
35th WEDC International Conference, Loughborough, UK, 2011

THE FUTURE OF WATER, SANITATION AND HYGIENE:
INNOVATION, ADAPTATION AND ENGAGEMENT IN A CHANGING WORLD

Comparative performance of bone char-based filters for the removal of fluoride from drinking water

P. M. Mutheki, L. Osterwalder, J. Kubai, L. Korir, E. Wanja, E. Wambui, T. Edosa,
R. B. Johnston & C.A. Johnson, Kenya

BRIEFING PAPER 1246

There is a great need for effective, reliable and inexpensive filters for the removal of fluoride for the millions of people affected in low and middle-income countries. This paper compares field and laboratory performance of bone char (BC) filters and filters, known as contact precipitation (CP), based on a combination of bone char and calcium-phosphate pellets. The comparison shows that despite the wide variety of filter design and water composition both methods yield comparable results and that the average uptake capacities to 1.5 mg/L in the treated water are 3.0 ± 1.0 mgF/g for CP and 1.2 ± 0.3 mgF/g for BC. Preliminary estimates indicate that CP filters are more economical and that further optimisation of the capacity of the CP filters would increase their advantage.

Introduction

According to UNESCO estimates, more than 200 million people worldwide rely on drinking water with fluoride concentrations exceeding the international WHO guideline of 1.5 mg/L (UNESCO, 2008). In Africa dependence on fluoride-contaminated water has been reported in Morocco, Algeria, Chad, Namibia and the Rift Valley countries Ethiopia, Kenya and Tanzania, are particularly affected (Fawell et al., 2006).

While the use of alternative fluoride-free water sources will always be the most favoured option, there is a great need for effective, inexpensive and reliable fluoride removal technologies for poor rural communities that have no alternatives. Industrialised countries commonly use activated alumina or membrane technologies to remove fluoride from drinking water but these methods are generally expensive and defluoridation is still uncommon in low and middle-income countries, though there are some excellent initiatives (NEERI-UNICEF, 2008). Bone char-based filters are being successfully implemented in Kenya (Mueller et al., 2006) and in Ethiopia a recent study shows that the material is also accepted in the Oromia Region (Samuel et al., 2009). Factors, such as the availability and distribution of filters and filter material, the pricing and government policy on subventions and the acceptability by the population, are all critical for the success of fluoride mitigation from drinking water. In addition food may be an important source of fluoride that needs to be considered (NEERI-UNICEF, 2008).

In 1998, the Water Quality Section of Catholic Diocese of Nakuru (CDN), Kenya, started a defluoridation programme on request of the drilling section for sustainable solutions in mitigating fluorosis. Specific efforts were made in up-scaling the production of bone char (BC) and improving the filter design and operation for implementation on both household and community level. After CDN had overcome initial challenges related to the production of high-quality bone char, the users fully accepted the filter material.

In the 1990s, first research experiments were conducted to extend the lifespan of BC filters by the addition of calcium and phosphate to the influent water (Larsen et al, 1999). In 1995, this method was field tested in a community pilot plant in Tanzania (Dahi, 1996). Though filter lifespan was increased, high maintenance requirements related to continuous calcium and phosphate supply hindered large-scale implementation. The water quality section of CDN has developed pellets that slowly release calcium and phosphate into the water for fluoride precipitation when mixed with BC without creating additional maintenance requirements for the end users.

In 2009 (Korir et al. 2009) we presented the performance of the CP filters in laboratory experiments. Here we show the performance of BC and CP filters and compare field results with laboratory data. This work is part of the CDN-Eawag collaboration to further develop and optimise low-cost defluoridation methods.

Material and methods

Filter material

Both bone char and calcium-phosphate pellets are produced in Kenya by CDN.

Dry animal bones are charred in a specially designed furnace with limited oxygen supply at temperatures between 350 - 400°C. The charred bones are brittle and easy to crush and following this they are sieved into different fractions. The material is then washed with caustic soda (NaOH) to reduce residual organic material (CDN et al, 2007). The resulting product is hydroxyapatite ($Ca_5(PO_4)_3OH$).

