HOUSEHOLD DEFLUORIDATION UNIT DESIGN AND DEVELOPMENT

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ABSTRACT

The 1984 World Health Organization (WHO) guidelines suggest the permissible fluoride concentration in drinking water to be 1.0 mg/l in warm climate and 1.2 mg/l in cooler areas. Excessive fluoride intake causes an irreversible health problem widely known as fluorosis. There are three stages of fluorisis: Dental, skeletal and crippling fluorosis and all of them are known to prevail in Ethiopia. In the sample areas in this project the fluoride concentration lies between 3.4 and 24.3 mg/l.

The objective of this paper is to present the result of a research aimed at designing and developing a household defluoridiation unit that is simple, inexpensive and that uses locally manufactured Aluminum Sulfate that will reduce the fluoride concentration to the recommended range.

The defluoridation unit developed by the researchers is simple, just a bucket with a tap. The bucket can be produced from plastic, clay or metal. A sample defluoridiation unit has been developed in the Chemical Engineering laboratory with a plastic bucket and it has been checked to be effective. For the sample produced in the laboratory the cost is around 25 Birr, just the cost of the bucket and the tap. The cost of locally produced Aluminum Sulfate and lime is 2.5 Birr/Kg and and 1 Birr/ Kg respectively, hence the total cost of chemicals for treating a 20 liter bucket of water is less than 10 cents.

INTRODUCTION

The 1984 World Health Organization [1] guidelines suggest the permissible fluoride concentration in drinking water to be 1.0 *mg/l* in warm climate and 1.2 *mg/l* in cooler areas. Excessive fluoride intake causes an irreversible health problem widely known as fluorosis. People in several regions of the Rift Valley of Ethiopia are consuming water with up to 33 *mg/l* of fluoride [2,3].

Prevalence of dental and skeletal fluorosis has been reported in several parts of the world including Ethiopia, where fluoride concentration in drinking water exceeded the guideline level [2,4,5]. In Ethiopia, fluorosis prevails in the rift valley areas that extends about 12^0 45 ' N to 5^0 15' N latitude and 38^0 40 ' E and 41^0 15' E longitude, crossing the regional states: Afar, Oromiya, Southern Nations Nationalities and Peoples regional state and some places in Gambela regional state. The concentration of fluoride in drinking water in the mentioned areas is higher than other areas of the country. A study carried out by Kloos H. and Tekle Haimanot R. [6] indicate that fluoride concentration above 1.5 mg/l is reported from all parts of Ethiopia, but the highest levels were found in the Rift Valley.

One of the most practical approaches against fluorosis is removal of the excess fluoride from the drinking water and the process is known as defluoridation. There are various defluoridation techniques that are used in different countries. Most of the affected communities in Ethiopia are poor and illiterate and thus cannot afford these defluoridation units. Therefore, defluoridation unit to be used by such communities should be simple, affordable and should use locally available materials. A review of potentially low cost methods has been presented in Zede which indicates the possibilities for such low cost technologies [7].

In this paper the researchers presented the design and development of a household defluoidation unit that is simple for production and operation, affordable and that uses locally available chemicals. The research is based on the Nalgonda Technique [8] with special emphasis to the situation in Ethiopia.

Aluminum Sulfate and lime are the only chemicals used in the designed and developed defluoridation unit . Aluminum sulfate is effective and cheaper coagulant and commonly used in water treatment plants. It is locally produced in Awash Melkassa Aluminium Sulfate and Sulphuric Acid Factory and lime is also locally produced and commonly used for adjusting *pH* of water.

EXPERIMENTS AND RESULTS

The following experiments were carried out to determine parameters that affect both the design and operation of the defluoridiation equipment.

Raw Water Analysis

F^- concentration in raw water in selected areas

Objective: To determine the concentration of (Fluoride ion) F^- concentration in drinking water before treatment in selected areas in the Ethiopian Rift Valley Region.

Samples: Untreated drinking water from Metehara, Wonji, Nazareth, Toga, Bulbula, and Alemtena. The sample are collected at three different times: 12/11/2001, 25-26/09/2002, 08/03/03; to see seasonal variation.

Instrument: ORION Portable *pH*/ISE Meter

Procedure: In accordance with the procedure required by the instrument manual.

Result
The result of the experiment is presented in Table 1. The fluoride concentration for each village or town and the corresponding date of sample collection is indicated.

