DEFLUORIDATION TREATMENT TECHNIQUES WITH COST ANALYSIS

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

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

Nalgonda Technique involves additional of aluminium salts, lime and bleaching powder followed by rapid mixing, flocculation sedimentation, filtration and disinfection. Aluminimum salt may be added as aluminium sulphate or aluminium chloride or combination of these two. Aluminium salt is only responsible for removal of fluoride from water. The dose of Aluminium salt increases with increase in the fluoride and alkalinity levels of the raw water. The selection of either aluminium sulphate or aluminium chloride also depends on sulphate and chloride contents of the raw water to avoid exceeding their permissible limits. The dose of lime is empirically $1/20^{th}$ that of the dose of aluminium salt. Lime facilitiates forming dense floc for rapid setting. Bleaching powder is added to the raw water at the rate of 3mg/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 combination of several unit operations and process incorporating rapid mixing, chemical interaction, flocculation, sedimentation, filtration, disinfection and sludge concentration to recover water and aluminum salt . (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.

Test Water Fluorides mg F/l	**Test Water Alkalinity, mg CaCO3/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 polyalumenic species formed in the system. The interaction between fluoride and aluminium species attains equilibrium.

- The chemical reaction involving fluorides and aluminium species is complex. It is a combination of polyhydroxy aluminium species complexation with fluorides and their adsorption on polymeric aluminium hydroxides (floc). Besides fluorides, turbidity, colour, odour, pesticides and organics are also remived. The bacterial load is also reduced significanly. All these are by adsorption on the floc.
- Lime or sodium carbonate ensures adequate alkalinity for effective hydrolysis of aluminium salts, so tht resideual aluminium dose not remain in the treated water.
- Simultaneous disinfection is achieved with bleaching powder and also keeps the system free from undesirable biological growths.

1. 3 Al2 (SO4) 3. 18 H2O NaF + NA2 CO3

[5Al (OH)3. Al(OH) 2 F] + 9 Na SO4 + NaHCO3 + 8 CO2 + 45 H2O

2. 3 Al2 (SO4) 3. 18 H2O NaF + 17 NaHCO3

[5Al (OH)3. Al(OH) 2 F] + 9 Na SO4 + NaHCO3 + 17 CO2 + 54 H2O

Sedimentation

Permits settleable floc loaded with fuorides, 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 predicated. Hence, various factors which influence sedimentation in relation to design and operation rely largely on experience.

Filtration.

Rapid gravity sand filters are sggested to receive caugulated 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.

Disinffection 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 m^3/d.
- Applicable in batch as well as in continuous operation to suit needs.
- Simplicity of design, construction, operation and maintenance.
- Local skills could be readily employed.
- Highly efficient removal of fluorides from 1.5 to 20 mg F/1 to desirable levlels.
- 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/1 and 400 mg/l alkalinity which requires 600 mg/l alum dose.
- Provides deluoridated 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 becomes a cause for rejection or adoption of deslination. 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 treater water pH between 6.5 and 8.5.
- Raw water fluorides ranging from 1.5 to 20 mg F/1.

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 withdrawl of treater 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 wter. 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 of consumption. The settled sludge is discarded. Approximate volumes of alum solutions for defluoridation of 40 L of water are given in Table.2.

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/1) of fluoride in water at various alkalinity and fluoride levels.

Test Water Fluorides mg F/l	**Test Water Alkalinity, mg CaCO3/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 l m depth equipped with a hand operated stirring mechanisms. The unit is filled with raw water and similar defluoridation operation is performaed 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 100 g Alumina ferric (commerical 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 aolution 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.

FILL - AND DRAW DEFLUORIDATION PLANT FOR SMALL COMMUNIT]

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 standposes. The settled sludge is discarded. Plant dimensions for various populations are given in Table 3.

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 teatment (grams, alumina ferric, IS: 299-1962)= (Water Volume, m^3) x (Alum dose of that particular water, mg/l)

Fresh bleaching powder (grams per batch) = 3 x (Water volume, m^3)

The notable features are:

- 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 re 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 plat 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 Nalgonda Technique is designed for removal of excess fluoride from water, which is most suitable for Rural Water Supply (Fig. 6).

