

Water

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Quality

&



Defluoridation Techniques



RAJIV GANDHI NATIONAL DRINKING WATER MISSION
NEW DELHI

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PREVENTION AND CONTROL OF FLUOROSIS

**WATER QUALITY
AND
DEFLUORIDATION TECHNIQUES**

Volume II



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MINISTRY OF RURAL DEVELOPMENT

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PREFACE

June 10, 1993

Fluorosis is a scourge affecting a large number of our population. It is endemic in as many as 15 important States in India. The excess fluoride is often based on drinking water fluoride content. It is further compounded by the fluoride content in the food and cosmetics consumed by these people. Control of fluorosis through provision of safe and sufficient water of acceptable quality is the main objective of the Sub-Mission on "Control of Fluorosis". Attack on this problem has to be multifaceted involving the individual, families and communities, and through the active participation of Public Health Engineers, Health sector personnel, district level Administrators and grass-root level field workers. The first priority, of course is to provide safe water from good sources identified in the village or in the neighbourhood. Where this is not possible, technologies developed by National Environmental Engineering Research Institute (NEERI) etc., are being used in the Sub-Mission for providing of community tanks, pump attachments and domestic filters.

The Rajiv Gandhi National Drinking Water Mission of Ministry of Rural Development, Government of India seeks to fight fluorosis and eliminate it completely in the country in a time bound manner. In this campaign the present volume is to be used as a guide book for all those involved and interested in this problem. This book will be particularly useful to those who actually collect the samples, analyse the physico-chemical content of water and plan for the type of technology suitable to local conditions. It is hoped that the users will find the volume simple and easy to handle. Experts who have prepared the volume and edited it carefully, have done a commendable job of presenting the facts in simple and lucid manner. The work was co-ordinated by Dr. A.K. Susheela, Co-Ordinator, Fluorosis Control Cell, All India Institute of Medical Sciences, New Delhi. I wish to congratulate Dr. Susheela and all other experts for this excellent effort and am sure that their continued dedication and work would contribute significantly towards the success of this important Sub-Mission.

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INTRODUCTION

An approach to problems in environmental science necessitates the application of analytical methods and procedures that have been proved to yield reliable results. Methods are available for the economical and satisfactory performance of the treatment facilities constructed.

Excess of fluoride in water causes dental and skeletal fluorosis and needs to be removed to acceptable limit of 1 mg F per L for drinking purposes. The excess of fluoride is removed by: 1) Nalgonda Technique developed by NEERI for batch operation from fill-and-draw units or continuous operation system; 2) Activated Alumina process, when the alkalinity of water to be treated is not high and where local skills for handling acids/alkalies for regeneration of the media are available.

For design, operation and maintenance of the defluoridation plants, information of turbidity, conductivity, dissolved solids, pH, alkalinity, hardness, chloride, sulphate and fluoride is desirable.

General information about the sampling procedures of water samples; methods of physico-chemical analysis of the relevant parameters; and defluoridation of water by Nalgonda Technique and Activated Alumina process are given in the subsequent sections.

SAMPLING

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 a series of steps, procedures and practices are required. 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 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 likelihood that such changes will occur in most of the waters. The arrangement should be such that these are prevented or at least minimised.

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 for collection of samples.

SITE SELECTION

The objectives of Water quality monitoring system are

- To assess the impact of activities by man upon the quality of water and its suitability for required uses
- To determine the quality of water in its natural state which might be available to meet the future needs and
- 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.

TYPE OF SAMPLES

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, 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 sample. 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.

COMPOSITE SAMPLES

The term composite refers to a mixture of grab samples collected at the same sampling point at different times. 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 cannot be used for determinations of components or characteristics subject to significant and unavoidable changes on storage.

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 streams. The preparation of integrated samples requires special equipment to collect samples from a known depth, with out

contamination by overlying water. Prior knowledge about volume, movement and composition of the various parameters of the water being sampled is also required.

SAMPLING FREQUENCY

The quality of water in various water bodies is rarely constant. Therefore, water samples should be collected at intervals so that no change in quality could pass unnoticed.

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, funds and personnel for the work.

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

- Weekly samples for one year
- Daily samples for 7 days consecutively (4 times/year)
- Round the hour sampling for 24 hours
- 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

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.

- It should easily be freed from contamination.
- It should not change the relevant water characteristics.
- It should have adequate capacity for storing the samples.
- 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-litre 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 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 $\text{Na}_2\text{Cr}_2\text{O}_7$ in 1-litre 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 carboys 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 re-inserted. 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 to be taken by immersing the container, as in ponds, cisterns, reservoirs, rivers, 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 Fig. 1 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 3 cm above the rubber stopper. The projecting tubes are connected by a piece of rubber

tube 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 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 detached. 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 detached by a slight jerk.

The apparatus is useful, when a sample has to be taken from a depth of not exceeding 100 meters 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.

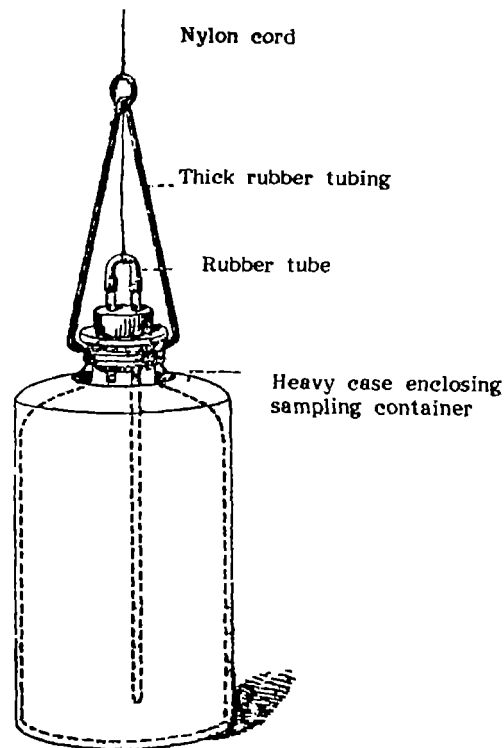


Fig. 1 Apparatus for water sampling from wells

SAMPLING PROCEDURE

The first thing 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.

A 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)

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'.

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

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. The installation of suitable sampling taps on the inlet and outlet mains of CWR is advisable.

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 tubewell

Location of the tubewell

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 data

From	To	Formations
.....
.....

Assembly of production well size Length..... Type

Perforation per meter.....

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.....

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.

FIELD MEASURED PARAMETERS

A number of parameters including pH, conductivity, dissolved oxygen, ammonia, CO₂, 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.

PHYSICO-CHEMICAL ANALYSIS

Physico-chemical analysis is the prime consideration to assess the quality of water for drinking. Surface sources often necessitate 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 suitable source of water and to determine the extent of treatment necessary to make it potable.

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

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 the sample can be done by multiplying specific conductance (in micro siemens/cm) by an empirical 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. The test facilitates weeding out of water sources with dissolved solids > 1500 mg/l. the permissible limit in the absence of alternate source prescribed by the Ministry of Rural Development. All other tests are performed on samples conforming to dissolved solids content < 1500 mg/l.

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°C).

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

- A source of alternating current.
- A wheatstone bridge, a null indicator, and,
- 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 micro Siemens/cm at temperature say 25°C at which measurement was made. With reasonable care, a conductivity meter needs very little maintenance and gives accurate results. However, few important points in this respect are:

- 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.
- Keep the electrode immersed in distilled water
- Organic material coating can be removed with alcohol or acetone followed by washing with distilled water.

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 turbulence 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 defluoridation 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 $< 1 \text{ NTU}$ with the corresponding aluminium concentration $< 20 \text{ micrograms/l}$.

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 is 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. Mix 5 ml of I with 5 ml of II. Allow to stand for 24 hrs. at $25 \pm 3^\circ \text{C}$ and dilute to 100 ml. This solution (III) will have turbidity of 400 units (N.T.U.)
4. Standard turbidity suspension: Dilute 10 ml of solution III as prepared above to 100 ml to have solution (IV) 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.

TOTAL DISSOLVED (FILTRABLE) SOLIDS

The dissolved (filtrable) solids can also be determined by the residue on evaporation. 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°C to constant weight. The increase in weight over the empty dish represents the dissolved solids.

APPARATUS

- Evaporating Dishes, 50, 100 ml capacity (Preferably porcelain or silica).
- Pipettes 25, 50 ml capacity
- Water bath & oven
- Balance to weigh up to 4th decimal.

PROCEDURE

Take known volume(V) of filtered sample in a previously ignited and weighed basin (W_1). Evaporate to dryness on a steam bath and further dry at 105°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

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

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

The pH is determined by measurement of the electromotive force of a cell comprising an indicator electrode (an electrode responsive to hydrogen ion 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°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 solution 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 latter type can be used for field measurements. The most accurate pH meters can be read to better than ± 0.005 pH unit.

REAGENTS

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

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° and 130°C in water and dilute to 1 litre at 25°C . The distilled water should be freshly boiled, cooled and free from CO_2 .

Buffer solution for pH 9.2 : Dissolve 3.80 gm $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10 \text{H}_2\text{O}$ in water and dilute to 1 litre at 25° 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

- Standardize the pH meter according to the manufacturer's instructions.
- Select a standard buffer solution with a pH value close to that of the water to be treated.
- Set the temperature control to the temperature of the buffer.
- Set the meter to the pH of the buffer at that temperature.
- Check the electrode response by measuring a second standard buffer solution of different pH.
- Wash the electrode thoroughly first with distilled water and then with the sample.
- Set the temperature control to the temperature of the sample.
- 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

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, borate, silicate and phosphate 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 to the water 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

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

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.