Table1: Drinking water F^- concentration at selected areas in the Ethiopian Rift Valley

No.	Date of collection Town/Village	F^- [mg/l]		
		12/11/2001	25-26/09/2002	08/03/03
1	Methara Town	6.53	-	-
2	2.2 Wonji (Drinking)	4.86	4.35	4.18
3	Nazreth* (Town)	5.46	0.03	-
4	Toga	6.55	6.32	6.76
5	Bulbula	3.40	3.07	4.14
6	Alem Tena	9.10	9.09	9.45
7	Koka	24.30	23.1	24.6

Nazreth: The source of water has been changed between the first and second test.*

pH of Raw Water

Objective: To determine the *pH* of the untreated drinking water. Aluminum Sulfate is known to reduce the *pH*. Thus, this experiment is especially required to determine the pH adjustment required.

Sample: Drinking water from the previously mentioned areas. Date of sample collection is 12/11/2001.

Instrument: ORION Portable *pH*/ISE Meter.

Procedure: In accordance with the procedure required by the instrument manual.

Result: The result is presented in Table 2.

Table 2: *pH* of Drinking water before treatment

No.	Town/Village	*pH*
1	Methara Town	7.72
2	2.2 Wonji (Drinking)	7.90
3	Nazreth* (Town)	8.10
4	Toga	7.80
5	Bulbula	8.00
6	Alem Tena	8.10
7	Koka	8.90

Determination of Optimum Alum-dose

Objective: This experiment is intended to determine the optimum dose of $Al_2(SO_4)_3$ to reduce the concentration of F^- from its initial concentration *(seen to be higher in the previous experiment)* to the range of 1mg/l to 1.2 mg/l recommended by WHO [1].

Apparatus: 500ml beakers, magnetic stirrer, ORION Portable pH/ISE Meter

Sample: 400 ml of untreated drinking water from each sample collected on 12/11/2001.

Procedure:

1. Each 400 ml water was treated by Aluminum Sulfate of concentration 130, 150, 170, 200 mg/ mg of F^-.
2. The mixture is stirred slowly, for 10 minutes by magnetic stirrer.
3. The solution is removed from the stirrer and settled for 2 hours.
4. The clear liquid is decanted and its fluoride concentration and the pH are measured according to the procedure recommended by the manual.

Result

The result of the experiment is presented in Table 3 below. It shows that the optimum alum dose is 170 mg / mg of F^-.

Determination of Optimum Lime-dose

Objective: The *pH* of the treated water, as can be seen in Table 3 is lower than the allowable range i.e., 6.5-8.5. To bring the treated water to this range lime is used. The objective of this experiment is to determine the optimum lime dose to adjust the pH to the required range.

Sample: 400 ml of untreated drinking water from each sample collected on 12/11/2001.

Apparatus: 500ml beakers, magnetic stirrer, ORION Portable pH/ISE Meter

Table 3: Optimum Alum Dose Determination

Sample Name	Before treatment		Alum Dose	After treatment		Optimum Alum Dose
	F^- [mg/l]	*pH*	mg Alum/mg F^-	F^- [mg/l]	*pH*	mg Alum/mg F^-
Methara	6.53	7.72	130	1.48	6.7	170
			150	1.31	6.4	
			170	**1.22**	**6.3**	
			200	1.07	6.1	
Wonji	4.86	7.9	130	1.48	6.8	170
			150	1.22	6.7	
			170	**1.27**	**6.6**	
			200	1.00	6.4	
Nazreth	5.46	8.1	130	2.40	6.3	170
			150	1.82	6.2	
			170	1.45	6.0	
			200	1.20	5.7	
Toga	6.55	7.8	130	1.76	5.9	170
			150	1.03	5.7	
			170	**1.24**	**5.2**	
			200	2.02	4.7	
Bulbula	3.4	8	130	1.83	6.5	170
			150	1.61	6.4	
			170	**1.33**	**6.3**	
			200	1.04	6.1	
Alem Tena	9.1	8.1	130	2.79	5.3	---
			150	3.29	4.8	
			170	**3.17**	**4.4**	
			200	2.44	4.3	
Koka	24.3	8.9	130	1.89	4.1	170
			150	1.47	4.0	
			170	**1.10**	**3.95**	
			200	0.75	3.9	

Procedure:

