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CONSTRUCTION AND OPTIMISATION OF A CARTRIDGE FILTER FOR REMOVING FLUORIDE IN DRINKING WATER

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ABSTRACT. An attempt has been made to construct a cartridge to be used for the defluoridation of drinking water. The cartridge packed with bone char material could be fixed onto a domestic faucet as a flow through defluoridizer. PVC cartridges of various sizes were made from a ¾ inch pipe. The efficiency of fluoride removal was determined for the following parameters: cartridge length, flow rate of water, compactness of bone char material and particle size with the aim of determining the optimum conditions for a good cartridge. It was found that the optimal conditions for the F^- filter that gave the best results in removing of F^- from water with minimum inconvenience were: particle size, 0.2 mm mean diameter; the flow rate, equal or less than 20 mL/min; cartridge length, 10 cm filled with 20 g of bone char material.

KEY WORDS: Bone char, PVC cartridge, Batch defluoridation, Flow-through defluoridation, Defluoridation efficiency

INTRODUCTION

The removal of F^- from potable water has seen many attempts over the years, using a wide variety of material giving various efficiencies. The Nalgonda technique, where alum is mixed with lime at the ratio 700/300 mg/L, was tested at a research station in Arusha, Tanzania and reduces fluoride concentration from 21 to 5 mg/L at pH 6.9 [1]. Clays, ion exchange resins, activated carbons, sulphonated coals, magnesium compounds, serpentine, iron and aluminium salts have been applied [2]. Use of activated alumina (2000 grains/ft^3) as filterbed shows that fluoride removal efficiency approaches 100% [3]. The use of polyaluminium chloride and magnesite has also been demonstrated to be 95% and 81%, respectively [4]. An electrocoagulation process has been suggested by Mameri [5], where aluminium bipolar electrodes were used with encouraging results. The process had to be optimised in terms of: inter-electrode distance, fluoride concentration, temperature and pH of the solution and the influence of current density. Local Kenyan soil derived from volcanic ash, i.e. Ando soils or soils with 'andic' properties has been used as a fluoride sorbent [6]. Defluoridation by bone char has been studied by several workers [7-9] with remarkable efficiency. The removal process is the ion exchange adsorption between fluoride in the solution and carbonate of the apatite comprising bone char.

Irrespective of the material or method used, there are generally two methods of fluoride removal namely: batch and continuous flow defluoridation. The bucket filter, marketed by the Catholic Diocese of Nakuru (CDN) Water Program, Kenya [8], is an example of continuous flow method and is designed such that water has to sit in the container for a minimum of 15 minutes before it is collected in one batch. The F^- free water is then transferred into another container for use by the family for a day or two depending on the capacity of the filter. This method is not only potentially costly because it requires a large container filled with bone char

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material, but also the water is likely to be contaminated since it has to be collected and transferred into a second container for storage before it is used.

The second form of filter, the continuous type, is usually a tube or cartridge fitted onto a domestic faucet, with an inlet and an outlet tube. Fluoridated water enters the cartridge and passes through the active material and comes out through the opposite side of the cartridge as defluoridated water. A typical example is the one reported by ENFO News [10], where a bone char filter was developed for use in Thailand villages. This particular filter was made of a 75 cm plastic tube equipped with inlet pipe and outlet water tap. In the filter is 300 g charcoal, 1 kg bone char and pebbles. When water of 5 mg F^-/L is run through the filter with a flow of 4 L/h, 480 L can be treated to less than 1 mg/L.

In this study, smaller size cartridges than in the previous study [10] were made and the filter material used were only bone char, unlike the previous study [10] where a mixture was used. Optimisation of physical conditions to provide the best F^- removal from drinking water was carried out. The conditions included: bone char particle size, water flow rate, cartridge length and compactness of the filter material.