Methyl orange indicator : Dissolve 0.5 gm and dilute to 1000 ml with CO₂ free distilled water.

PROCEDURE

- Take 25 or 50 ml sample in a conical flask and add 2-3 drops of phenolphthalein indicator.
- If pink colour develops, titrate with 0.02 N H₂SO₄ till it disappears or pH is 8.3. Note the volume of H₂SO₄ required (A).
- Add 2-3 drops methyl orange to the same flask, and continue titration till pH down to 4.5 or colour changes to orange to pink. Note the vol . of H₂SO₄ added (B).
- In case pink colour does not appear after addition of phenolphthalein, continue as in step above.
- Calculate Total (T), phenolphthalein (P) and methyl orange (M) alkalinity as follows for 0.02N H₂ SO₄ and express in mg/l as CaCO₃.

P - Alkalinity, mg/l as CaCO₃ = A X 1000/ml sample.

M - Alkalinity, mg/l as CaCO₃ = B X 1000/ml sample.

T - Alkalinity, mg/l as CaCO₃ = (A+B) X 1000/ml sample.

In case H₂SO₄ is not 0 02 N, apply the following formula:

$$\text{Alkalinity, mg/l as CaCO}_3 = \frac{K \times N \times 50000}{\text{ml Sample}}$$

Where, N =Normality of H₂SO₄ used and

K = ml standard acid used to reach P or M end point.

Once the phenolphthalein and total alkalinity is determined, then three types of alkalinities, i.e. hydroxide, carbonate and bicarbonate (all expressed as calcium carbonate) are calculated from the table given below.

<u>Values of P&T</u>	<u>OH</u>	<u>CO3</u>	<u>HCO3</u>
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

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

Acceptable limit	200 mg/l
Cause for Rejection limit	600 mg/l

The Cause for Rejection limit is applied in the absence of alternate sources of water. Internationally, waters with hardness > 180 mg/l are to be softened to prevent incrustation in the pipes and to reduce soap consumption.

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

PRINCIPLE

Hardness is determined by EDTA Titrimetric Method. 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 ± 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

Buffer Solutions: 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 unavailable, dissolve 1.179 gm disodium salt of EDTA (AR Grade) and 780 mg $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ or 644 mg $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ in 50 ml distilled water. Add to above solution of NH_4Cl in NH_4OH and dilute to 250 ml.

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

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

Murexide Indicator : Prepare by grinding a mixture of 200 mg of murexide (ammonium purpurate) with 100 gm of solid NaCl.

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

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 CaCO₃.

Standard Calcium Solution: Weigh accurately 1.0 gm AR grade CaCO₃ and transfer to 250 ml conical flask. Place a funnel in the neck of a flask and add 1+1 HCl till CaCO₃ dissolves completely. Add 200 ml distilled water and boil for 20-30 min. to expel CO₂. Cool and add methyl red indicator. Add 3 N NH₄OH dropwise till intermediate orange colour develops. Dilute to 1000 ml to obtain 1 ml = 1 mg CaCO₃.

PROCEDURE - TOTAL HARDNESS

- Take 25 or 50 ml well mixed sample in porcelain dish or conical flask.
- Add 1-2 ml buffer solution followed by 1 ml inhibitor.
- 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)
- Run a reagent blank. Note the volume of EDTA(B)
- Calculate volume of EDTA required by sample, from volume of EDTA required in above steps (C)

$$C = (A - B)$$

- Calculate as follows :

$$\text{Total hardness as CaCO}_3 \text{ mg/l} = \frac{CXDX1000}{\text{ml sample}}$$

where C = Vol. of EDTA required by sample

D = mg CaCO₃ per 10 ml. EDTA (0.01 M) used as titrant

PROCEDURE - CALCIUM HARDNESS

- Take 25 or 50 ml sample in porcelain dish.
- Add 1 ml NaOH to raise pH to 12.0 and a pinch of murexide indicator.
- Titrate immediately with EDTA till pink colour changes to purple. Note the vol. of EDTA used (A').
- Run a reagent blank. Note the volume of EDTA (B') required and keep it aside to compare end points of sample titrations.
- Calculate as follows:

$$\text{Calcium hardness as CaCO}_3 = \frac{C'XD'X1000}{\text{ml sample}}$$

Where C' = Volume of EDTA used by sample (A'-B')

D' = mg CaCO₃ per 1.0 ml EDTA (0.01 M) used for titration

CALCULATION MAGNESIUM HARDNESS

Magnesium hardness as CaCO_3 mg/l = total hardness as CaCO_3 mg/l - Ca hardness as CaCO_3 mg/l

CHLORIDE

Chloride ion is generally present in natural waters. The salty taste produced by chloride depends on the chemical composition of the water. A concentration of 250 mg/l may be detectable in some waters containing sodium ions. **The Water mission prescribed the acceptable requirement of Chloride as 200mg/l from the point taste consideration.** The limit in the absence of alternate sources is 1000 mg/l, a cause for rejection of water source.

A combination of aluminium sulphate and/or 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 flocculation followed by filtration prior to the estimation of chloride.

REAGENTS

- **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.
- **Silver nitrate (0.0141N) :** 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.
- **Sodium Chloride 0.0141 N :** Dissolve 824.1 mg NaCl dried at 140°C and dilute to 1000 ml. 1 ml = 0.5 mg Cl.
- **Special reagent to remove colour and turbidity :** Dissolve 125 g $\text{K}_2\text{Al}_2(\text{SO}_4)_4 \cdot 12\text{H}_2\text{O}$ or $(\text{NH}_4)_2\text{Al}_2(\text{SO}_4)_4 \cdot 24\text{H}_2\text{O}$ and dilute to 1000 ml. Warm to 60°C and add 55 ml conc. NH_4OH slowly. Allow to stand for 1 hr. Solution should be free from Cl.

PROCEDURE

- Take 100 ml sample and adjust the pH between 7.0 and 8.0
 - Take 50 ml well mixed sample adjusted to pH 7.0 - 8.0 and add 1.0 ml K_2CrO_4
-

-
- Titrate with standard AgNO_3 solution till AgCrO_4 starts precipitating
 - Standardize AgNO_3 against standard NaCl .
 - For better accuracy titrate distilled water (50 ml) in the same way to establish reagent blank
 - 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
 N = Normality of AgNO_3 used.

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. 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 source.

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.

PRINCIPLE :

Sulphate is determined by turbidimetric method through precipitation 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 excess of 500 ppm interfere in this estimation. Filtration is adopted to remove colour and turbidity.

APPARATUS

- magnetic stirrer
 - colorimeter for use at 420 nm
 - stopwatch
 - Nessler's tubes, cap 100 ml
 - measuring spoon cap - 0.2 to 0.3 ml
-

REAGENTS

- **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.
- **Barium chloride** Crystals. 20-30 mesh.
- **Standard sulphate solution** : Dissolve 147.9 mg anhydrous Na_2SO_4 and dilute to 1000 ml.
1 ml = 100 $\mu\text{g SO}_4$.

PROCEDURE

- Take suitable vol. of sample in 250 ml conical flask and dilute to 100 ml.
- Add 5.0 ml conditioning reagent accurately. Mix well.
- 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 .
- 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.
- 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.
- Read mg SO_4 present in the sample from the standard curve.
- Calculate as follows :

$$\text{mg/l SO}_4 = \frac{\text{mg SO}_4 \times 1000}{\text{ml Sample}}$$

FLUORIDES

Fluoride ions in excess in water supplies are known to damage teeth, skeleton and other organs. High concentration of F^- causes dental fluorosis (discolored teeth). The BIS mentions the permissible upper limit as 1 mg F^-/l . Further BIS mentions that fluoride may be kept as low as possible

Among the many methods suggested for the determination of fluoride ion in water, the colorimeter method (SPADNS) and the ion selective electrode method are the most satisfactory and applicable to variety of samples. Because all colorimetric methods are subject to errors due to presence of interfering ions, it may be necessary to distil the sample before making the fluoride estimation. 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 colorimeter methods. However, unknown samples must be subject to preliminary distillation step in either of the methods.

PRELIMINARY DISTILLATION STEP

Place 400 ml distilled water in the distilling flask and carefully add 200 ml conc. H_2SO_4 . Swirl

until the flask contents are homogenous, add 25 to 30 glass beads and connect the apparatus as shown in Figure.. Begin heating slowly at first and then rapidly until the temperature of the flask reaches exactly 180° 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°C or below, add 300 ml of sample, mix thoroughly, and distil as before until the temperature reaches 180°C. Do not heat above 180° C to prevent sulphate carryover.

Add Ag_2SO_4 to distilling flask at the rate of 5 mg/mg 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.

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 Beers law in a reverse manner.

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

- Distillation apparatus
- Colorimeter for use at 570 nm.
- Nessler's tubes, cap. 100 ml

Reagents

- Sulphuric acid, H_2SO_4 , conc.
 - Silver sulphate Ag_2SO_4 crystals.
 - SPADNS solution : dissolve 958 mg SPANDS and dilute to 500 ml.
 - Zirconyl acid reagent : Dissolve 133 mg $\text{ZrOCl}_2 \cdot 8\text{H}_2\text{O}$ in 25 ml water. Add 350 ml conc. HCl and dilute to 500 ml.
 - Mix equal volumes of SPANDNS solution and Zirconyl acid reagent to produce a single reagent. Protect from direct light
 - 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.