1. 400 *ml* of water was taken from each sample.
2. Aluminum sulfate was added in each sample based on the initial fluoride concentration and optimum dose of 170 $mg\ Al_2(SO_4)_3/mgF^-$.
3. Lime was added with concentrations 10%, 20%, 50% of $Al_2(SO_4)_3$
4. The mixture is stirred using magnetic stirrer for 15 minutes
5. The mixture was allowed for precipitation for 2 hours
6. The pH an F^- are measured

Result

Table 4: Optimum lime dose

No.	Sample Name	pH at lime concentration			Optimum Lime dosage As % $Al_2(SO_4)_3$	pH at Optimum lime dosage
		10% of $Al_2(SO_4)_3$	20% of $Al_2(SO_4)_3$	50% of $Al_2(SO_4)_3$		
1	Methara	5.8	6.15	7.00	50	7
2	Wonji	5.85	6.10	7.05	50	6.7
3	Nazareth	5.6	6.00	7.55	50	6.8
4	Toga	5.4	5.80	6.80	50	6.9
5	Bulbula	6.2	6.50	7.70	50	7.3
6	Alemtena*	4.9	5.90	6.80	55	7.0
7	Koka*	3.9	4.05	5.8	62	6.95

* Additional tests were carried for these two

Determination of Amount of Sludge

Objective: This experiment is carried out to determine the % of sludge expected from a given amount of raw water to be treated. This is a design parameter that will determine the position of the tap.

Sample: 100 *ml* of water sample collected on 08/03/03. The fluoride concentration in each sample area is indicated in Table 5.

Procedure:

1. 400 ml of water from each of the samples is treated with the optimum dose of aluminum sulfate and lime.
2. The mixture was stirred slowly for 15 minutes and was left to settle for two hours.
3. The clear liquid is carefully removed and the volume of sludge remaining in the beaker measured.

Result:

Table 5: Amount of sludge

No.	Sample Name	Initial F^- concentration Mg/l	Amount of sludge % of volume of raw water
1	Wonji-1*	13.2	16.5
2	Wonji-2**	4.18	9.9
3	Toga	6.76	17.8
4	Bulbula	4.14	4.8
5	Alemtena	9.45	16.5
6	Koka	24.6	28.8

* Washing water, **Drinking water

Determination of Total Water Quality before Treatment and after Treatment

Objective: To determine the effectiveness of the defluoridation equipment developed, the effect of the chemical used and the process of treatment on the total water quality. All major drinking water quality parameters are tested.

Sample: Sample water from selected high fluoride areas as indicated in Table 6.

Procedure: According to QSAE.

Table 6: Test Results of Raw and Treated Water Samples as Analyzed by QSAE

		Wonji -1		Toga		Bulbula	
		Untreated	Treated	Untreated	Treated	Untreated	Treated
Aluminium	*mg/l*	0.74	ND	ND	0.28	2.03	ND
Cadmium	>>	0.006	0.02	0.07	0.009	0.01	0.009
Calcium	>>	30.46	278.34	23.4	157.36	36.30	81.16
Chromium	>>	ND	ND	ND	ND	ND	ND
Cobalt	>>	ND	ND	ND	ND	ND	ND
Copper	>>	0.03	0.04	0.03	0.04	ND	0.03
Iron	>>	ND	0.04	0.28	0.11	1.06	0.05
Lead	>>	0.02	0.01	0.02	0.02	0.01	0.01
Magnesium	>>	9.79	14.81	9.73	11.34	15.24	14.72
Arsenic	*ng/l*	38.5	ND	1.8	ND	ND	ND
Seleniom	*ng/l*	ND	ND	ND	ND	ND	ND
Manganese	*mg/l*	0.001	0.09	0.73	0.30	0.29	0.08
Nickel	>>	ND	ND	ND	ND	ND	ND
Mercury	*ng/l*	ND	ND	ND	ND	ND	ND
Silver	*mg/l*	0.014	0.019	0.015	0.011	0.012	0.013
Sodium	>>	271.97	269.19	131.44	126.68	102.87	103.12
Potassium	>>	25.42	27.24	15.17	16.03	12.37	12.37
Zinc	>>	ND	ND	0.16	ND	0.05	ND
Barium	>>	0.8	1.35	0.90	1.10	0.95	1.15
Beryllium	>>	0.01	0.06	0.02	0.04	0.02	0.05
Chloride	>>	71.94	73.33	26.98	24.29	15.91	15.22
Sulphate as SO4	>>	36.63	973.43	ND	443.29	ND	217.32
Hardness as $CaCO_3$	>>	116.25	755.36	98.39	439.24	153.48	263.02

ND: Not detected by the applied procedure

DISCUSSION

Raw water analysis

The sample area extends southwards from Nazereth 100km from Addis Ababa to Toga 257km from Addis near Awassa. The raw water analysis indicates that in all the sample areas the fluoride concentration is above the allowable limit 1-1.5 *mg/l*. As can be seen in Table 1 the minimum amount is 3.40 at Bulbula and the maximum is at Koka 24.3 *mg/l*.

