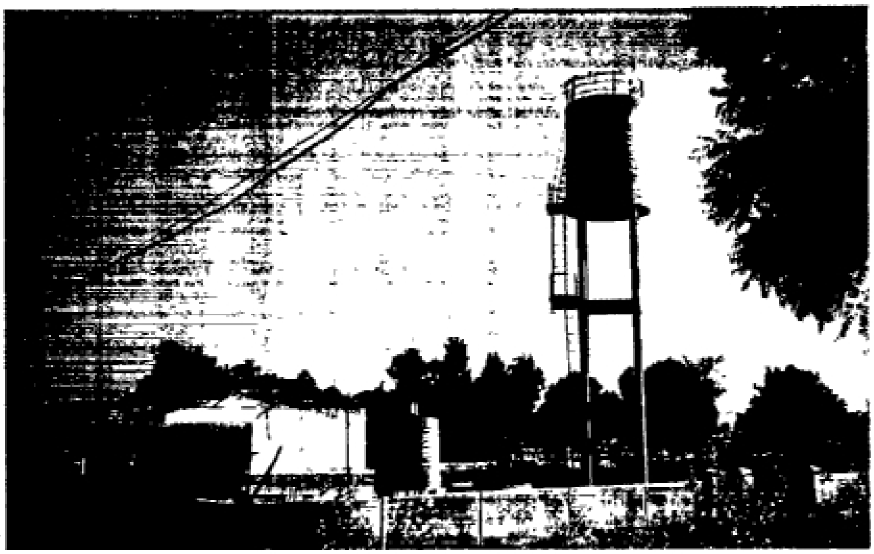


Plate 7. Fill-and-Draw Defluoridation Plant at Sheshpur, Gujarat

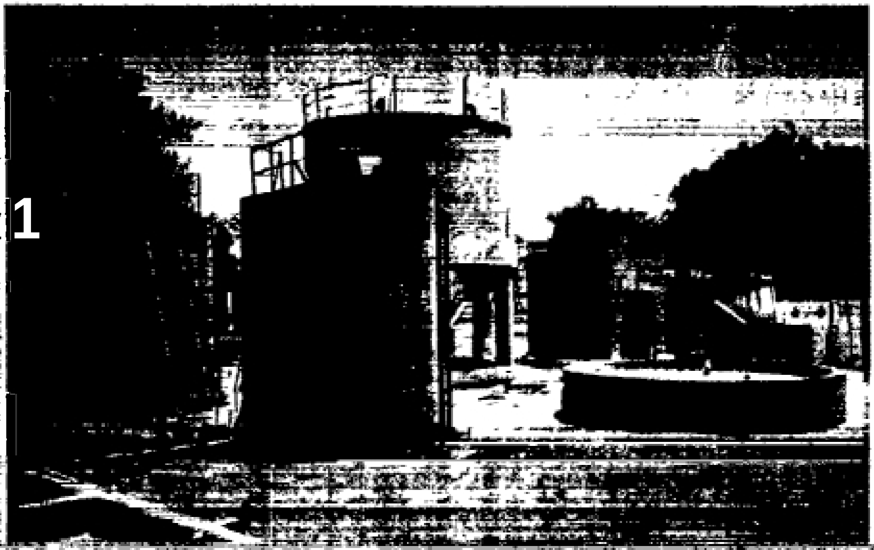


Plate 8. Fill-and-Draw Defluoridation Plant at Ranchodpura, Gujarat

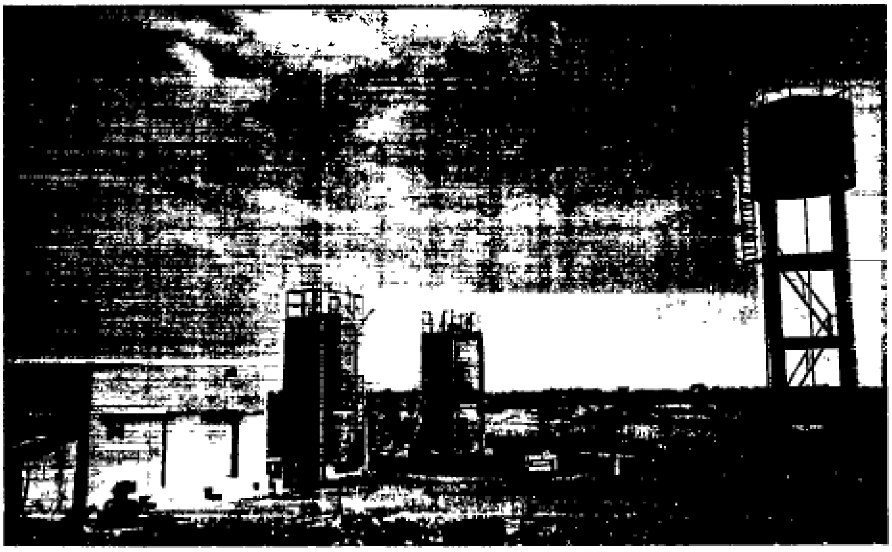


Plate 9. Fill-and-Draw Defluoridation Plant at Samadhiyala, Gujarat

excessive limit of 1500 mg/L in defluoridated water at Ranchodpura. Sulphates are within limits in all the defluoridated waters.