EXPERIMENTAL

The cartridges were constructed by the use of PVC tubing cut into small pieces of desired lengths. The internal diameter of the tubing was ¾", the same as standard domestic faucets. The cartridge construction procedure is as follows: (1) using adhesives, a rubber stopper with connector tubing was attached to one end of the of PVC pipe of desired length; (2) using an analytical balance the desired amount of bone char was placed into the PVC tubing; for parameters other than compaction effect, 2 g bone-char per cm of PVC pipe length were packed; (3) a rubber stopper with tubing was fixed to the other end of the PVC pipe; after packing and sealing, the cartridges were left for at least 15 minutes before use, for the adhesive to dry properly. The water samples were collected by the following procedure: (1) the cartridge is attached to the tap using a laboratory clip or any other device that is suitable; (2) water is allowed to flow through the cartridge for 15 minutes; (3) the flow is adjusted to desired rate; (4) a sample of 100 mL is collected in a graduated cylinder.

The fluoride meter used was an Ion Selective Combination Electrode, model: Thermo ORION, 96-09 manufactured by Orion Research, Inc. of Beverly Mass, USA. A TISAB (total ionic strength adjustment buffer) and fluoride standards were obtained from the same company. Prior to analysis, the samples were treated as follows: (1) all samples and standards were placed in a water bath (25 ^{0}C) for at least 30 minutes; (2) a 50 mL sample and 5 mL TISAB III were placed in a 150 mL beaker and the mixture was stirred thoroughly using a magnetic stirrer; (3) the electrode sensing element was immersed in the mixture at least 1", and the mV reading was taken after stabilization. The method of "standard addition" was used, where known concentration of F^- was added to the sample, the total potential difference before and after addition was recorded and the F^- in water determined.

The filter material was bought from the CDN in various particle size sets of 0.2, 0.6, 2, and 4 mm mean diameter. The PVC tube was cut into various lengths of 5, 10, 15, and 20 cm. The flow rate was varied from 5 to 60 mL/min. Optimum compaction was achieved by varying bone char mass from 20 to 35 g in a 10 cm cartridge after optimising the rest of the parameters.

RESULTS AND DISCUSSION

The findings for the study of the effect of particle size on fluoride removal are presented in Figure 1. The smaller the particle size of the material, the higher is the efficiency of removal. The smallest size, 0.2 mm gives the highest efficiency, where only 0.02 mg/L of F^- remain after filtration of water originally containing 3.96 mg/L. This is equivalent to 99.5% removal efficiency. Other particle sizes with their efficiencies under the same experimental conditions were: 0.6 mm, 74%; 2 mm, 41%; and 4 mm, only above 4%. The higher efficiency of smaller particle size is due to the provision of larger surface area necessary for adsorption of F^- from water onto the bone char material.

The set of data reported for the effect of flow rate (Figure 2), was obtained from a cartridge of 10 cm and 0.2 mm particles size. The two parameters were optimised before the flow rate. The flow rate effect seems to be levelled at near 100% (actually 99.7%) for 5, 10 and 15 mL/min. At higher flow rate than this, the trend starts to deviate downward and at 20 mL/min it was about 97%. At 40 mL/min, the efficiency was still above 90%. It dropped to about 70% at 60 mL/min. Practically, when the filter is used at a flow rate below 20 mL/min., it is too slow and therefore inconvenient. On the other hand, the higher the flow rate of water, the lower is the resident time in the filter, thus there is not enough time for F^- to interact with the bone material to be adsorbed.