The samples were taken at three different times (Table 1). This was intended to check the seasonal dependence of the fluoride concentration in the areas. The first set of samples was taken in November the second in August and the third in March. By doing so it was tried to get sample both from the dry and rainy season.

As can be seen from the table there is no significant variation in concentration in different seasons. By significant it is meant here a concentration that will affect the design of the defluoridiation equipment. The mean seasonal deviation of the concentration, excluding Nazerth, is 0.43 *mg/l*. Nazreth is excluded because the water source has been changed from ground water to surface water between the first and latter sample dates.

Optimum Alum Dose

Figure 1 presents the result of the test, which is fully presented in Table 3. A dose of 170*mg* Alum/*mg* of F^- reduces the F^-concentration to the required range 1mg/l – 1.5 *mg/l* in all cases except for the sample with initial concentration of 9.1 mg/l *(Sample from Alem Tena)*. It should also be noted the 170*mg* Alum/*mg* of F^- dose is effective even for higher concentration, i.e., 24.3*mg/l* of initial fluoride concentration.

The exceptionality of the Alem Tena sample is not specific to the 170 *mg/mgF*$^-$ dose alone. As can be seen in the figure all the four doses could not reduce the F^- to an acceptable level. This case needs special study.

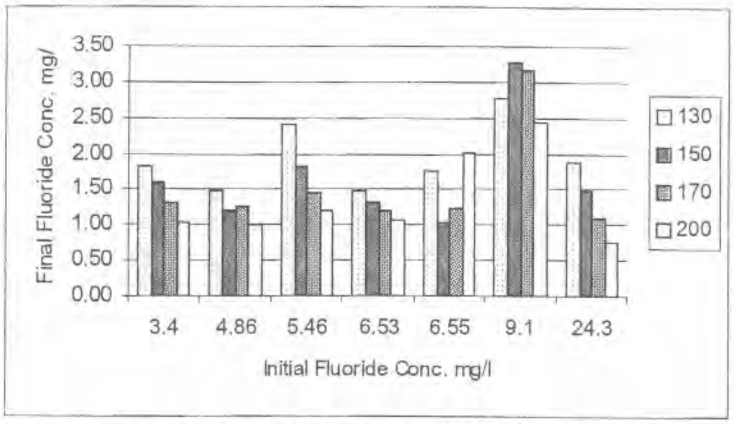

Figure 1 Dependence of optimum dose on initial fluoride concentration

Figure 2 shows the *pH* of the Alum-treated water dependence on the initial *pH*, initial concentration of the fluoride and the dose. The *pH* of the treated water drops as the initial *F* concentration and the dose of alum increases. This is because the total amount of Alum added per liter of raw water increases both with increase in initial *F* concentration and the Alum dose.

The pH for the optimum dose varies from 4 to 6.8. However for drinking water the pH should be in the range of 6.5 - 7.5. Therefore the *pH* should be increased to the acceptable range. This is commonly carried out by adding lime. Therefore the next test was intended for finding the optimum lime concentration for adjusting the *pH* in the range of 6.5-7.5.

Table 4 shows the result of the experiment for identifying the optimum lime dose. The final *pH* is already shown to depend on the concentration of Aluminum Sulfate added per liter of water to be treated. As it can be seen from the result a lime concentration of 50% of Alum is sufficient in all cases except two.

Determination of Amount of Sludge

The amount of sludge after the recommended settling time, in this case 2 hours, is needed for determining the position of the tap and to evaluate the percentage of clear, treated water that the user can get for any given amount of raw water he treats.

To draw clear, clean treated water out of the defluoridiation bucket the position of the tap should be above the settled sludge. *C* are should also be taken not to place the tap very far from the settled sludge because in that case the percentage of the treated water obtainable will be very low, which means a lot of water wastage. It has been checked that the tap should be positioned 1-2cm above the top surface of the sludge to avoid disturbance of the settled sludge.

