CHAPTER III

DEVELOPMENT OF AN INDIGENOUS TECHNOLOGY BASED ON ACTIVATED ALUMINA
CHAPTER III

III.1 INTRODUCTION

It has been concluded in the chapter II of this thesis that among the four adsorbent materials studied, viz. magnesium oxide, activated alumina, tricalcium phosphate and bone charcoal, activated alumina wins over the other three for the practical defluoridation purposes. In this chapter the experiments related to the development of defluoridation unit at domestic level for a 3 mg/l fluoride water, using activated alumina are presented in detail. These experiments ultimately resulted in developing a defluoridation unit at domestic level, the design and other specifications of which are given. The details regarding the field studies in a fluorosis - affected village nearby Gandhigram are also discussed,

III.2 MATERIALS AND METHODS

III.2.1 Activated alumina

The activated alumina, Grade G-87 was obtained from I.P.C.L., Vadodara. This alumina is made by I.P.C.L. for a different purpose and the particle size is so high, that it cannot be used as such for defluoridation purposes. Therefore from this material, various grades of activated alumina with lower
particle sizes were prepared with the help of a mechanical grinder and the Scientific sieves (ELITE - make) of various mesh-sizes, the details of which were already given in the chapter II under section 11.2-2-2-of this thesis.

Several grades were discarded by the trial and error method itself, taking into consideration the defluoridation capacity of the material and the rate of flow of water through the bed of activated alumina. Ultimately, three different particle sizes were selected for further investigation with an aim to select the most suitable one among them for use in the defluoridation unit.

The particle sizes of the three different grades of activated alumina studied, are as follows.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Grade No.</th>
<th>Particle size of activated alumina (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>I</td>
<td>&gt; 300 &lt; 355</td>
</tr>
<tr>
<td>2.</td>
<td>II</td>
<td>&gt; 150 &lt; 300</td>
</tr>
<tr>
<td>3.</td>
<td>III</td>
<td>&gt; 125 &lt; 150</td>
</tr>
</tbody>
</table>

Table III.1 Particle size of activated alumina selected
III.2.2 Column experiments for determination of rate of flow of water through alumina bed

The column experiments were carried out in order to find out the variation of the rate of flow of water through the packed bed of activated alumina with a change in the height of the bed keeping the height of the water column above the bed $a_1$ constant. These experiments were performed (with each of the three grades of alumina) at three different heights viz. $20$, $25$, and $30$ cm of the activated alumina column.

The diameter of the column used was $3.7$ cm and perfectly dried alumina of each grade was used in the experiments.

The height of the water ($3$ mg/l fluoride) column above the activated alumina bed was kept constant by continuously $0<1c(in^3mg/l$ fluoride water from a reservoir at the same rate matching with the rate of flow of water through alumina bed.

Water was collected in each case for exactly $1$ hour and the volume of water collected was measured with a measuring cylinder of $1$ litre capacity.
III.2.3 Column experiments for determination of defluoridation capacity

The defluoridation capacities of the three grades of activated alumina were determined by column experiments, fixing the height of the column of alumina as 25 cm. The input water with 3 mg/l fluoride and with an alkalinity of 432 mg/l was actually selected from a fluorosis-affected village, Kolinjipatty, situated nearby Gandhigram after carefully analysing various drinking water sources of that village for fluoride concentration by the fluoride electrode essentially in the same manner as described in the chapter II under section II.2.3.1 of this thesis. The same water was obtained in large volume and used in all these experiments.

The concentration of fluoride in output water was monitored periodically and defluoridation experiments were continued till the output water fluoride did not exceed 1 mg/l which is the tolerance limit as prescribed by the Bureau of Indian Standards.
The defluoridation capacity was calculated in a simple way as follows.

1. Concentration of fluoride in input water = \(3 \text{ mg/l}\)
2. Volume of water collected till the fluoride in output water did not exceed 1 mg/l = \(V \text{ litres}\)
3. Concentration of fluoride in output water = \(1 \text{ mg/l}\)
4. Total fluoride removed = \((3-1)V = 2V \text{ mg}\)
5. Weight of activated alumina packed in the column = \(W \text{ kg}\)
6. Defluoridation capacity of activated alumina = \(\frac{2V}{W} \text{ mg F}^-/\text{kg}\)

III.2.4 Column experiments for regeneration of alumina

Regeneration of exhausted alumina was carried out with two different regenerant solutions, viz. 2% sodium hydroxide and 2% hydrochloric acid.