BComponents 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 electricty.

- Each reactor will be of 10, 20, or 30 m^3 capacity.
- The capacity of raw water pump will be sufficient to fill up the reactors within an hour.
- The defluoridation water from the sump well will be pumped to the elevated service reservoir and distributed by gravit through stand posts and house connections.
- The capacity of the elevated service reservoir will be half of the capacity of the sump well.

Reactors.

The raw water from the soruce is pumped to the reation-cum-sedimentation tank which is referred to us reactor (Fig.7). The reactors are of HDPE, Ferro-cement of RCC, circular in shape with dished bottom of epoxy coating (in cause of RCC). The top position of the reactor is covered with a sturdy lid. A manhole with al lid is provided for inspection and to pour chemicals intor 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 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, oujtlet pipe, sludge drain, 50 cm. dia, or 50 cm x 50 cm manhole for inspection and adding chemicals; and agitator assembly (details given separtely)
Capacity of Reactor	- 10.20 Or $30m^3$
Setting time	- 2 to 44 hours
Other aspects	- Each reactor needs 4-6 hrs for complete operation.

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 colled induction motor of specified rating, 3 phase, 50 Hz, AC, 1440 RPM with 415 ± 6% voltage fluctuation.

Material of paddles - Mild steel

Width of paddles - $^{1}/_{3}$ dia, of the 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	-	3 HP for 10 m^3 Reactor
		5 HP for 20 m^3 Reactor
		7.5 HP for 30 m^3 Reactor
Make	-	Elecon/Radicon

- The gears are hobbed, hardened and lapped. The output shaft of the gear box can be rotated in either direction.
- The gear box is equipped with
  - CI bush intermediate support for agitator shaft
  - Input and output cushioned drive type flexible couplings
  - Agitator shaft top end coupling with the output of the gear box.

Platform-cum-walkway

A suitable sturdy M.S.platform with sturdy rallings across the sides supported over horizontal girders is provided at a height of 20cm 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 atleast 6 adults. Alumand lime solution tanks are kept on this platform for adding into the raw water.

Each reactor is provided with a sturdy ladder with rallings 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 reactangular 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 m^3

Table 5: Dimensions of Elevated Service Reservoir for Various Capacities

Capacity of ESR m^3	Diameter m	Height 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 decondition of defluoridated water, the settled sludge with about 1% (W/V) solids is discharges once every day over sludge drying beds. The number and size of beds for various plant capacities are give in Table 6.

Table 6: Sizes of Sludge Drying Beds.

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

Electric Panel Room

The electric panel room 2.5 x 3.0, 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 Electrical 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 time, 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, m3/d	Quantity of Chemicals (kg)			Area Required for storage of Chemical m2”	Size of Chemical House, 1 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	6	3.0 x 3.0 x 3.0
100	10000	1000	50	10	3.0 x 3.0 x 3.0
120	20000	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 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 m3/day	Configuration of Reactors			Personnel		
	Capacity m3	Number of Reactors	Number of operations per day	Supervisor	Chemist	Helpers
10	10	1	1	NIL	1	2
20	10	1	2	NIL	1	2
40	20	1	2	NIL	1	2
60	20	1	3	NIL	1	4
80	20	2	2	NIL	1	4
120	20	2	3	1	1	6
180	30(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 IIDPE reactors. The total estimates also include pump house-cum-chemical house, treated water sumps, chemical solution tanks, interconnecting piping, valves and fixtures and electrical items.

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

The considerations for calculating the costs are as follows:

Depreciation	5%	per annum on capital cost
Maintenance	5%	per annum on capital cost

Interest	12%	per annum on capital cost

Cost of power	Rs.0.50 per unit
Cost on 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.