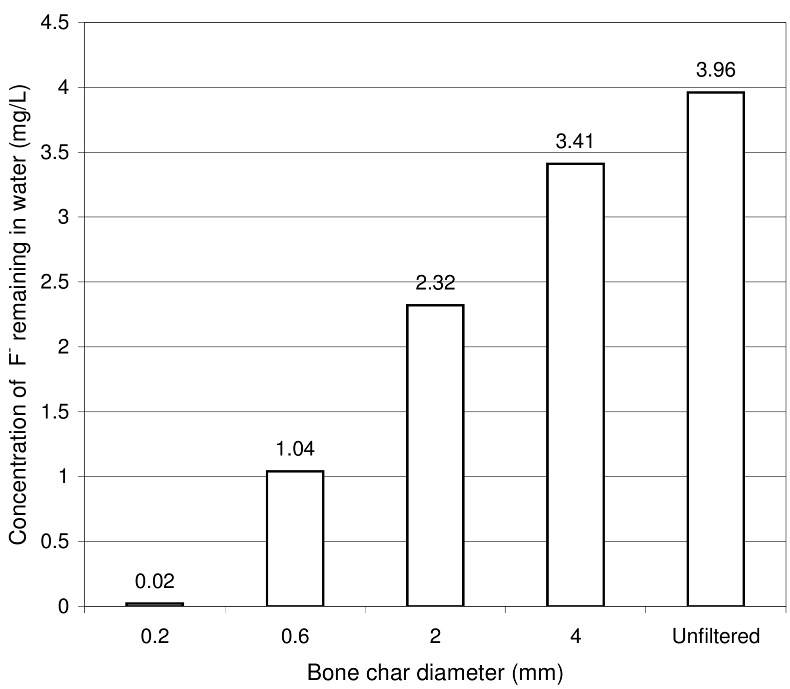

Figure 1. Effect of bone char particle size on fluoride removal from water.

The other parameter studied was the cartridge length effect (Figure 3). The figure shows that using the smallest length of 5 cm (and packed with 2 g/cm as optimised in Table 1), only about 94% F^- was removed. The removal increases sharply to 99.5% when the length is doubled. This percentage remains almost constant when the length is doubled again to 20 cm, to about 99.7%. This means that for economical purposes, one does not have to make a cartridge that is longer than 10 cm because there is no significant gain in terms of F^- removal efficiency beyond 10 cm. For convenience sake, therefore it is advisable to make a 10 cm long cartridge that can easily be fixed onto a kitchen faucet without taking too much space. The effect of length is similar to that of flow rate in that, there is an optimum length for F^- present in water to adequately interact with the active material. At least 10 cm appears to be the compromise length when all other parameters namely flow rate, particle size and compactness are optimised as reported here.

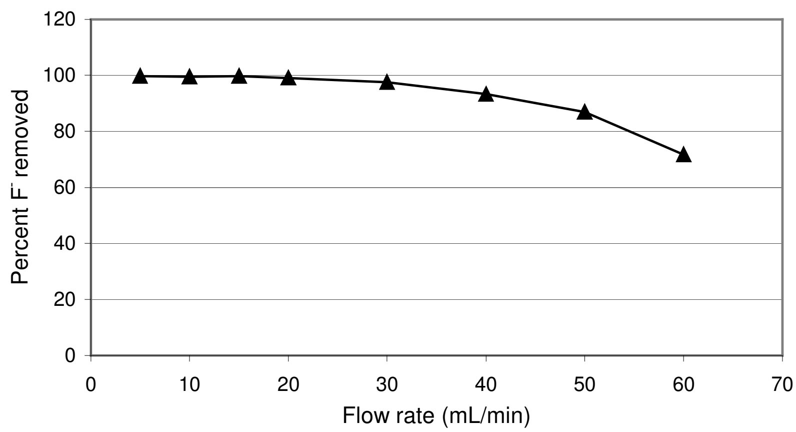

Figure 2. Effect of flow rate of water on the removal of fluoride.

Table 1. Effect of compactness of bone char material.

Bone char mass packed in 10 cm cartridge	[F^-] Remaining from the original (3.96 ppm)	Efficiency of removal
20 g	0.02 ppm	99.5%
25 g	0.02 ppm	99.5%
30 g	0.01 ppm	99.7%
35 g	0.01 ppm	99.7%

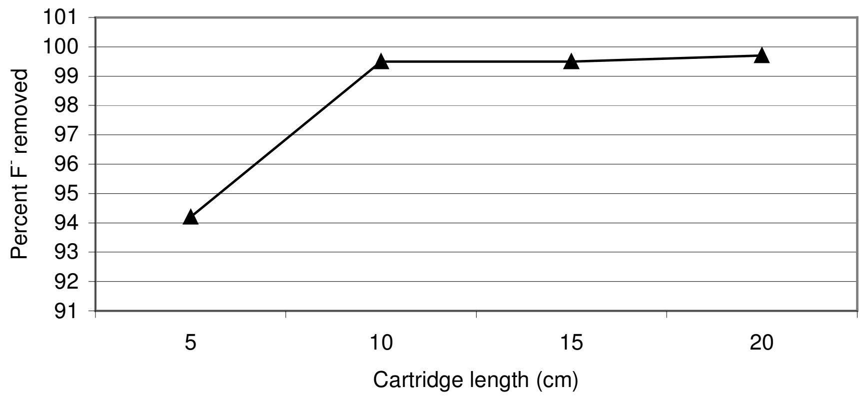

Figure 3. Effect of cartridge length on fluoride from water.