**Table 17 : Water Quality of Defluoridated Water**

| S No | Village | Total Dissolved Solids, mg/L | pH | Alkalinity mg $CaCO_3$/L | Sulphate mg $SO_4$/L | Fluoride mg F/L |
|---|---|---|---|---|---|---|
| 1. | Tartur | 863 | 6.8 | 186 | 240 | 1.00 |
| 2 | Fazilpur | 750 | 6.9 | 320 | 213 | 0.90 |
| 3 | Tavadia | 907 | 6.8 | 197 | 370 | 0.90 |
| 4 | Badarpur | 990 | 6.6 | 380 | 342 | 0.92 |
| 5 | Sheshpur | 588 | 6.7 | 68 | 325 | 0.92 |
| 6 | Ranchodpura | 1525 | 7.0 | 354 | 253 | 1.00 |
| 7 | Samadhiyala | 978 | 7.0 | 367 | 325 | 1.00 |

### 7.8.3 Cost Estimates

Capital cost, operational cost and running cost for seven defluoridation plants are given in Table 18. The cost estimates include depreciation, interest and maintenance, salaries of personnel and cost of chemicals and power.

**Table 18 : Cost Estimates for Various Defluoridation Plants**

| S No. | Village | Plant Capacity $m^3$/Day | Capital Cost,Rs | Total Annual Cost of Operation Rs. | Total Operational Cost, Rs /$m^3$ | Running Cost, Rs./$m^3$ |
|---|---|---|---|---|---|---|
| 1 | Tartur | 40 | 2,12,000 | 90,500 | 6.20 | 1.52 |
| 2 | Fazilpur | 80 | 6,00,000 | 1,97,100 | 6.75 | 1.00 |
| 3 | Tavadia | 40 | 4,05,000 | 1,55,000 | 5.31 | 1.53 |
| 4. | Badarpur | 40 | 3,62,000 | 1,48,600 | 5.09 | 1.63 |
| 5. | Sheshpur | 20 | 3,44,400 | 1,06,300 | 14.56 | 2.70 |
| 6 | Ranchodpura | 180 | 8,74,700 | 3,05,500 | 4.65 | 1.39 |
| 7 | Samadhiyala | 120 | 6,96,200 | 2,67,200 | 6.10 | 2.10 |

# 8. MECHANICAL FLOCCULATION CONTINUOUS DEFLUORIDATION SYSTEM FOR LARGE SCALE COMMUNITY WATER SUPPLY

The scheme intends to supply defluoridated water to population more than 5000. It includes chemical house, flash mixer, clariflocculator, filters, sump well, sludge drying beds and elevated service reservoir (Fig. 8). Flocculation and sedimentation operations are performed in the clariflocculator, over which operations are performed using electrical power.

The flocculator is equipped with an agitator assembly consisting of reduction gear box to attain an output speed of 6 RPM, complete with downward shaft to hold the agitator paddles. The flocculator basin is perforated with orifices, which permit entry of flocculated water into the sedimentation zone. The clarifier is provided with a hopper to handle the flow of flocculated water. A settled water receiving launder at the top internal periphery of the clarifier collects the overflow of the clarifier. The sludge is collected in the hopper bottom.

The alum, lime and bleaching powder solutions are added by gravity into the raw water channel through a constant head and flow regulation devices. The raw water containing these chemicals flows into the flash mixer and then into the clariflocculator The flocculated and settled water is collected in a peripheral launder and flows into the sump well through a filter. The defluoridated water, collected in the sump well, is pumped to the elevated service reservoir and supplied to the consumer through standposts and house connections.