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

Raw Water Fluoride = 5 mg F/1
Raw water alkalinity = 400 mg CaCO3/1

Plant Capacity m3/day	Capital cost	Annual Expenditure				Total amount cost of operation	Total cost of operation	Trai ope
Rs.	Rs.	Depreciation + Interest + Maintenance Rs.	Personnel Rs.	Power Rs.	Chemicals Rs.	Rs.	Rs./m3	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	15,680	18,200	1,56,120	10.69	1.64
60	4,21,000	92,620	61,200	8,250	27,300	1,89,370	8.64	1.62
80	6.77.000	1,48,940	61,200	11,000	36,400	2,57,540	8.82	1.62
120	6,77,000	1,48,940	1,06,800	16,130	54,600	3,26,440	7.45	1.61
180	8,85,000	1,94,700	1,06,800	17,410	81,900	4,04,650	6.16	1.57
240	11,20,000	2,46,400	1,06,800	31,890	1,09,200	4,94,300	5.64	1.61
360	12,31,000	2,70,820	1,06,800	44,725	1,63,800	5,86,145	4.46	1.59
480	15,55,000	3,42,100	1,28,400	59,250	2,18,400	7,48,150	4.27	1.58

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

Raw Water Fluoride = 5 mg F/1
Raw water alkalinity = 400 mg CaCO3/1

Plant Capacity m3/day	Capital cost	Annual Expenditure	Total amount cost of operation	Total cost of operation	Trainin operati

Rs.	Rs.	Depreciation + Interest + Maintenance Rs.	Personnel Rs.	Power Rs.	Chemicals Rs.	Rs.	Rs./m3	Rs./m
10	3,81,000	83,820	39,600	2,510	4,550	1,30,480	33.75	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	1,227,380	61,200	8,250	27,300	2,24,130	10.23	1.62
80	9,48,000	2,18,560	61,200	11,000	36,400	3,17,160	10.86	1.62
120	9,48,000	2,08,560	1,06,800	16,130	54,600	3,86,090	8.81	1.61
180	13,77,000	3,02,940	1,06,800	17,410	81,900	5,09,050	7.75	1.57

The total operational cost ranges between Rs.33.70/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 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, m3/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 calculation 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 mm2/g(min)
Bulk density	:	0.80 – 0.85 Jg.1
Bore 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 p**H,** the contact time, the ratio of adsorbate (fluoride ion) to absorbent (activated alumina) on the rate of fluoride removal in batch operations was studies. 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 p**H** 9 to 4;

(iii) The adsorption fluoride from water is relatively more rapid the more dilute the solution;

(iv) The adsorption isotherms poorly conform to Freundilich and Langmuir isotherms;

(v) by employing **BET** equation and intricate analysis, very good linerisation is observed for all reaction times at various p**H;**

(vi) the rate of adsorption of fluoride increases with the decreasing p**H** of the solution;

(vii) although activated alumina is a good adsorbent for fluoride in water with fairly good capacity the slowess 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 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 HCI solutions. Forty cycles were carried out for each basicity 4, 8 and 16 meq/I in test water. The deluforidation 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.

<u>The Water Characterists</u>

P**H**	**:**	**7.6 – 8.5**

Fluorides : 5.2 + 0.2 mg/1 (a)

Basicity : 400 mg/1

Capacity (corresponding) : Max.315 mg F/1

To values 'a' & 'b') Min. 143 mg F/1

Ave.164 mg F/1

COMPONENTS OF AA DEFLUORIDATION PLANT – COST ASPECTS (1991 BASE) – (2.82M3 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 network 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/10m Head)

Rs.4,00,000

2.81 m 3 of Activated Alumina (AA) Rs.1,60,000

The ultimate capacity of the AA for fluoride removal studied at 4, 8, 16 meq/1 basicity has been calculated as 1503, 1168 and 662 mg F/1 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 realisation at various basicities and at different cycles of operation.