The effect of compactness of packing or density of the filter material in the cartridge is presented in Table 1. Twenty grams of bone char represent a compactness of 2 g/cm using a 10 cm cartridge length. This length was the optimised size in the previous sets of experiments (Figure 3). The table shows that by increasing the compactness from 2.0 to 2.5, 3.0 and 3.5 g/cm, we are increasing the amount of F^- removed from 99.5% to 99.7% only. This is a very small gain on efficiency. Other observations showed that, this insignificant gain is also associated with creation of too much backpressure in the cartridge as well as significantly reducing the flow rate. As a result of these twin drawbacks (back pressure coupled with reduced flow rate), the optimised condition is to make a cartridge with 2 g/cm of cartridge material packing, specifically 20 g in 10 cm cartridge. The compactness of cartridge packing is technically a measure of the pressure of water passing through the cartridge. The more compact the packing, the higher is the pressure. However, if a higher pressure is desired, it will be at the expense of reduced flow rate and higher backpressure.

CONCLUSION

The study has found that the optimal conditions for the locally manufactured F^- filter which gave the best results in terms of removal of F^- from water with minimum inconvenience were: particle size of the bone char grains, 0.2 mm mean diameter, which was the smallest size; the flow rate, 20 mL/min which was a medium rate; cartridge length, 10 cm filled with 20 g of bone char material. The latter condition reflects the compactness or density of cartridge packing, i.e. 2 g/cm. Higher compactions like 3 or 3.5 g/cm produced too much backpressure and lower, non optimal flow rate. In future this research group will focus on refining the engineering of the cartridge, especially to alleviate the backpressure problem on the one hand and on the other, to determine the life span of the cartridge or the maximum duration for use before the capacity of the material to adsorb F^- is exhausted. Equally important to find out is the quality of the drinking water after passage through the cartridge. It should be important therefore to investigate the quality of water from the new cartridges in terms of metal ions and microbial contents as well as other physico-chemical properties including the pH.

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REFERENCES

1. Bregnhoj, H., Norremark, E.T., Orio, L. *Field Study Report, Center for Developing Countries, Technical University of Denmark,* Copenhagen, **1990**.
2. Bulusu, K.R.; Sunaresan, B.B.; Pathak, B.N.; Nawlakhe, W.G. *J. Inst. Eng. (India)* **1979**, 60, 1.
3. Christoffersen, J.; Christofferson, M.R.; Larsen, R.; Moller, I.J. *Water Res.* **1991**, 25:2, 227.
4. Mjengera, H.J. *M.Sc. Thesis*, Tempere University of Technology, Tempere, Finland, **1988**.
5. Mameri, N.; Yeddou, A.R.; Lounici, H.; Belhocine, D.; Grib, H.; Bariou, B. *Fluoride* **1998**, 31, 227.
6. Zevenbergen, C.; Reeuwijik, L.P.; Franpport, G.; Louws R.J.; Schiling, R.D. *Fluoride* **1997**, 30, 128.
7. Jacobsen, P.; Dahi, E. "Effect of Ca addition on the defluoridation capacity of bone char", *The Second International Workshop of Fluorosis and Defluoridation of Water*, Arusha, Tanzania, **1994**.
8. Mavura, W.J.; Bailey, T. *J. Civ. Eng., JKUAT* **2003**, 8, 79.
9. Watanesk, R.; Watanesk, S. "Comparative study of fluoride absorption behaviour on activated charcoal and bone char" in *Proceedings of the 3rd International Workshop on Fluorosis and Defluoridation of Water*, The International Society of Fluoride Research, Auckland, New Zealand, **2000,** pp 80-83.
10. ENFO, ENFO News, "Defluoridator for individual household: The ICOH defluoridator". **1989**, May/August, p 3-4, ICOH, Intercountry Center of Oral Health, Bangkok, Thailand.