- Sodium arsenite solution: dissolve 5.0 g NaAsO₂ and dilute to 1000 ml.
- Stock F⁻ solution: Dissolve 221.0 mg anhydrous NaF and dilute to 1000 ml. 1 ml = 100 µg F⁻
- Standard F⁻: Dilute stock solution 10 times to obtain 1 ml = 10 µg F⁻.

Procedure

- 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.
- Add 10.0 ml mixed reagent prepared as above to all the samples, mix well and read optical density of bleached colour at 570 nm using reference solution for setting zero absorbance.
- Plot concentration Vs % transmission or absorbance.
- If sample contains residual chlorine, remove it by adding 1 drop (0.05 ml) NaAsO₂ solution per 0.1 mg Cl₂ and mix. NaAsO₂ concn. should not exceed 1300 mg/l to avoid error due to NaAsO₂. Take suitable aliquot and dilute it to 50 ml.
- Add 10 ml acid Zirconyl - SPADNS reagent; Mix well and read % transmission or absorbance.
- Take suitable aliquots of sample either direct or after distillation, in Nessler's tubes. Follow the step above.
- Calculate the mg F⁻ present in the sample using standard curve.

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 Sr (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 adjusting the pH in between 5 to 8 no interference occurs.

Apparatus

- Ion meter (field/laboratory model) or pH/mV meter for precision laboratory measurements.
- Reference electrode (calomel electrode)
- Fluoride sensitive electrode.
- Magnetic stirrer
- Plastic labwares (Samples and standards should always be stored in plastic containers as fluoride reacts with glass)

Reagents

- Standard fluoride solution prepared as directed in SPADNS method
- 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 tetra acetic 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

- For connecting the electrode to meter and for further operation of the instrument follow the instruction manual supplied by the manufacturer.
- Check the electrode slope with the ion meter (59.16 mV for monovalent ions and 29.58 mV for divalent ions at 25° C)
- 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.
- Transfer 50 ml of sample to a 150 ml plastic beaker. Add TISAB as mentioned in step above.
- Rinse electrode, blot dry and place in the sample. Stir thoroughly and note down the steady reading on the meter.
- Recalibrate every 2 hours.
- 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.
- 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.

DEFLUORIDATION OF WATER USING NALGONDA TECHNIQUE

Defluoridation is removal of excess fluorides from water. Removal is achievable either by precipitation and complexation process (Nalgonda Technique) or by fixed bed regeneratable Activated Alumina process. The recommended defluoridation method is Nalgonda Technlque.

After extensively testing since 1961, many materials and processes including activated alumina, NEERI has evolved an economical and simple method for removal of fluoride which is referred to as Nalgonda Technique.

Nalgonda Technique involves addition of aluminium salts, lime and bleaching powder followed by rapid mixing, flocculation, sedimentation, filtration and disinfection. 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 aluminum chloride also depends on sulphate and chloride contents of the raw water to avoid exceeding their permissible limits. The dose of lime is empirically 1/20th that of the dose of aluminium salt. Lime facilitates forming dense floc for rapid setting. Bleaching powder is added to the raw water at the rate of 3 mg/l for disinfection. Approximate doses of alum required to obtain Acceptable limit (1.0 mg F/l) in water at various fluoride and alkalinity levels are given in the Table 1.

MECHANISM OF DEFLUORIDATION BY NALGONDA TECHNIQUE

Nalgonda Technique is a combination of several unit operations and process incorporating rapid mixing, chemical interaction, flocculation, sedimentation, filtration, disinfection and sludge concentration to recover water and aluminum salts (Fig. 2).

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.

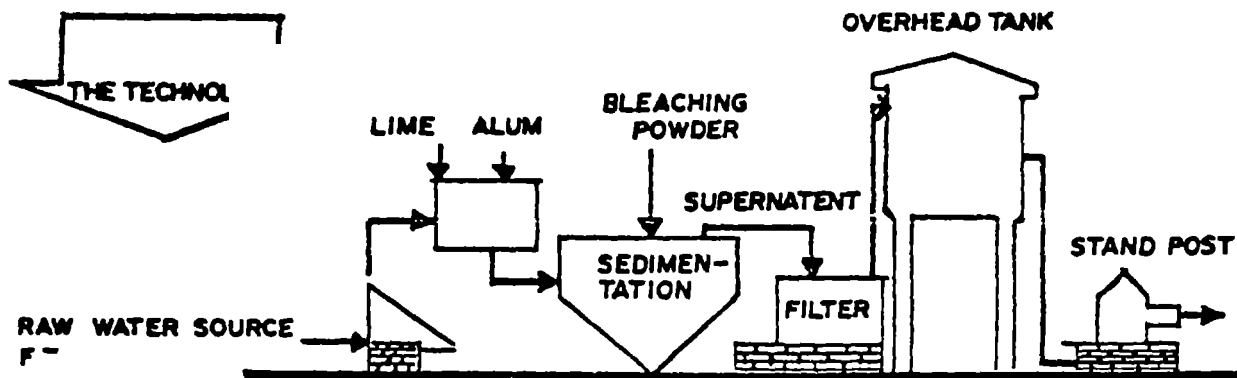


Fig. 2 Layout Plan of Nalgonda Technique.

Table 1 : Approximate Alum Dose (mg/l) Required to Obtain Acceptable Limit (1 mg F/l) of Fluoride in Water at Various Alkalinity and Fluoride Levels.

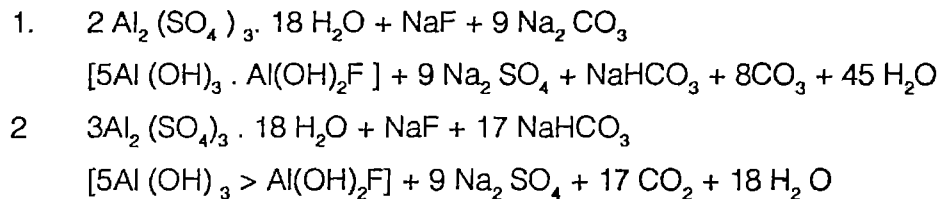
Test Water Fluorides, mg F/l	Test Water Alkalinity, mg CaCO ₃ /l							
	125	200	300	400	500	600	800	1000
2	145	220	275	310	350	405	470	520
3	220	300	350	405	510	520	585	765
4	*	400	415	470	560	600	690	935
5	*	*	510	600	690	715	885	1010
6	*	*	610	715	780	935	1065	1210
8	*	*	*	*	990	1120	1300	1430
10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

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

Flocculation:

Flocculators provide subsequent gentle agitation before entry to the sedimentation tank. The flocculation period permits close contact between the fluoride in water and polyaluminic 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 aluminium 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.
- * Lime or sodium carbonate ensures adequate alkalinity for effective hydrolysis of aluminium salts, so that residual aluminium does not remain in the treated water.
- * Simultaneous disinfection is achieved with bleaching powder and also keeps the system free from undesirable biological growths.



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 largely on experience.

Filtration

Rapid gravity sand filters are suggested to receive coagulated and settled water. In these filters 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.

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
- Adaptable to domestic use
- Flexible upto several thousands m³/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 1.5 to 20 mg F/l to desirable levels.
- Simultaneous 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 (1991 basis) 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.

WHEN TO ADOPT NALGONDA TECHNIQUE

- Absence of acceptable, alternate low fluoride source within transportable distance
- Total dissolved solids are below 1500 mg/l; desalination may be necessary when the total dissolved solids exceed 1500 mg/l, the cause for rejection limit in the absence of alternate source.
- Total hardness is below 600 mg/l, the 'cause for rejection' limit in the absence of alternate source. Hardness does not interfere in the defluoridation.
- Hardness > 200 mg/l and < 600 mg/l require precipitation softening, and > 600 mg/l becomes a cause for rejection or adoption of desalination. Between 200 mg/l and 600 mg/l hardness precipitation softening techniques supplement Nalgonda Technique and, such waters are to be dealt individually on merits.

- Alkalinity of the water to be treated must be sufficient to ensure complete hydrolysis of alum added to it and to retain a minimum residual alkalinity of 1 to 2 meq/L in the treated water to achieve treated water pH between 6.5 and 8.5.
- Raw water fluorides ranging from 1.5 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 dissolved solids are above 1500 mg/l and hardness above 600 mg/l.

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 solutions for defluoridation of 40 L of water are given in Table 2.