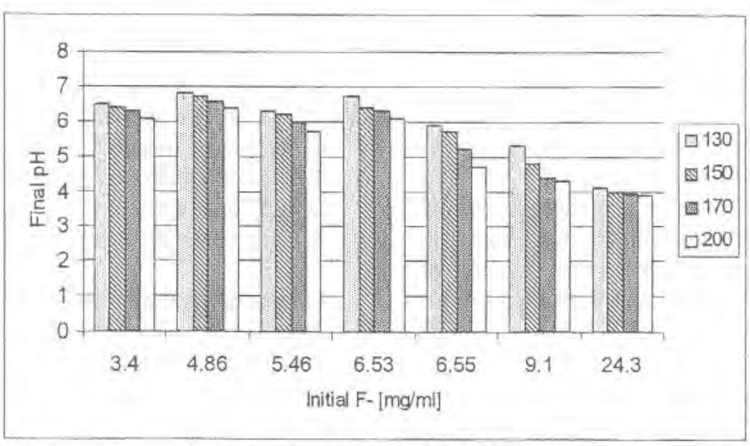

Figure 2 Dependence of Final *pH* on the initial fluoride conc. at different doses

As it can be seen in Table 5 the percentage of sludge increases with the initial *F* concentration. The Alemtena sample seems to contradict here also; it shows sludge percentage less than expected. This is due to the fact that not much defluoidation occurs in the Alemtena sample as shown in Fig. 1.

The Total Water Quality after Using the Developed Defluoridation Equipment

Table 1 deliverers the result of the total water quality test of raw water and water from the same sample treated using the technique developed in the research. The major objective of this test is evaluating the developed defluoridation technique, i.e., the equipment, the chemicals used and the procedure applied.

The concentrations that are expected to be directly affected due to the treatment with aluminum sulfate and lime are the concentration of aluminum, sulfate, calcium and carbonate ions (hardness). As it can be seen in Table 6 the concentration of the aluminum ion has reduced in the two cases and increases a little in the other one. The concentration of sulfate, calcium and carbonate ions has increased significantly. However all the values are within the permissible range for the Bulbula sample and all the samples satisfy the requirement for content of toxic and/or disease causing substances of Ethiopian standards of drinking water (Ethiopian Standard, 2001). The permissible concentration of various components is given in the Appendix.

DESIGN OF THE DEFLUORIDATION EQUIPMENT

Preliminary Design

The preliminary design assumes three sections, namely mixing, filtration and clear liquid collection section (see Fig. 3).

The mixing section is where the reaction first takes place. After waiting for a while the liquid will be let to go through the filtration section where part of the coagulated precipitate will be filtered out and the clear liquid will be collected in the third chamber.

The prototype was produced at the technology faculty workshop and tested. The test confirmed that the design could accomplish the required defluoridiation task, however it was observed that significant improvements could be carried out. The most import improvement stems from the fact that the filtration step doesn't have any significant impact on the treatment process as a whole.

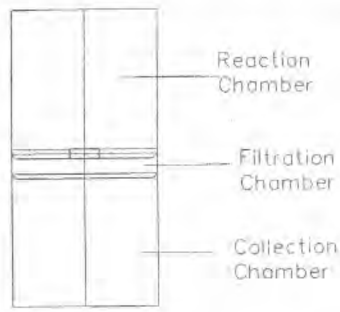

Figure 3 Preliminary Design

This leads to a very simple design without the two chambers: the filtration and collection chamber. This however changes the design of the reaction chamber too. According to the preliminary design the three chambers were to be mounted one on another.

Final Design

A sample of the final design is presented below. However the bucket can be of any, size and material. The only important design parameter that affects the operation is the position of the tap.

The final design has a number of advantages over the preliminary design. It is simple in design and operation, low cost and it can be made out of cheaper materials like plastic and clay.