The solution of regenerant was taken in a reservoir, connected to the column through a plastics tube. The regenerant solution was allowed to pass through the column of the activated alumina continuously and aliquots of the output solution were periodically analysed for fluoride after neutralising them with 2% sodium hydroxide solution each time. The regeneration process was continued till it was evident from
the fluoride analysis data that no further elution of fluoride was possible.

Calculation of regeneration capacity of the regenerant

1. Fluoride adsorbed on activated alumina = \( W_1 \text{ mg} \)

2. Fluoride that could be eluted = \( W_2 \text{ mg} \)

3. Weight of the regenerant used = \( W \text{ kg} \)

4. Elution capacity of the solution = \( \frac{W_2}{W} \text{ mg F}^{-1}/\text{kg} \)

5. Regeneration capacity = \( \frac{\text{Volume of the bed regenerated (m}^3\text{)}}{\text{Weight of the regenerant used (kg)}} \text{ m}^3/\text{kg} \)

III.3 RESULTS AND DISCUSSION

III.3.1 Results of rate of flow of water

Results of the experiments on determination of rate of flow of water through the activated alumina column, at various heights of the column are given in table III.2 below.
Table III.2 Rate of flow of water through activated alumina

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Grade No. of activated alumina</th>
<th>Particle size (microns)</th>
<th>Height of the alumina column (cm)</th>
<th>Rate of flow of water through alumina column (litres/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I</td>
<td>&gt; 300 &lt; 355</td>
<td>20</td>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>25</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>2. II</td>
<td>&gt; 150 &lt; 300</td>
<td>20</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>25</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>3. III</td>
<td>&gt; 125 &lt; 150</td>
<td>20</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>25</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

These results indicate that there is a significant change in the rate of flow of water with a change in particle size as well as in the height of the column. The rate of flow is found to increase in the order with an increase in particle size because, the pore volume of the bed increases with increasing particle size. There is a decrease in rate of flow with increase in the height of the bed because the resistance offered by the bed itself increases with the increase in the
height. Selection of a suitable height of the adsorbent column is essential before we design any defluoridation unit because of two reasons.

(i) A minimum contact time is necessary between the fluoride and activated alumina particles as discussed in detail in chapter II of this thesis. (ii) On the other hand, the rate of flow should not be too low in which case there will be problem of acceptability of the design by the users.

Thus, the rate of flow depends both on the particle size and the height of the column.

III.3.2 Results of defluoridation capacity

The results of defluoridation capacities of the three grades of activated alumina are given in table III.3 below.

Table III.3 Defluoridation capacity of the three grades of activated alumina

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Grade No.</th>
<th>Particle size (microns)</th>
<th>Defluoridation capacity (mg F⁻/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Grade I</td>
<td>&gt; 300 &lt; 355</td>
<td>960</td>
</tr>
<tr>
<td>2.</td>
<td>Grade II</td>
<td>&gt; 150 &lt; 300</td>
<td>1140</td>
</tr>
<tr>
<td>3.</td>
<td>Grade III</td>
<td>&gt; 125 &lt; 150</td>
<td>1220</td>
</tr>
</tbody>
</table>
These results indicate that there is increase in defluoridation capacity in the order, grade I < grade II < grade III as expected. These values are higher than the defluoridation capacity of activated alumina A.C.C. grade G-80, reported to be 450 mg F⁻/kg in the literature (90). These values are less than the corresponding values reported in the chapter II of this thesis for activated alumina. The difference can be explained in terms of the fact that

1. the particle sizes used here are much higher than those used in laboratory studies

2. the sample used here is of commercial grade while the samples used in laboratory studies are of LR grade

III.3.3 Discussion and the final choice

Out of the three grades, grade III showed somewhat higher defluoridation capacity but with this grade the rate of flow of water is lowest. On the other hand, for the grade I the rate of flow of water is highest but it suffers from the disadvantage of having lowest defluoridation capacity among the three. As both the factors viz. defluoridation capacity and rate of flow of water are equally important (none of the two can be given preferential treatment over other), it was felt reasonable to select the grade II which has good defluoridation
capacity as well as good pore volume to give the necessary rate of flow of water.