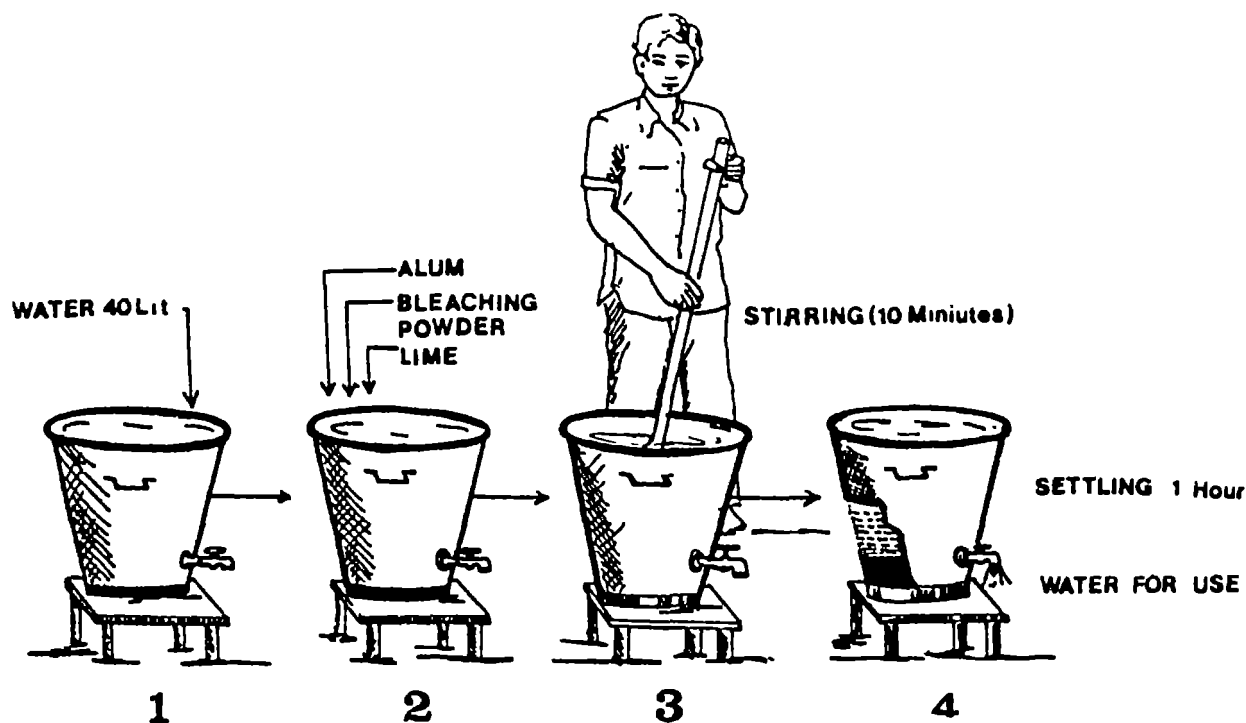


Fig 3 Defluoridation at Domestic Level

Table 2 : Domestic Defluoridation : Approximate volume of alum Solution (millilitre) Required to be Added in 40 litres Test Water to Obtain Acceptable Limit (1.0 mg F/l) of Fluoride in Water at Various Alkalinity and Fluoride Levels.

Test Water Fluorides, mg F/l	Test Water Alkalinity, as 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 (Fig. 4). 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.

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 carboy. 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.

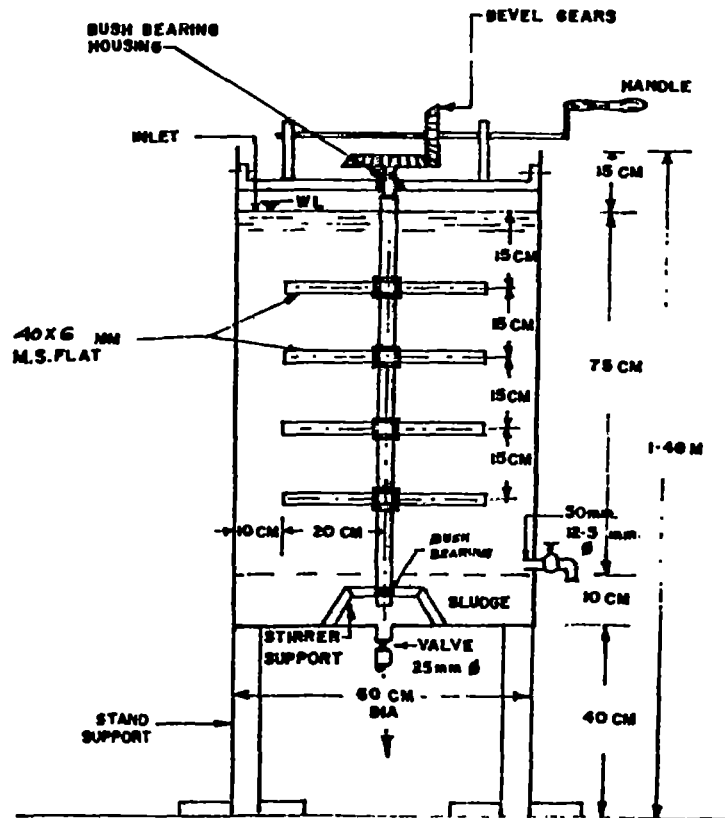


Fig. 4. Fill - and -Draw Domestic Defluoridation Unit.

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 3.

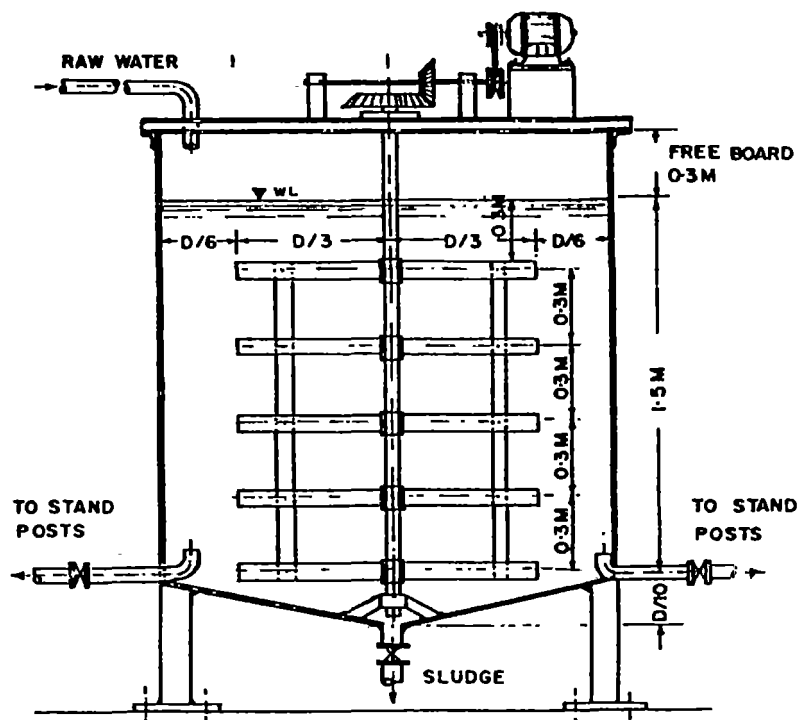


Fig. 5 Fill-and-Draw Defluoridation Plant for Small Community

Table 3 : Plant Diameter for Populations upto 200 on the Basis of 40 lpcd Defluoridated Water

Population	Water Volume m ³	Plant Diameter m	Suggested H.P. for Motor
50	2	1.30	1.0
100	4	1.85	2.0
200	8	2.60	2.0

Alum required to be added per batch of treatment (grams, alumina ferric, IS : 299 - 1962)
 = (Water Volume, m³) X (Alum dose of that particular water, mg/l).

Fresh Bleaching Powder (grams per batch) = 3 X (Water Volume, m³)

The notable features are:

- 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.
- 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).

- The plant can be located in the open with precautions to cover the motor.
- Semi-skilled labour can perform the function independently.

FILL-AND -DRAW DEFLUORIDATION PLANT TECHNOLOGY FOR RURAL WATER SUPPLY

Fill-and-draw defluoridation plant technology based on Nalogonda Technique is designed for removal of excess fluoride from water, which is most suitable for Rural Water Supply (Fig. 6).