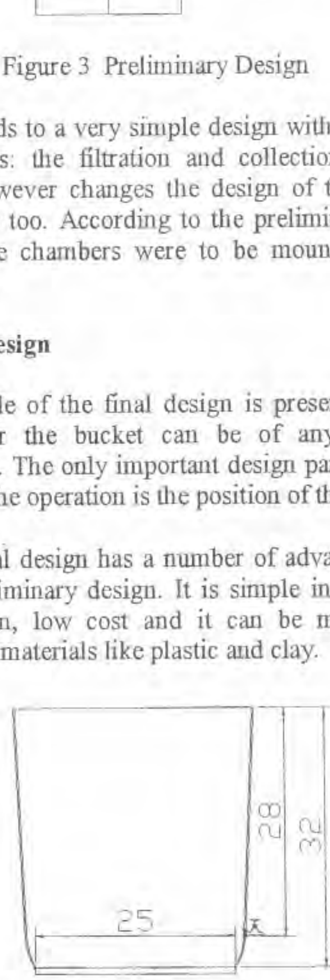

Figure 4 Final design for fluoride concentration of less than 10%, all units in cm.

As shown in the figure above, the final design is just a bucket with a tap. The only critical design parameters are the height of the bucket and the position of the tap. The height of the bucket affects the settling time while the position of the valve affects the proper functioning of the equipment.

The settling time depends on the height of the bucket and the speed of the flocs. The speed of the focs, in its turn, depends on the size of the flocs. Larger flocs have high settling speed while smaller flocs have low setting speeds. Large flocs are formed by slow stirring rate. In the commonly available buckets of volume 15-25 liter and a slow rate of stirring two hours of settling time is proved to be sufficient to get clear, clean treated water.

The position of the tap is also a very critical parameter. If the tap is positioned below the surface of the sludge, obviously the sludge will come out through the tap. The major problem will even be that the settling will be disturbed and the users will not get clear liquid. On the other hand, if it is put very much above the sludge level, the users will get only part of the clear, treated water. Therefore only a small margin is sufficient.

The position of the tap is determined first by calculating the amount of sludge. The percentage of sludge for different initial concentration has been already found (Table 5). If the concentration is very different from those found in the experiment, a test should be carried out to determine the percentage of sludge. The percentage of sludge should be multiplied by the total volume of the bucket to get the total amount of the sludge. The position of the surface of the sludge can be determined by marking the position of the volume of the sludge. Once the position of the surface of sludge is obtained the tap should be positioned 1-2 cm above it.

The fact that the design is so simple makes it very flexible in production and cheaper in cost. It can be manufactured from plastic, metals, even clay. In case of plastic and metal the bucket can be easily pierced and the tap can be put to place. In case of clay, the producers should take care to place the tap properly and in the correct position. It is not too difficult to make a clay tap also. In that case the cost of the defluoridiation equipment will be nearly the cost of only the pot.

OPERATION PRINCIPLE

For a given defluoridiation bucket the Lime and Aluminum Sulfate amounts will be calculated and prepared in small bags. Then the user will follow the following steps to accomplish the required defluoridiation.

1. Pour some of the water into the defluoridiation bucket.
2. Carefully Open the chemical bags and empty them into the water completely.
3. Add the rest of the water up to the marked maximum point.
4. Stir the mixture quickly until all the chemical is dissolved.
5. Stir the solution slowly for 5-10 minutes.
6. Let the mixture settle for two hours.
7. Open the tap and empty the clear, treated water in another bucket.
8. Remove the sludge and clean the defluoridiation bucket for future use.

CONCLUSION

In this research project independent study of the concentration of fluoride in drinking water in different areas has been carried out. It is found out in all the sample arrears the fluoride concentration is higher, between 3.4 and 24.3 *mg/l*, than which is recommended by WHO which is between 1-1.5 *mg/l*. Due to this most of the residents in theses areas suffer from dental and skeletal and crippling fluorosis.

Affordable defluoridiation equipment is designed and a prototype is produced in the technology faculty workshop. The defluoridiation equipment is a simple bucket with a tap. The cost of the equipment is nearly the sum of the cost of the bucket and the tap. For a plastic material the cost may range between 20-25 E birr. It can also be produced from metal, and clay.

The equipment is simple, affordable, and flexible. It does not need any special facility to produce it. Any bucket available on the market can be used. The only critical design parameters that will affect the proper functioning are the height and the position of the tap.

If it is made of clay special tap of clay (outlet and stopper) may be designed to reduce the cost further. This however needs to train a special manufacturer, to position the tap correctly.

This defluoridiation technique is very effective up to fluoride concentration of to 10*mg/l*. For higher concentration the water loss will be very high and it is not recommended. However for many areas the fluoride concentration is low and medium and can be covered by this equipment.

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