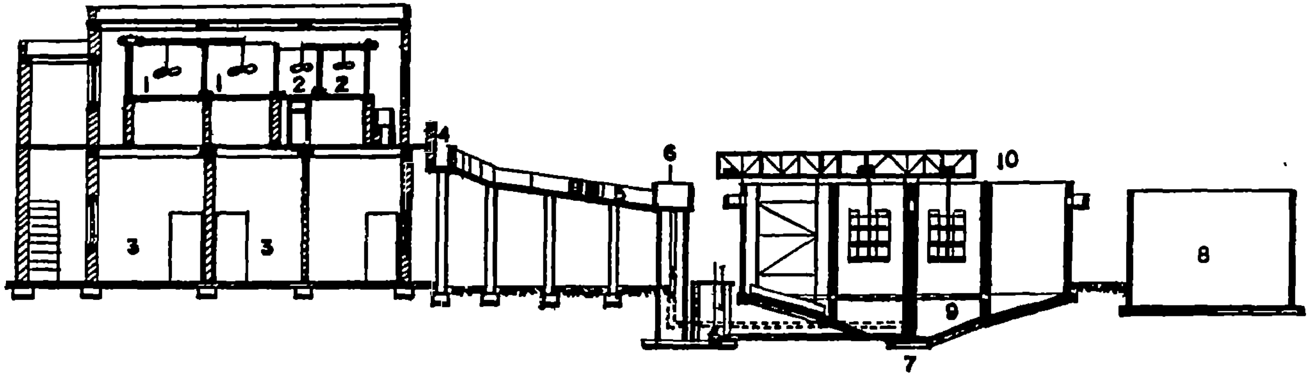
The design of different units of this system is based on the following considerations :

| | | | | |
|---|---|---|---|---|
| (i) | Flash mixing | - | detention period | 1 minute |
| (ii) | Flocculation | - | detention period | 1 hour |
| (iii) | Clarifier | - | vertical depth | 4 m |
| | surface overloading rate | | | 20 $m^3/m^2/d$ |

The largest defluoridation plant in India of 2273 $m^3$/day capacity has been commissioned at Kadiri town in Andhra Pradesh in 1980.

## 8.1 Defluoridation Plant at Kadiri

Kadiri is the taluka head quarter in Anantpur district in Andhra Pradesh. The population of Kadiri as per 1971 census was 33,820. Kadiri town is surrounded by hills and hillocks. There are no rivers worth mentioning within a distance of 64 km except what was locally termed as Vankas (dry rivulets), viz., Gurralvanka and Pillavanka located about 5 to 7 km away from the town. Gurralvanka was selected as the raw water source for defluoridation plant at Kadiri.



1 ALUM TANK
2 LIME TANK
3 CHEMICALSTORE
4 RAW WATER INLETCHANNEL
5 MIXING DUCT
6 FLASH MIXER
7 CLARIFLOCCULATOR
8 SUMP
9 PERFORATED RCC SLAB
10 PORT HOLE
11 ELEVATED SERVICE RESERVOIR

Fig.8. Schematic Layout of Continuous Defluoridation Plant Based on mechanical Agitation

## 8.2 Components of Defluoridation Plant at Kadiri

- Two infiltration wells, 4.58 m diameter each with 12.19 m and 15.24 m depths
- submercible pumpsets on infiltration wells
- interconnecting mains and inspection well between infiltration wells
- infiltration galleries-cum-tank having a size of 18.29 m at bottom with a central trench of size 92 m x 12.2 m x 3.1 m in Gurralvanka rivulet bed
- suction well and pump house with pump sets including inter connecting pipe works and related accessories
- pumping main (4725 m) and railway crossing to it
- raw water channel
- flash mixer
- two cariflocculators
- sump well with holding capacity for 30 min.
- elevated service reservoir
- pump house
- alum solution and lime slurry tanks
- chemical store house
- distribution network to Kadiri town with provision for water meters.

The estimated value of the scheme was Rs. 25 lakhs in 1980.

## 8.3 Design Features

The plant is based on the assumption that the maximum assured availability of water from Gurralavanka water source will be around 2273 $m^3$/day.

*Flash mixer*: 0.90 m x 0.90 m with 2.13 m depth and 60 seconds detention time at 0.0263 $m^3$/s flow.

*Clariflocculator* : It is a combined unit with inner unit as flocculator and the outer unit as the carifier. The flocculation basin is 4.57 m in diameter having 2.51 m water depth with 40.45 m3 capacity and 50 min detention time. The flocculators are equipped with two stirrers with a total paddle area of 0.74 $m^3$. The paddles rotate at 6 RPM and provide Gt = 45288 with relative velocity between paddle and water as 0.283 m/s. The flocculator basin perforated with 52 orifices of 5 cm diameter each permit entry of flocculated water into the sedimentation zone at 0.13 m/s velocity.

Each clarifier is having 9.75 m diameter with 3.28 m water depth and is provided with a hopper of depth 0 46 m and base diameter 5.03 m to handle the design flow of 47.35 $m^3/h$. A settled water receiving launder, 0.46 m x 0.53 m in size, at the top internal periphery of the clarifier collects the over flow of the clarifier. The effective volume of each clarifer is 208 $m^3$ and the detention period is 264 min. The provision of sludge blanket is nearly 100 $m^3$ out of this volume, while the thickened sludge, additional about 20 $m^3$ is available in hopper bottom volume. The surface loading rate of the clarifier is

$$\frac{1136\ 5\ m^3/day}{41.51\ m^2} = 27.38\ m^3/(m^2)(d)$$

The weir loading is

$$\frac{1136.5\ m^3/day}{27\ 78\ m} = 40.91\ m^3/(m)(d)$$

*Chemical Building* : Chemicals are stored on the ground floor and chemical solution tanks are provided on the first floor for this building

There are four alum tanks each having 5 $m^3$ capacity with 1.92 m x 1.92 m x 1.73 m dimesions The internal surface of each tank is provided with perforated tray to hold alum lumps. When jets of water are directed against them, solution is formed which is kept stirred by mechanically operated stirrers. The width of the tray is 0.61 m.