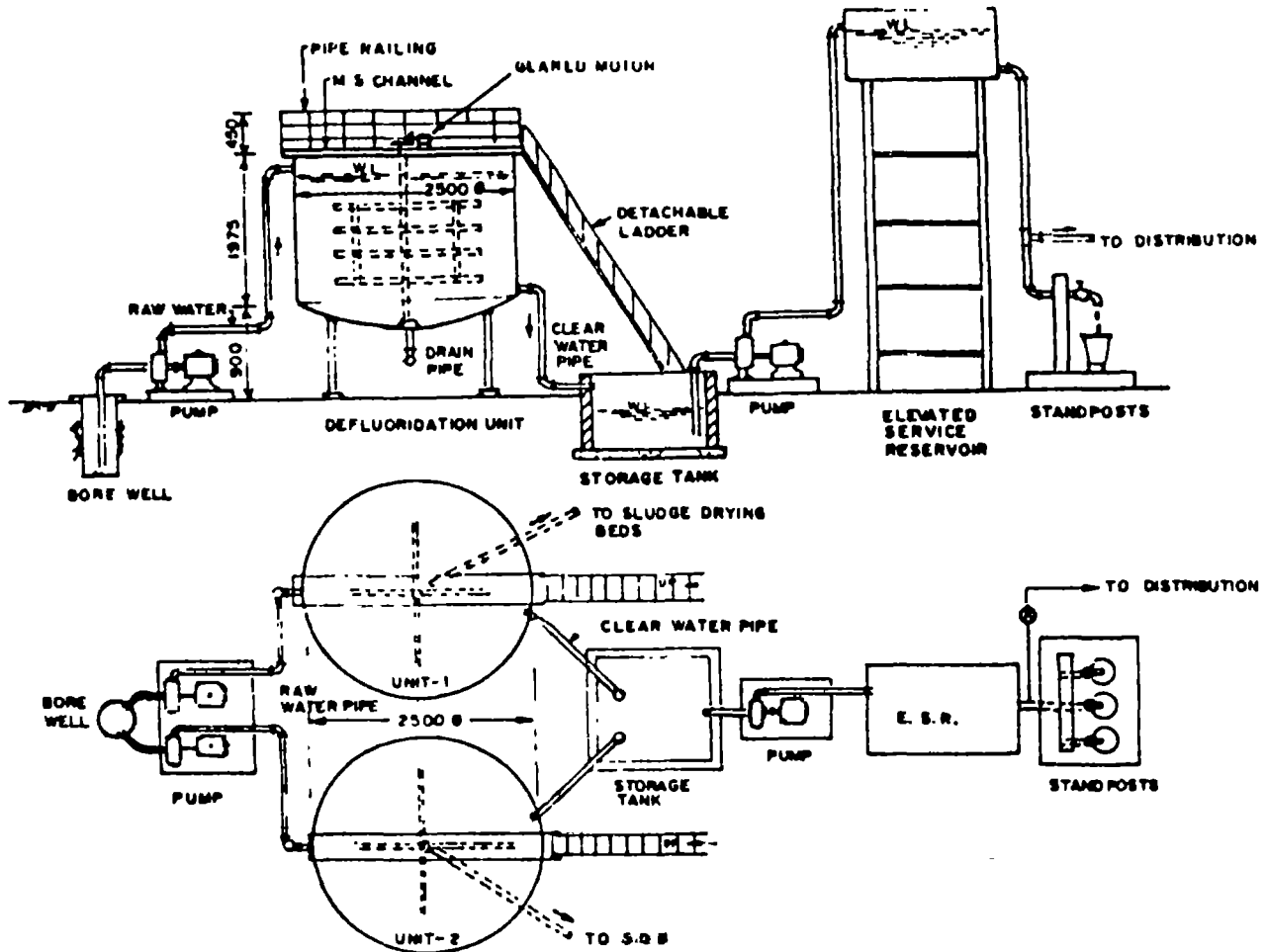


Fig. 6. Fill-and-Draw Defluoridation Plant for Rural Water.

Components of Fill-and-Draw Defluoridation Plant

- 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

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 m³ 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.

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 across the platform is provided. The settled water outlet with

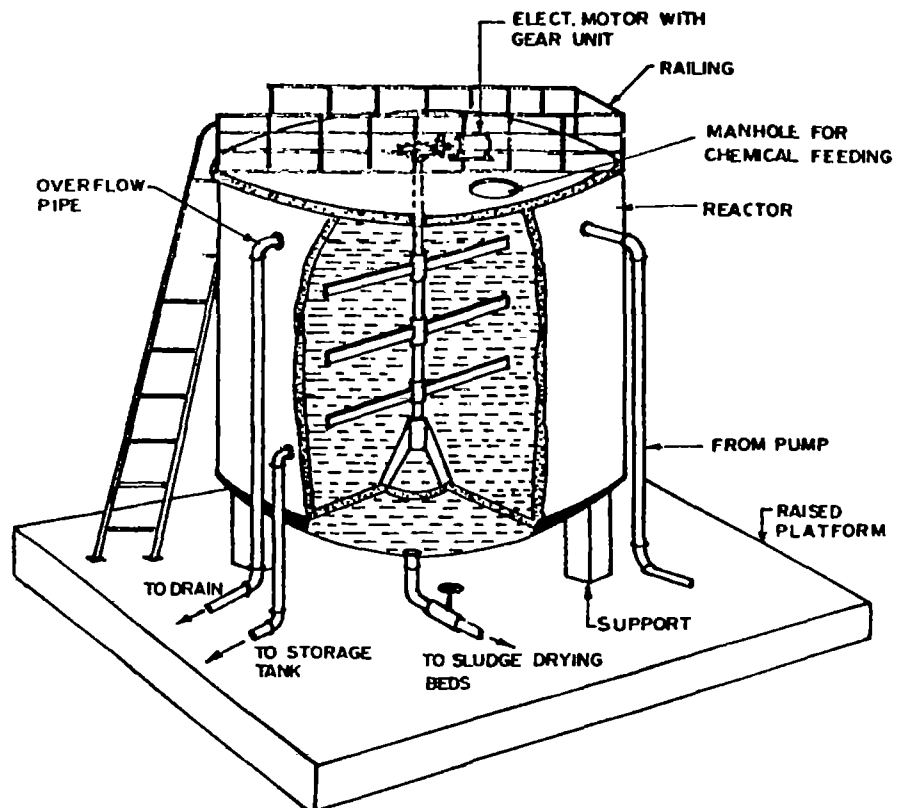


Fig 7. Reactor for Defluoridation Operation

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.

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; and agitator assembly (details given separately).
Capacity of Reactor	-	10, 20, Or 30 m ³
Settling time	-	2 to 4 hours
Other aspects	-	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

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 $415 \pm 6\%$ voltage fluctuation.

Material of 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

Gear Box

* Worm reduction gear box

Input speed	-	1440 RPM
Output Speed	-	20 RPM
Reduction	-	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 hobbled, 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.

Platform-cum-Walkway

A suitable sturdy 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.

Other Plant Components

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

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 (Table 4).

Table 4 : Details of Sump Wells for Various Plant Capacities

Capacity 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

Elevated Service Reservoir

Treated water from sump well is pumped to the elevated service reservoir (Table 5). It should be a RCC circular 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 m³.

Table 5 : Dimensions of Elevated Service Reservoir for Various Capacities

Capacity of ESR 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

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 6.

Table 6 : Sizes of Sludge Drying Beds

Plant Capacity m ³ /d	Size of Bed m	No. of Beds
10	2.5X2.5	2
20	2.5X2.5	2
30	3.2X3.2	2
40	4.5X4.5	2
60	4.5X4.5	2
80	5.5X5.5	2
100	5.5X5.5	2
120	4.5X4.5	4
180	5.5X5.5	4

Electric Panel Room

The electric panel room 2.5 mx 3.0mx3.0m, is of brick masonry with RCC slab to house the pumps and electrical controls of reactors (Table 7).

Table 7. : 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

Chemical Store House

This is adjacent to Electric Panel Room and of brick masonry with RCC slab to store lime, alum and bleaching powder sufficient for 100 days operation of the plant at the capacity indicated in Table 8. A ram with big door is provided to unload material from a truck.

Table 8 : 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, weighing balance and minor stores

CONFIGURATION OF REACTORS

The configuration of reactors depends upon water demand, size of reactors, number of reactors and number of operations per day. The optimal configurations for various water demands are given in Table 9.

Table 9 . 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 per day	Super-visor	Chemist	Hel-pers
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 (RCC)	2	3	1	1	6
180	20 (HDPE)	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

COST ESTIMATION (1991 BASE)

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 9 shows configuration of reactors and personnel depending upon the amount of water to be treated daily upto 480 m³ /d for RCC and upto 180 m³/day for HDPE reactors. 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 anum on capital cost
Maintenance	5%	per annum on capital cost
Interest	12%	per annum on capital cost

Cost of power	Rs. 0.50	per Unit
Cost of alum	Rs. 2.00	per kg.
Cost of Lime	Rs. 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

Tables 10 and 11 give capital costs, total operational costs/m³ and running costs/m³ for various capacities per day for RCC and HDPE reactor systems respectively. The cost per m³ decreases as the per day plant capacity increased. There are exceptions to this and these exceptions are due to plant configurations.

The total operational cost ranges between Rs. 33 70/m³ and Rs. 4.27/m³ for plant capacity ranging between 10 and 480 m³/day for RCC reactor system. The running cost varies between Rs. 1.93 and Rs. 1.57/m³.

The water demands in arid and semi-arid regions are more, because the cattle population is also to be 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

Table 10 : cost Estimates for RCC Defluoridation Plants of Various Capacities @ 40 lpcd

Raw water fluoride = 5 mg F/l

Raw Water alkalinity = 400 mg CaCO₃/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	1,56,80	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

Table 11 : cost Estimates for HDPE Defluoridation Plants of Various Capacities @ 40 lpcd

Raw water fluoride = 5 mg F/l

Raw Water alkalinity = 400 mg CaCO₃/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	3,81,000	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

demands, capital costs for 10, 20 40, 70 and 100 lpcd were estimated for various populations and are shown in Table 12

Table 12 : Capital Costs 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 10m³ and 480 m³

DEFLUORIDATION OF WATER USING ACTIVATED ALUMINA PROCESS

MEDIA SPECIFICATIONS

Specifications of AA	:	ACC Grade G-80
Particle size	:	2-3 mm sphere
Surface area	:	250 m ² /g (min)
Bulk density	:	0.80 - 0.85 Kg/l
Pore volume	:	0.3 - 0.4 cc/g

LABORATORY EXPERIMENTS

NEERI has extensively studied the usefulness of activated alumina (AA) for the removal of excess fluoride from potable waters. The fluoride removal capacity of activated alumina was reported to vary considerably, apparently caused by difference in the physico-chemical characteristics of activated alumina and regenerative procedure. The effect of controlling factors such as pH, the contact time, the ratio of adsorbate (fluoride ion) to adsorbent (activated alumina) on the rate of fluoride removal in batch operations was studied. The kinetics of adsorption on 105 to 88 micron size activated alumina powder showed that: (i) initial rates of adsorption of fluoride decrease progressively after the initial 30 minutes and give rather slow approach to equilibrium; (ii) nearly linear variation of the amount adsorbed with square root of the time of reaction has been found to obtain for the initial fraction of the adsorption reaction studies at pH 9 to 4; (iii) the adsorption of fluoride from water is relatively more rapid the more dilute the solution; (iv) the adsorption isotherms poorly conform to Freundlich and Langmuir isotherms; (v) by employing BET equation and intricate analysis, very good linearisation is observed for all reaction times at various pH; (vi) the rate of adsorption of fluoride increases with the decreasing pH of the solution; (vii) although activated alumina is a good adsorbent for fluoride in water with fairly good capacity the slowness with which the potential capacity is attained in the batch experiments makes a consideration of techniques important for effective utilisation of the good capacity (viii) the rate of adsorption is controlled by rate of diffusion of solute within the micropores of activated alumina; (ix) the batch studies showed that activated alumina for defluoridation of water could be used effectively in continuous flow columns.