III.3.4 Results of regeneration experiments

The results of regeneration experiments with 2% hydrochloric acid and 2% sodium hydroxide solutions are given in table III.4

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Regenerant used</th>
<th>Regeneration capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>2% HCl</td>
<td>$2.2 \times 10^{-2}$ m$^3$ of alumina/kg of HCl</td>
</tr>
<tr>
<td>2.</td>
<td>2% NaOH</td>
<td>$1.8 \times 10^{-2}$ m$^3$ of alumina/kg of NaOH</td>
</tr>
</tbody>
</table>

It is clear that among the two regenerants viz. 2% hydrochloric acid and 2% sodium hydroxide, hydrochloric acid has higher regeneration capacity. Moreover the cost of hydrochloric acid/kg is much less than that of sodium hydroxide/kg. Therefore, hydrochloric acid was selected as regenerant and 2% hydrochloric acid is recommended for all the regeneration purposes.
III.3.5 Design and specifications of the unit at domestic level

Based on the results obtained in III.3.3, activated alumina grade II with the particle size $> 150 < 300$ microns was finally selected. Using this material the height of the column has to be finalised. Secondly, the quantity of the activated alumina to be taken in the unit is to be decided taking into account the cost factor also. Several trials were made with different quantities of activated alumina in stainless steel cylindrical columns of different dimensions. The most optimum dimensions of the column were found to be as follows,

i) Radius of the column = 5 cm

ii) Height of the column = 25 cm

With these dimensions of the column, the volume of the activated alumina bed comes to be 1.964 litres which accommodates about 2 kg of the material.

Using this stainless steel cylindrical column with the dimensions of 5 cm radius and 25 cm height, attempts were then made to develop a suitable design of the unit with the provision for the input water reservoir at the top and the treated water collector at the bottom.

The radius of the column is such that a vertical three container design keeping the column in the middle,
reservoir for input water at the top and the collector for treated water at the bottom is not easily acceptable by the users. Acceptability of any model by the users is the most important criterion for the success of any technology. Being-conscious of this point, we surveyed the various water filters available in the market which are already accepted by the people. The objective of the survey is whether we can fit in our design into the already accepted model. After several attempts, it was possible to attach the column to the input reservoir of the existing filter itself. The design and the specifications of the defluoridation unit developed are shown in Fig.III.1.

The capacities of the various components of the unit are as follows.

1) Input reservoir capacity = 12 lit.
2) Column capacity = 1.964 lit. $\pm$ 2 kg of activated alumina
3) Capacity of treated water = 13 lit,

Details regarding defluoridation of water with this unit.

- Rate of flow of water = 3 lit./hr
- Input water fluoride = 3 mg/l
- Output water fluoride = 1 mg/l
- Defluoridation capacity of the material = 1.140 mg/kg
Fig. III.1  DEFLUORIDATION UNIT USING ACTIVATED ALUMINA
FIG.III.2 Defluoridation unit at domestic level based on activated alumina
FIG.III.3 Stainless column inside which activated alumina is packed is shown
* Frequency of regeneration = 3 months

The frequency of the regeneration of the material is based on the calculations shown below

fluoride removed from each litre of water = 3 - 1 = 2 mg

Defluoridation capacity for 2 kg of the material = 1140 x 2 = 2280 mg

Volume of water (3 mg F⁻/l) that can be defluoridated with 2 kg of activated alumina = \frac{2280}{1140} = 2 lit.

At the rate of consumption of 12 lit/day, for a family of three to five, exclusively for drinking and cooking purposes, the material gets exhausted only after 95 days that is, approximately after 3 months.

III.3.6 Cost analysis

III.3.6.1 Regeneration cost for every three months or cost of defluoridation of water

a. Cost of hydrochloric acid

Regeneration capacity of hydrochloric acid = 2.2 x 10⁻² m³ of alumina bed/kg of hydrochloric acid

The volume of the alumina bed = 1.964 lit.

= 1.964 x 10⁻³ m³
Quantity of hydrochloric acid required for regeneration of $1.964 \times 10^{-3}$ m$^3$ of activated alumina

\[
\begin{align*}
1.964 \times 10^{-3} \text{ m}^3 \times 1 \\
2.2 \times 10^2 \text{ m}^3
\end{align*}
\]

\[= 0.089 \text{ kg}\]

At the rate of 40 Rs/kg for LR hydrochloric acid, the cost of hydrochloric acid used for regeneration works out to be $0.089 \times 40 = Rs. 3.56$

b. Cost of alkali and deionised water

The excess acid in the bed has to be neutralised with dilute alkali solution and then washed with enough quantity of deionised water till the output water does not show any alkalinity. The cost of alkali and deionised water = Rs. 0.44

c. Charge of skilled labour

\[
\begin{align*}
\text{Rs. 2.00} \\
\text{Total cost of regeneration} \\
\text{Rs. 6.00} \\
\text{Cost of defluoridation of water} \\
\text{Rs. 6.00 / 3 months.} \\
\text{Cost of defluoridation/annura for} \\
\text{a family of three to five persons} \\
\text{6 x 4 = Rs. 24.00}
\end{align*}
\]