	Basicity, meq/L					
	4		8		16	
Breakkthrough level, mg F/1	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 mg F/1 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: B **Overall performance of columns in 40 cycles of operation**

	Basicity, meq/L					
	4		8		16	
Breakkthrough level, mg F/1	1	2	1	2	1	2
Duration of operation, hr	727	1292	587	880	308	575
HCL/1	268	151	332	222	632	339

The HCL requirements for treating 1 m3 of water containing around 5.4 + 0.2 mg F/1 and upto a fluoride break-through level of 1 mg F/L were 268, 332 and 632 g too 4, 8 and 15 meq/1 basicity, respectively: the corresponding values for 2 mg F/1 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 : 5.2 + 0.2 say 'a'

Basicity : 4 or 8 or 16 say, 'b'

Capacity of AA at 'b' : c mg F/1 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/hr. water was considered.

a. Capital Cost

Civil works	**Rs.4,00,000**
Plant	**Rs.8,20,000**
2.81 m3 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/1 and 'b' meq/1 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

Length of run between Successive regeneration $= \dfrac{2.82\,(c/a)\,m3}{10.4\,m3} = 0.2712\,(c/a)$ **hrs.**

Time required per regeneration is 2 hours.

Number of regenerations per 24 hours working day, allowing 2 hrs. per regenerations $= \dfrac{24a}{0.27120 + 2a}$

Quantity water treatable in 24 hrs. working allowing for regeneration $= \dfrac{24a}{0.2712\ c + 2a} \times \dfrac{2.82\ c}{a}$

$= \dfrac{67.68\ c}{0.2712\ c + 2a}\ m3$

Acid require ent per regeneration is 4 bed volumes of 0.1 M HC1 or 2.82 m3 AA3 x 4 x 0.1m = 1.28 m3 or 0.09803m3 Con HC1 or 116 Kg. HC1.

Cone HC1 requirement per day is

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

Cost of HC1 per day at Rs.3/kg is $= \dfrac{67.68\ c}{0.2712\ c + 2a}$ **in Rs.** **(1)**

Pumping costs of Qm3 against a total head of 20m to ESR through the plant (including friction loses and at Re.0.50/unit):

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

Interest on capital at 12% per annum on Rs.13,80,000 (in Rs. 1,65,600)

= Rs.453.70/day **(3)**

Maintenance at 5% on civil works, and plant per annum on

In Rs.13,80,000 (i.e. Rs.69,000) = Rs.189.04/day (4)

d. **Manpower per annuam**

Superintendent-cum-chemist	**1**	**Rs.24.000**
Junior chemist	**1**	**Rs.18,000**
Watchman/labour	**3**	**Rs.10,800**
Total	**=**	**Rs.52,000**
	=	**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) =

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

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

Cost of treatment per m3 = K/Q = 10776 a + 384 c

------------------------- in Rs.

67.68 c

In this study 'a' has a fixed value of 5.2 + 0.2 mg F/1. Therefore, cost of treatment per m3; K/Q will bey (56,035 + 348c)/67.68c; which 'c' is a variable, i.e. capacity of AA at different basicities. The values are shown in the Table 15.

Table 15: **Average capacity values corresponding to various basicities**

Basicity	**Capacity (c), mg F/1 Medium, corresponding to**					
	1 mg F/1			**2 mg F/1**		
	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**

Capital cost per m3 = 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 480m3/d and for raw water characteristics, F = 5.2+0.2 mg/1 and 400 mg/1 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 16: Cost Analysis at 4, 8, 16 meq/1 Basicity for 5.2 + 0.2 mg. F/1 Test Water

Basicity of test water meq/1	**Fluoride, level in effluent, mg**	**Quantity of water treated per**	**Quantity of water treated per 24 hour working allowing 2h**	**Cost of treatment per m3 including depreciation, acid,**	**HCI (11.5M) required**	**Runni cost operati**

	F/1	regeneration at a maximum rate of 10.4 m3/hm3	per regeneration, m3	power, staff, interest on capital and maintenance, Rs.	per day kg.	per r Rs.
4	1 2	204.8	226.5	7.33	129	1.98`
8	1 2	89.1 143.7	202.3 218.0	10.18 8.26	264 176	4.19 2.69
16	1 2	58.6 90.0	184.2 202.7	12.80 10.12	365 261	6.21 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/1 and 400 mg/1 basicity (total columns are 24)