COLUMN STUDIES

The batch studies on the rates of adsorption by activated alumina from solution are strongly dependent upon the particle size of the adsorbent and hence activated alumina of 0.25-0.35 mm size were employed in column studies. Column type continuous flow operations were made for removal of fluoride using activated alumina. The regeneration was accomplished by four bed volumes of 0.1 M HCl solutions. Forty cycles were carried out for each basicity 4, 8 and 16 meq/l in test water. The defluoridation capacity of activated alumina depends upon the basicity of water and decreases with increasing basicity. Within 40 cycles of operation, the capacity of activated alumina decreased rapidly.

Test Water Characteristics

PH	:	7.6 - 8.5
Fluorides	:	5.2 ± 0.2 mg/l (a)
Basicity	:	400 mg/l (b)
Capacity (corresponding to values 'a' & 'b')	:	Max. 315 mg F/l Min. 143 mg F/l Ave. 164 mg F/l

COMPONENTS OF AA DEFLUORIDATION PLANT - COST ASPECTS (1991 BASE) - (2.82 m³ OF AA) - 200 m³/d PLANT

Main Plant, comprising acid proof pressure vessel, piping, valves, regeneration system with control valves, acid pump, backwash pump, regulators, piping net work etc. Rs. 8,20,000

Civil Works, acid proof drains, regenerant/wash water neutralisation system, electrical panel room, chemical store house and elevated service reservoir (40 m³ capacity /10 m Head) Rs. 4,00,000.

2.82 m³ of Activated Alumina(AA) - Rs. 1,60,000

The ultimate capacity of the AA for fluoride removal studied at 4, 8, 16 meq/l basicity has been calculated as 1503, 1168 and 662 mg F/l activated alumina; the experiments showed the different percents of the ultimate capacity realised for various basicities at initial, middle and last runs of operation (Table 13).

Table 13 : Percent Capacity Realization at Various Basicities and at Different Cycles of Operation

	Basicity, meq/L					
	4		8		16	
Breakthrough level, mg F/l	1	2	1	2	1	2
Initial run	42	62	27	49	38	75
Twentieth run	14	19	15	25	14	21
Last run	15	19	12	15	9.5	13

Table shows quantitatively the variation of capacity to 1 and 2 mgF/l break-through levels. Undoubtedly the capacity realisation actually tapers off as adsorption-near-capacity is reached.

However, relationships of this sort obtained with varying bed depth, flow rate, initial fluoride values will be interesting but time limitation restricted prolonged work with these variables.

TOTAL QUANTITY OF WATER TREATED IN 40 CYCLES OF OPERATION

To evaluate the overall performance of the medium with natural waters in columnar operations the total quantity of Water treated in all forty cycles of operation and acid consumed was worked out (Table 14).

Table 14 : Overall Performance of Columns in 40 cycles of Operation

	Basicity, meq/l					
	4		8		16	
Breakthrough level, mg F/l	1	2	1	2	1	2
Duration of operation, hr	727	1292	587	880	308	575
HCl/l of water treated, mg	268	151	332	222	632	339

The HCl requirements for treating 1 m³ of water containing around 5.4 ± 0.2 mg F/l and upto a fluoride break-through level of 1 mg F/L were 268, 332 and 632 g too 4, 8 and 15 meq/l basicity, respectively: the corresponding values for 2 mg F/l break-through level were 151, 222 and 339 g.

OPERATING AND TREATMENT COSTS (1991 BASE)

Characteristics of Test Water

pH	:	7.4 - 8.5
Fluorides, mg/l	:	5.2 ± 0.2 say, 'a'
Basicity, meq/l	:	4 or 8 or 16, say, 'b'
Capacity of AA at 'b'	:	c mg F/l of AA

Typical Basis for Calculation (200 m³ /d AA plant)

A pressure acid proof plant with 2.82 m³ of AA capable of treating 10.4 m³ / h water was considered.

a. Capital Cost

Civil Works	Rs. 4,00,000
Plant	Rs. 8,20,000
2.82 m ³ of AA	Rs. 1,60,000
Total	Rs. 13,80,000

b. Depreciation

Plant, at 10% pa	Rs. 82,000
Civil works, at 5% pa	Rs. 20,000
Medium, at 33.33% pa	Rs. 53,000
Total	Rs. 1,55,000

Capital Cost of Plant Based on Ten Year Life Expectancy

Cost = Civil Works + Plant + (Medium x 3.33)

$$= 4,00,000 + 8,20,000 + 5,30,000 = 17,50,000$$

c. Sample Calculation for 5.2 ± 0.2 mg F/l and 'b' meq/l Basicity

Total fluoride removal capacity of AA between two successive regeneration is 2820 c mg F⁻

Quantity of Water treated per regeneration is 2.82 (c/a) m³

$$\text{Length of run between successive regeneration} = \frac{2.82 (c/a) \text{ m}^3}{10.4 \text{ m}^3} = 0.2712 (c/a) \text{ hrs}$$

Time required per regeneration is 2 hours.

$$\text{Number of regenerations per 24 hours working day, allowing 2 hrs. per regeneration is} = \frac{24a}{0.2712c + 2a}$$

$$\begin{aligned} \text{Quantity water treatable in 24 hrs working allowing for regeneration time (Q)} &= \frac{24a}{0.2712c + 2a} \times \frac{2.82c}{a} \\ &= \frac{67.68c}{0.2712c + 2a} \text{ m}^3 \end{aligned}$$

Acid requirement per regeneration is 4 bed volumes of 0.1 M HCl or 2.82 m³ AA3 x 4 x 0.1m = 1.128 m³ or 0.09803 m³ Con HCl or 116 Kg. HCl.

Conc HCl requirement per day is

$$\frac{24 \times 116 a}{0.2712c + 2a} = \frac{2784 a}{(0.2712c + 2a)} \text{ kg}$$

$$\text{Cost of HCl per day at Rs. 3/kg is} \frac{8352 a}{(0.2712c + 2a)} \text{ in Rs. (1)}$$

Pumping costs of Q m³ against a total head of 20 m to ESR through the plant (including friction losses and at Re.0.50/unit) :

$$\frac{1000 \times Q \times 20 \times 50}{102 \times 60 \times 60 \times 100} = 0.27233 Q = \frac{18.431 c}{0.2712c + 2a} \text{ in Rs. (2)}$$

$$\begin{aligned} \text{Interest on capital at 12\% per annum on} & \text{ Rs. 13,80,000} & \text{(in Rs. 1,65,600)} \\ & = \text{Rs. 453.70/day} & \text{(3)} \end{aligned}$$

$$\begin{aligned} \text{Maintenance at 5\% on civil works, and plant per annum on} & \text{ in Rs. 13,80,000 (ie Rs. 69000)} \\ & = \text{Rs. 189.04/day} & \text{(4)} \end{aligned}$$

d. Manpower Per Annum

Superintendent -cum -Chemist	1	Rs. 24,000	
Junior Chemist	1	Rs. 18,000	
Watchman/labour	3	Rs. 10,800	
Total	=	Rs. 52,800	
	=	Rs. 144, 60/d	(5)
Depreciation per day = Rs. 155000/365	=	Rs. 424.66	(6)

Cost of treatment per day, K, is charges due to

$$(1) + (2) + (3) + (4) + (5) + (6) =$$

$$8352 a \quad 18.431 c$$

$$\frac{8352 a}{0.2712 c + 2a} + \frac{18.431 c}{0.2712 c + 2a} + 453.70 + 189.04 + 144.60 + 424.66$$

$$= \frac{10776 a + 348 c}{2a + 0.2712 c}$$

$$\text{Cost of treatment per m}^3 = K/Q = \frac{10776 a + 384 c}{67.68 c} \quad \text{in Rs.}$$

In this study 'a' has a fixed value of 5.2 ± 0.2 mg F/l. Therefore, cost of treatment per m^3 ; K/Q will be : $(56,035 + 348 c)/67.68 c$; where c is a variable, i.e. capacity of AA at different basicities. The values are shown in the Table 15

$$\text{Capital cost per m}^3 = \text{Rs. } 17, 50, 000/Q$$

- e. The cost analysis at different basicities of the test water is shown in Table 16
- f. The estimated cost analysis of activated alumina defluoridation system at various plant capacities from 10 to 480 m^3/d and for raw water characteristics, $F = 5.2 \pm 0.2$ mg/l and 40°C mg/l basicity are given in Table 17
- g. Summary cost for activated alumina pressure type defluoridation plants of various capacities is given in Table 18

Table 15 : Average Capacity Values Corresponding to Various Basicities

Basicity,	Capacity (c), mg F/l Medium, Corresponding to					
	1 mg F/l *			2 mgF/l*		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
4	633	229	225	930	284	377
8	315	143	164	575	173	265
16	253	63	108	495	87	166

* In the column effluent

OBSERVED LIMITATIONS OF ACTIVATED ALUMINA PROCESS

- Capacity of activated alumina depends upon the basicity of water and decreases considerably with increasing basicity.