III.3.6.2 Initial Cost investment

\[
\begin{align*}
a) & \quad \text{Cost of activated alumina} \\
& \quad \text{for 2 kg (at the rate of Rs. 75/Kg)} \\
& \quad \text{Rs. 150} \\
b) & \quad \text{The unit (all components stainless steel)} \\
& \quad \text{Rs. 400.00} \\
c) & \quad \text{Profit at the rate of (10%)} \\
& \quad \text{Rs. 55.00} \\
\text{Total} & \quad A = a + b + c \\
& \quad \text{Rs. 605.00}
\end{align*}
\]
The initial investment cost compares well to the existing ordinary water filter which can remove only suspended matter and not fluorides. (The market cost of the filter = Rs.600). Thus without any additional investment, the model developed in the present work gives not only clear water but also water with fluoride within permissible limits.

III.3.7 Field trials

Field trials were carried out in a village Kolinjipatti, Nallakkottai block, Dindigul Anna District of Tamilnadu. This village has been selected for field trials because of two reasons.

1) it consists of natural drinking water sources with 3 mg/l fluoride for which the unit is actually designed.

2) This village is in proximity to the Gandhigram Rural Institute.

The selection of the family was also based on two considerations.

a) The water source nearest to the location of their house and on which they are mainly dependent consists of 3 mg/l fluoride.

b) Assurance that the family would use the unit on trial basis and cooperate with our study.
FIG. III.4 Village woman using the defluoridation unit
FIG. III.5 Village woman using the defluoridation unit
This unit was used by the members of the selected family continuously for a period of three months. Periodically (once in a week) the treated water samples were analysed for fluoride and pH in the laboratory and the results are given in the table III.5.

Table III.5 Concentration of fluoride and pH of the samples studied during field trial

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Raw water Fluoride (mg/l)</th>
<th>Raw water pH</th>
<th>Treated water Fluoride (mg/l)</th>
<th>Treated water pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>3.0</td>
<td>7.6</td>
<td>0.70</td>
<td>7.7</td>
</tr>
<tr>
<td>2.</td>
<td>3.0</td>
<td>7.7</td>
<td>0.72</td>
<td>7.9</td>
</tr>
<tr>
<td>3.</td>
<td>2.9</td>
<td>7.6</td>
<td>0.70</td>
<td>7.7</td>
</tr>
<tr>
<td>4.</td>
<td>3.0</td>
<td>7.8</td>
<td>0.75</td>
<td>8.0</td>
</tr>
<tr>
<td>5.</td>
<td>3.0</td>
<td>7.7</td>
<td>0.79</td>
<td>7.8</td>
</tr>
<tr>
<td>6.</td>
<td>3.0</td>
<td>7.5</td>
<td>0.81</td>
<td>7.8</td>
</tr>
<tr>
<td>7.</td>
<td>3.0</td>
<td>7.6</td>
<td>0.83</td>
<td>7.8</td>
</tr>
<tr>
<td>8.</td>
<td>3.0</td>
<td>7.7</td>
<td>0.85</td>
<td>8.0</td>
</tr>
<tr>
<td>9.</td>
<td>3.0</td>
<td>7.8</td>
<td>0.87</td>
<td>8.0</td>
</tr>
<tr>
<td>10.</td>
<td>3.0</td>
<td>7.6</td>
<td>0.98</td>
<td>7.9</td>
</tr>
<tr>
<td>11.</td>
<td>3.0</td>
<td>7.6</td>
<td>0.92</td>
<td>7.9</td>
</tr>
<tr>
<td>12.</td>
<td>3.0</td>
<td>7.7</td>
<td>0.93</td>
<td>7.9</td>
</tr>
</tbody>
</table>

Acceptability by the family

After just one week of using this defluoridation unit, the family got adapted to it and they have used the unit for a period of three months without any complaints. The fluorosis affected families in the village, out of curiosity,
visited the unit and got convinced of the ease of operation of
the unit. The point that for the same cost of an ordinary water
filter, they can get defluoridated water, impressed the people
very much. Thus, the field trials clearly indicated that the
unit meets all the characteristics, we envisaged before starting
this work.