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

Plant capacity m3/D	M3/D appx	AA litres	Capital cost towards (in Rs.)				Depreciation/day (in Rs.)				Chemica
			Civil works	Plant	AA	Total	Civil works 5% p.a.	Plant 10% p.a.	Medium 33.3% p.a.	Total	HC1 Kt
1	2	3	4	5	6	7	8	9	10	11	12
10	0.5	165	185000	385000	9400	579400	25.34	105.48	8.53	139.41	6.8
20	1	322	200000	400000	18350	618350	27.40	109.59	16.76	153.75	13.3
40	2	630	200000	415000	35910	650910	27.40	113.70	32.80	173.90	26
80	4	1204	295000	605000	68630	968630	40.41	165.75	62.68	268.84	50
120	6	1764	345000	705000	100550	1150600	47.26	193.15	91.83	333.22	73
150	75	2153	375000	765000	122720	1262700	51.37	209.59	112.07	373.03	89
200	10	2800	400000	520000	159600	1379600	54.80	224.66	145.75	425.21	115

240	12	3276	440000	895000	186800	1471800	60.27	245.21	170.59	476.07	135	
480	24	5712	800000	1655000	325580	2780600	109.59	453.42	297.33	860.34	235	

Table 17 continued

Columns 17 to 24 (see previous page for columns 1 to 16)

Power consumption p-er 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 (col 11+16+17+18+19+20)		Runni (col.16
				Total/day Rs.	Rs./m3	Total/d
17	18	19	20	21	22	23
3.23	78.90	190.49	79.37	532.20	53.20	122.93
6.29	78.90	203.39	84.75	606.88	30.34	164.99
12.31	78.9	214.00	89.17	724.28	18.11	247.21
23.52	144.66	318.45	132.69	1188.20	14.85	468.18
34.46	144.66	378.28	157.62	1486.20	12.38	617.12
42.06	144.66	415.13	172.97	1681.9	11.21	720.72
54.69	144.66	453.57	188.99	1957.10	10.18	889.35
63.99	144.66	483.88	201.62	2180.20	9.08	1018.7
111.57	144.66	914.17	380.90	3821.60	7.96	1666.2

Table 18: **Summary cost for activated alumina pressure type defluoridation plants of various capacities**

Raw water fluoride; 5.0 + 0.2 mg F/1; Raw water alkalinity 400 mg/1 corresponding 'c' (mg F/1) to obtain on average 1 mg F/1 in treated water = 164 mg F/1.

Plant capacity	Capital cost including	Daily expenditure, Rs.	Total daily cost of operation	Total cost

capacity m3/day	including civil work Rs.	Depreciation + Interest + maintenance	Personnel	Power	Chemical HC1 for regeneration +NaOH for neutralising	of operation	operation Rs.
10	579400	409.27	78.90	3.23	40.8	532.20	53.20
20	618350	441.89	78.90	6.29	79.8	606.88	30.34
40	650910	477.07	78.90	12.31	156	724.28	18.11
120	1150600	869.08	144.66	34.46	438	1486.20	12.38
150	1262700	961.18	144.66	42.06	534	1681.90	11.21
200	1379600	1067.80	144.66	55.69	690	1957.10	10.18
240	1471800	1161.50	144.66	63.99	810	2180.20	9.08
480	2780600	2155.40	144.66	111.57	1410	3821.60	7.96

Power = 365 x 18.431 c/ (0.2712c + 2a) = 20105 Rs.

HC1/day = 8352a / (0.2712c+2a) Rs.HCI @ Rs.3/- per kg.

NaOH: ½ of HCI requirement (assumed) (for washing and regeneration).

NaOH reqt/day = 0.5 x 2784a x 6/(0.2712c + 2a) = 8352a / (0.2712c = 2a).

NaOH @ Rs.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 12.80 for test water basicity values of 4,8 and 16 meq/1 respectively, when the runs are terminated with 1 mg F/1 in the effluent. The corresponding values for 2 mg F/1 int eh 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 mg F/1.**
- **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.**

- **Activated alumina, cost Rs.per litre.**
- **Capital cost of plants capable to treat 10, 20, 30, 40, 60, 80 and 120 m# per day of 5 mg F/1 and 400 mg/1 basicity raw water complete with regenerant, electricity, manpower and total raw water requirements.**

Life expectancy of plant and activated alumina.