Table 16 : Cost Analysis at 4, 8, 16 meq/l Basicity for 5.2 ± 0.2 mg F/l Test Water

Basicity of Test Water, meq/l	Fluoride, Level in Effluent, mg/F/l	Quantity of Water Treated per Regeneration at a maximum rate of $10.4 \text{ m}^3/\text{h}$ m^3	Quantity of water Treated per 24 hour working allowing 2 h per regeneration, m^3	Cost of Treatment per m^3 including depreciation, acid, power, staff, interest on capital and maintenance, Rs	HCl (11.5 M) Required per day, kg	Running cost of operation per m^3 , Rs.
4	1	138.3	216.9	8.38	182	2.79
	2	204.8	226.5	7.33	129	1.98
8	1	89.1	202.3	10.18	264	4.19
	2	143.7	218.0	8.26	176	2.69
16	1	58.6	184.2	12.80	365	6.21
	2	90.0	202.7	10.12	261	4.14

TABLE 17 Cost Analysis of Activated Alumina defluoridation System at Various Plant Capacities (10 to 480 m³/D and for raw water characteristics F = 5.2 ± 0.2 mg/l and 400 mg/l basicity (Total columns are 24).

Columns 1 to 16 (See next page for columns 17 to 24)

Plant capacity m ³ /D	m ³ /D appx	AA litres	Capital cost towards (in Rs.)				Depreciation/day (in Rs.)				Chemicals/day (Rs.)				
			Civil Works	Plant	A A	Total	Civil works 5% p.a	Plant 10% p.a.	Medium 33.3% p.a.	Total	HCl Kg	NaOH Kg	Cost, (in Rs.)		
													HCl Rs.3/kg	NaOH Rs.6/kg	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
10	0.5	165	185000	385000	9400	579400	25.34	105.48	8.53	139.41	6.8	3.4	20.4	20.4	40.8
20	1	322	200000	400000	18350	618350	27.40	109.59	16.76	153.75	13.3	6.7	39.9	39.9	79.8
40	2	630	200000	415000	35910	650910	27.40	113.70	32.80	173.90	26	13	78	78	156
80	4	1204	295000	605000	68630	968630	40.41	165.75	62.68	268.84	50	25	150	150	300
120	6	1764	345000	705000	100550	1150800	47.26	193.15	91.83	333.22	73	36.5	219	219	438
150	7.5	2153	375000	765000	122720	1262700	51.37	209.59	112.07	373.03	89	44.5	267	267	534
200	10	2800	400000	820000	159600	1379600	54.80	224.66	145.75	425.21	115	57.5	345	345	690
240	12	3276	440000	895000	186800	1471800	60.27	245.21	170.59	476.07	135	67.5	405	405	810
480	24	5712	800000	1655000	325580	2780600	109.59	453.42	297.33	860.34	235	117.5	705	705	1410

Capital cost = Plant cost + (AAx Rs. 57 per l x 3.33) or plant cost = cap cost - 190xAA

Power Cost = 0.27233 Q, Where Q= 24X (AA, in m³) x 'c'/(0.2712 c + 2a) + 71.7 (AA vol, in m³)

@ 0.50/unit = 19.533x(AA volume, in m³)

(c=164 mg F/l; a = 5.2 mg F/l)

Table 17 continued
Columns 17 to 24 (See previous page for columns 1 to 16)

Power consumption per day Rs.0.50 per unit Rs.	Personnel [Supdt. Chem. (plants>80 m3/d) + Jr.Chemist and Electrician (for all capacity plants	Interest on capital @12% p.a per day Rs.	Maintenance @ 5% p.a per day Rs	Total cost of operation (col11+16+ 17+18+19+20)		Running cost of operation (col.16+17+18)	
				Total/day Rs.	Rs /m ³	Total/day Rs.	Rs. /m ³
17	18	19	20	21	22	23	24
3.23	78.90	190.49	79.37	532.20	53.20	122.93	12.29
6.29	78.90	203.39	84.75	606.88	30.34	164.99	8.25
12.31	78.90	214.00	89.17	724.28	18.11	247.21	6.18
23.52	144.66	318.45	132.69	1188.20	14.85	468.18	5.85
34.46	144.66	378.28	157.62	1486.20	12.38	617.12	5.14
42.06	144.66	415.13	172.97	1681.90	11.21	720.72	4.81
54.89	144.66	453.57	188.99	1957.10	10.18	889.35	4.45
63.99	144.66	483.88	201.62	2180.20	9.08	1018.70	4.25
111.57	144.66	914.17	380.90	3821.60	7.96	1666.20	3.47

TABLE 18 Summary Cost for Activated Alumina Pressure Type Defluoridation Plants of Various Capacities

Raw Water fluoride; 5.0 ± 0.2 mgF/l; Raw water Alkalinity 400 mg/l corresponding 'c' (mgF/l) to obtain on average 1 mgF/l in treated water = 164 mgF/l

Plant Capacity m ³ /day	Capital Cost including civil work Rs.	Daily Expenditure, Rs.				Total Daily cost of operation	Total cost of operation Rs /m ³	Running cost of operation Rs./m ³
		Depreciation +Interest + Maintenance	Personnel	Power	Chemical HCl for regeneration + NaOH for neutralising			
10	579400	409.27	78.90	3.23	40.8	532.20	53.20	12.29
20	618350	441.89	78.90	6.29	79.8	606.88	30.34	8.25
40	650910	477.07	78.90	12.31	156	724.28	18.11	6.18
80	968630	720.02	144.66	23.52	300	1188.20	14.85	5.85
120	1150600	869.08	144.66	34.46	438	1486.20	12.38	5.14
150	1262700	961.18	144.66	42.06	534	1681.90	11.21	4.81
200	1379600	1067.80	144.66	55.69	690	1957.10	10.18	4.45
240	1471800	1161.50	144.66	63.99	810	2180.20	9.08	4.25
480	2780600	2155.40	144.66	111.57	1410	3821.60	7.96	3.47

Power = $365 \times 18.431 c / (0.2712 c + 2a) = 20105$ Rs.

HCl/day = $8352 a / (0.2712 c + 2 a)$ Rs.; HCl @ Rs. 3/- per kg.

NaOH : 1/2 of HCl requirement (assumed) (for washing and regeneration)

NaOH reqt/day = $0.5 \times 2784 ax6 / (0.2712 c + 2a) = 8352 a / (0.2712 c + 2a)$

NaOH @ 6/-per kg.

-
- The output decreases significantly with progress of cycles. Within 40 cycles of operation, the capacity of activated alumina decreased rapidly.
 - The cost analysis on the basis of 40 cycles of operation reveals that the costs per m³ treated water are Rs. 8.38, Rs. 10.18 and Rs. 12.80 for test water basicity values of 4, 8 and 16 meq/l respectively, when the runs are terminated with 1 mg f/l in the effluent. The corresponding values for 2 mg F/l in the effluent are Rs. 7.38, Rs. 8.36 and Rs. 10.12. These does not include cost of NaOH for neutralisation.

ESSENTIAL INFORMATION REQUIRED ON ANY OTHER GRADE OF ACTIVATED ALUMINA TO DETERMINE ITS APPLICATION IN RURAL AREAS OF INDIA

a. Operating Characteristics

- Capacity Curves
- Exhaustion curves
- Exchange Capacity and corresponding regenerant requirement with concentration
- Theoretical regenerant quantity vs practical requirement per unit volume of activated alumina
- Backwash and rinse water quantity and rate of application
- Service loading rate
- Attrition losses and replacement requirement
- Anticipated cycles of operation before fluoride in treated water cannot be lower than 1 mgF/l
- Impact of variation of (Ca⁺⁺ + Mg⁺⁺ + Na⁺) bicarbonates to total electrolyte concentration, ion exchange capacity of the AA for Ca⁺⁺ and Mg⁺⁺ ions.

b) Waste Disposal

- Activated alumina regenerant Waste water quantity and quality
- Method and Cost of effluent treatment and/or disposal

c) Cost Aspects

- Activated alumina, cost Rs. per litre
- Capital cost of Plants capable to treat 10, 20, 30, 40, 60, 80 and 120 m³ per day of 5 mgF/l and 400 mg/l basicity raw water complete with regenerant, electricity, man-power and total raw water requirements
- Life expectancy of Plant and activated alumina

CURRICULUM FRAMES - WATER QUALITY TESTING AND DEFLUORIDATION OF DRINKING WATER - COURSE CONTENT (CLASS ROOM ORIENTED)

WATER QUALITY TESTING:

- Selection of sampling sites, facilities and sampling frequency
-

- Sampling procedures, containers and samples preservation

- Mineral analysis:

- a) pH
- b) Conductivity
- c) Dissolved Solids
- d) Total Alkalinity
- e) Total Hardness
- f) Calcium Hardness
- g) Chloride
- h) Sulphate
- i) Fluoride

Estimation of Fluoride in water samples and demonstration of Ion Selective Electrode Method

ALTERNATIVE APPROACHES FOR SAFE DRINKING WATER

- 1) Bringing water from a distance through laying pipe line - cost aspects - cut-off distance vis-a-vis defluoridation
- 2) Deepening tube wells for providing water with a fluoride content within acceptable limit along with other mineral content
- 3) Selection of Defluoridation Technologies
- 4) Adopt defluoridation
 - a) Domestic use
 - b) Fill & Draw systems for community
- 5) Field studies for defluoridation
 - a) Treatability study to validate technology for that water
 - b) Treatment flow sheet and design specifications
- 6) Demonstration of Technology /Field visits
- 7) Wastes generated by Defluoridation Technology and Disposal cost aspects
- 8) Performance Evaluation of Defluoridation Technology
 - a) Quality of defluoridated water (pH, fluoride and alkalinity)
 - b) Operation and Maintenance Aspects
 - c) Cost estimation based on O&M experience

TRAINERS (DISTRICT):

Participants' category:

- Medical Officers
- Supervisory Staff of Health Services
- Paramedical Workers/and Grass root-level workers.
- Water Quality testing laboratory personnel.
- Engineers/Public Health Engineers
- NGO's

WATER QUALITY TESTING AND DEFLUORIDATION OF DRINKING WATER

COURSE CONTENT (CLASS ROOM ORIENTED)

WATER QUALITY TESTING:

- Selection of sampling sites, facilities and sampling frequency
- Sampling procedures, containers and sample preservation
- Mineral analysis
 - (a) pH
 - (b) Conductivity
 - (c) Dissolved Solids
 - (d) Total Alkalinity
 - (e) Total Hardness
 - (f) Calcium Hardness
 - (g) Chloride
 - (h) Sulphate
 - (i) Fluoride
- Estimation of Fluoride in water samples and demonstration of Ion Selective Electrode Method

ALTERNATIVE APPROACHES FOR SAFE POTABLE WATER

- (i) Bringing water from a distance through laying pipe line-cost aspects-cut-off distance vis-a-vis defluoridation.