Four lime tanks of 1.07 m x 1.07 m x 1.73 m are provided adjacent to alum solution tanks.

All solution tanks are equipped with electrically driven stirrers to keep contents stirred.

The solutions from the alum and lime tanks drain into a constant head float regulated side chambers from where the solutions are regulated and drawn by garvity into the raw water channel after 'V' notch.

*'V' Notch* : 'V' notch of size 22.86 cm x 25.72 cm capable of measuring flow rate upto 0.03452 $m^3/s$ is installed into the raw water channel.

## 8.4 Performance of Defluoridation Plant at Kadiri

Defluoridation plant at Kadiri is shown in Plate 10. Gurralvanka raw water is collected by infiltration galleries in a raw water sump well located at Kutagulla village about 4 km from the defluoridation plant. The raw water is pumped from Kutagulla directly into a raw water channel outside the chemical house of the defluoridation plant. The alum and lime solution tanks are added by gravity into the water channel through a constant head and flow regulation devices provided by the side of the solution tanks.

The chemical dosed raw water is flash mixed and flows into the clariflocculators. The floccuclated and settled water is collected in a peripheral launder and flows into sump well. The clear defluoridated water is pumped into the elevated service reservoir and is supplied to the consumers through standposts and house connections.

The raw water contains an average value of 4.3 mg/L fluoride and 450 mg/L alkalinity.

The dose of alum for removal of fluoride is worked out as 494 mg/L.

The treated water has an average fluoride value in the range of 0.70 - 1.20 mg F/L.

### 8.5 Cost of Defluoridation

Cost estimates were made as per present rates of chemicals and salaries of the personnel engaged for operation and maintenance of the defluoridation plant. Annual cost of operations works out to be Rs. 4,85,340. The total cost of operation is worked out as Rs. 1.75/$m^3$ and the running cost as Rs. 1.29/$m^3$.

### 8.6 Sludge -Water and Alum Recovery

The sedimentation tanks should be desludged on alternate days for five minutes. The total loss of water in desludging amounts to 1.0-1.5% of the total water quantity pumped into the treatment plant. This can be reduced considerably in community plants by making provision for sludge concentration well and drying beds. The recovered alum can be used for purposes other than defluoridation. The fluoride in recovered alum is 8 to 10 g F per kg alum.

The solids in sludge from sedimentation basins are 0.8- 1.1% (W/V). By plain sedimentation, the concentration is increased to 2.5 - 3.1% (W/V) in 24 hours. Subsequent exposure of this concentrate of drying beds increases the solid to 28-30% (W/W).

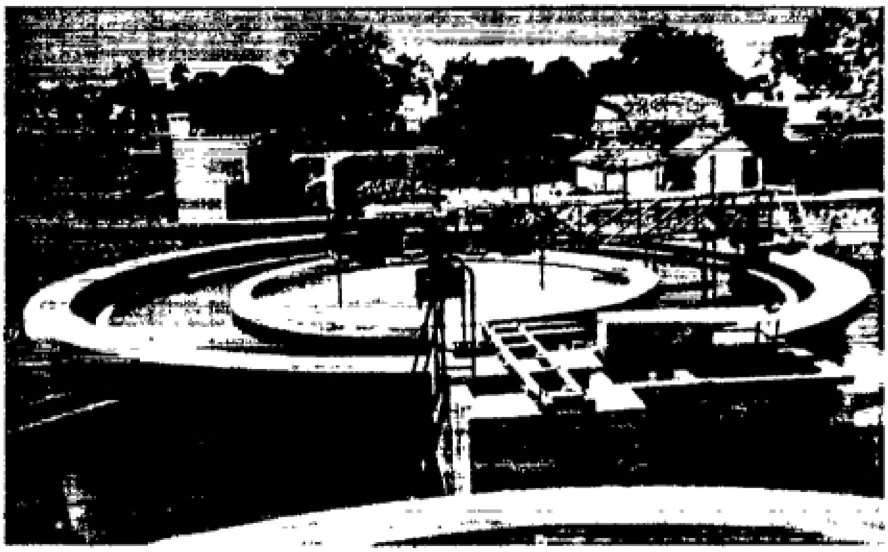


Plate 10. Defluoridation Plant at Kadiri

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