-
- (ii) Deeping tube wells for providing water with a fluoride content within permissive limit along with other mineral content.
 - (iii) Adopt defluoridation
 - (a) Domestic use
 - (b) Fill & draw systems for community
 - (iv) Related Approaches for defluoridation
 - (a) Treatability study to validate technology for that water
 - (b) Treatment flow sheet and design specifications
 - (v) Defluoridation Technologies
 - (vi) Wastes generated by Defluoridation Technology and disposal - cost aspects.
 - (vii) Performance Evaluation of Defluoridation Technology
 - (a) Quality of defluoridated water (pH, fluoride and alkalinity)
 - (b) Operation and Maintenance Aspects
 - (c) Cost estimation based on O & M experience
 - (viii) Demonstration of Technology/field visits

OTHER POINTS

- (i) The water sources be initially screened for conductivity, ensure their conformity with the guidelines of WM/BIS for drinking water requirements, and further analysis for mineral content as per guidelines provided in this Volume.

Water quality testing be undertaken only on those water sources that otherwise qualify WM/BIS guidelines
- (ii) The guidelines of WM/BIS for drinking water are rather rigid for arid and semi-arid zones in India. For small supplies which frequently are to be provided from individual wells or other ground water sources, the water quality guidelines of WM/BIS for drinking water may have to be relaxed in these areas particularly dissolved solids, fluoride, nitrate, chloride and sulphate. Obviously, in all instances everything possible should be done to safeguard health of consumers.
- (iii) Nalgonda technique is to be applied at domestic and community levels. The system is not recommended for Hand Pumps
- (iv) Other defluoridation technologies, such as Activated Alumina and Ion Exchange requires detailed field evaluation and validation and if found suitable and appropriate, may be considered for rural conditions in India.

PHYSICAL AND CHEMICAL STANDARDS PRESCRIBED BY THE MINISTRY. TEST CHARACTERISTICS FOR DRINKING WATER

Sl. No.	Substance or Characteristic	Requirement Acceptable Limit)	Undesirable Effect Outside the Acceptable Limit	Cause for Rejection in the Absense of Alternate Source	Methods of Test (Ref to IS)	Remarks
1	2	3	4	5	6	7
Essential Characteristics						
i	Colour (Units on Platinum Cobalt scale)	5	Above 5, consumer Acceptance decreases	25	3025 (Part4), 1983	Extended to 25 only if toxic substances are not suspected, in absence of alternate sources
ii)	Odour	Unobjectionable	--	Unobjectionable	3025 (Part 5), 1983	a) Test cold and when heated b) Test at several dilutions
iii)	Taste	Unobjectionable	--	Unobjectionable	3025 (Parts 7 and 8) . 1984	Test to be conducted only after safety has been established
iv	Turbidity, (Units on JTU Scale)	2.5	Above 2.5, Consumer Acceptance decreases	10	3025 (Part 10); 1984	
v)	pH value	7.0 to 8.5	Beyond this range the water will affect the mucous membrane and/ or water supply system	6.5 to 9.2	3025 (Part 11); 1984	
vi)	Total hardness (mg/l): (as CaCO ₃)	200	Encrustation in water supply structure and adverse effects on domestic use	600	3025 (Part 21); 1984	
vii)	Iron (as fe) mg/l	0.1	Beyond this limit Taste/appearance are affected, has adverse effect on domestic uses and water supply structures & promotes Iron bacteria	1.0	32 to 3025 : 1984	

Sl. No.	Substance or Characteristic	Requirement Acceptable Limit)	Undesirable Effect Outside the Acceptable Limit	Cause for Rejection in the Absense of Alternate Source	Methods of Test (Ref to IS)	Remarks
1	2	3	4	5	6	7
viii)	Chlorides (as Cl) (mg/l,	200	Beyond this limit, taste, corrosion& palatability are affected	1000	3025 (Part 32): 1988	
ix)	Residual, free chlorine, mg/l,Min.	0.2	--	--	3025(Part 26) : 1988	To be applicable only when water is chlorinated, to be tested at consumer end When protection against viral infection is required, it should be Min 0.5 mg/l
x)	Total Dissolved solids (mg/l)	500	Beyond this palatability decreases, may cause gastro intestinal irritation	1500	3025(Part 16): 1984	
xi)	Calcium (as Ca) (mg/l)	75	Encrustation In water supply structure and adverse effects on domestic use	200	3025 (Part 40): 1991	
xii)	Copper (as Cu) (mg/l)	0.05	Astringent taste, discoloration and corrosion of pipes, fittings and utensils will be caused beyond this	1.5	36 of 3025 : 1964	
xiii)	Manganese (as mn) (mg/l,)	0.05	Beyond this limit taste/appearance are effected, has adverse effect on domestic uses and water supply structures	0.5	35 of 3025 : 1964	

Sl. No.	Substance or Characteristic	Requirement Acceptable Limit)	Undesirable Effect Outside the Acceptable Limit	Cause for Rejection in the Absence of Alternate Source	Methods of Test (Ref to IS)	Remarks
1	2	3	4	5	6	7
xiv)	Sulphate (as SO ₄) (mg/l)	200	Beyond this causes gastro intestinal irritation when magnesium or sodium are present	400 (See col,7)	3025 (Part 24) : 1986	May be extended up to 400 provided magnesium (asMg) does not exceed 30.
xv)	Nitrate (as NO ₃) (mg/l)	45	Beyond this methaemoglobinemia takes place	45	3025 (Part 34): 1988	
xvi)	Fluoride (as F)	1.0	Fluoride may be kept as low as possible. High fluoride may cause fluorosis	1.5	23 of 3025 : 1964	
xvii)	Phenolic compounds (as C ₆ H ₅ OH), (mg/l)	0.001	Beyond this, it may cause objectionable taste and odour	0.002	54 of 3025 : 1964	
xviii)	Mercury (Total as Hg) (mg/L), Max	0.001	Beyond this, the water becomes toxic	0.001	Mercury ion analyser	To be tested when pollution is suspected
xix)	Cadmium as Cd), (mg/l)	0.01	Beyond this, the Water becomes toxic	0.01	(see Note)	To be tested when pollution is suspected
xx)	Selenium as Se) (mg/l)	0.01	Beyond this, the Water becomes toxic	0.01	28 of 3025 1964	To be tested when pollution is suspected
xxi)	Arsenic as As.) (mg/l)	0.05	Beyond this, the Water becomes toxic	0.05	3025 (Part 37), 1988	To be tested when pollution is suspected
xxii)	Cyanide as CN), mg/l	0.05	Beyond this limit, the water becomes toxic	0.05	3025 (Part 27) : 1986	To be tested when pollution is suspected

Si No.	Substance or Characteristic	Requirement Acceptable Limit)	Undesirable Effect Outside the Acceptable Limit	Cause for Rejection in the Absence of Alternate Source	Methods of Test (Ref to IS)	Remarks
1	2	3	4	5	6	7
xxiii)	Lead as Pb mg/l	0.1	Beyond this limit, The water becomes toxic	0.1		To be tested when pollution/plumbo-solvency is suspected.
xxiv)	Zinc as Zn mg/l	5	Beyond this limit, it can cause astringent taste and anopalescence In waters	15	39 of 3025 : 1964	To be tested when pollution is suspected
xxv)	Anionic detergents as MBAS mg/l	0.2	Beyond this limit, it can cause a light froth In water	1.0	Methylent-blue extraction method	To be tested when pollution is suspected
xxvi)	Chromium (as Cr ⁶⁺), (mg/l)	0.05	May be carcinogenic above this limit	0.05 0.05	38 of 3025 : 1964	To be tested when pollution is suspected
xxvii)	Polynuclear aromatic hydrocarbons (as PAH),	0.2	May be carcinogenic	0.2 mg/L		
xxviii)	Mineral oil (mg/L)	0.01	Beyond this limit, Undesirable taste & odour after chlorination takes place	0.3 0.3	Gas chromatographic method	To be tested when pollution is suspected
xxix)	Radioactive Substances:					
	a) Alpha emitters	3 pci/l		-	3Pci/l	
	b) Beta emitters -	30 pci/l		-	3 pci/l	
xxx)	Alkalinity mg/l, Max	200	Beyond this limit taste becomes unpleasant	600	13 of 3025 : 1964	

*"Achievement requires character.. discipline.. united action and the
readiness to sacrifice the individual self for the larger cause"*

Nehru

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This job has been executed by :



CREATIVE MASS COMMUNICATION

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