Calcium-phosphate pellets are formed by mixing calcium hydroxide ($Ca(OH)_2$) and a commercially available phosphate source (Kynofos21, a mixture of $CaHPO_4$ and $Ca(H_2PO_4)_2$) in a concrete mixer. After the addition of water and bone char dust, the pellets are sprinkled with water to enable the formation of a robust calcium carbonate ($CaCO_3$) coating. After washing, the pellets are ready for use.

It must be noted that the amount of soluble calcium and phosphate in the pellets can vary and that a quality control test has been developed in order to optimise production. The test is performed as follows: 200 g pellets are placed in a PVC column. These are flushed 2 times with 200 mL and 150 mL water respectively and then a 3rd aliquot (150 mL) is allowed to equilibrate with the pellets for 1 hour. The water is then removed and the phosphate concentration determined. The pellets “high” released 343 mg PO_4/L to solution and the pellets “low” released 120 mg PO_4/L. (It should be noted that these values are high and not representative of drinking water). A lower release is achieved, amongst other reasons, if scrapings from the production of previous batches are added during production in order to minimize waste production. CDN’s policy is to add the same amounts each time to ensure reproducibility.

Fluoride measurements and fluoride uptake capacity

Fluoride concentrations were measured potentiometrically with an ion-selective electrode. The fluoride-removal capacity is calculated from the water consumption, the average fluoride concentration in the raw water and the weight of the total filter media (a bulk density of 800 g/L was assumed). The fluoride measured in the treated water is deducted from the fluoride uptake capacity (the average between two consecutive measurements).

Laboratory column experiments

At CDN and Eawag PVC columns (diameter 2.5 cm) were filled with filter material. The particle sizes for pellets and bone char was 4-6.3 mm and 2-4 mm respectively. The columns were run at constant flow rates of 3.3-20 eBV/d (eBV = empty bed volume, equivalent to the bulk volume of the filter media used) and were checked gravimetrically at the outflow. Distilled water spiked with fluoride was used at Eawag, tap water from a near borehole at CDN. A list of column experiments is given in Table 1.

Table 1. Laboratory and field experiments

	Filter description	Volume L	Ratio pellet/BC	[F] mg/L	Flow rate (eBV/d)
CP - NLK	Two columns at CDN	0.26	3	6.2	10
CP - CK	Community filter “St. Mary’s” in Kenya	3’000	1.7	6.2	0.9
CP - NCK	Four community filters in Kenya	1’300 - 4’820	1.2 - 1.9	5.6 - 8.3	0.7 - 2.5
CP - EHR	Column at Eawag “high release”	0.30	3	15.0	3.3
CP - ELR	Column at Eawag “low release”	0.30	3	15.0	3.3
BC-ELR	Four columns at CDN	0.26 - 0.52	-	6.2	10 - 20
BC - NCK	Two community filters in Kenya	2’500 - 5’000	-	6.7	1.0 - 1.1
BC - NHE	Two household filters in Ethiopia	12	-	11.2	0.8 - 1.1

Field tests

Water samples at the community filter “St. Mary’s” were taken after every 5’000 L of treated water. The water samples of the other CDN community filters, both CP and BC, were taken at different time intervals. The water consumption was measured with water meters installed at the water points. Water samples of the

BC household filters in Ethiopia were taken every 1 to 2 weeks. The water consumption was measured with a pressure gauge placed in the filter (Johnston 2011). A list of the monitored filters is given in Table 1.

Results and discussion

Bone char filters

Fluoride breakthrough curves for BC column experiments and field community and household filters are presented in Figure 1. The uptake capacity to 1.5 mg F/L in the treated water ranges from 0.9 mg F/g to 1.5 mg F/g with an average of around 1.2 mg F/g. The range of uptake capacities of BC the filters is quite narrow. It can be seen that though the data is from very different tests with different input fluoride content water composition, the uptake capacity is remarkably similar.

Contact precipitation

Fluoride breakthrough curves for CP column experiments and field community filters are presented in Figure 1 as a function of fluoride uptake (mg F/g) in order to compare filter performance. The uptake capacity of most of the filters ranges from 2.0 mg F/g to 4.0 mg F/g with an average of around 3.0 mg F/g. It can be seen that the uptake capacity is spread over wider range than for BC. The filter material in St Mary's community filter has an uptake capacity equivalent to "low" release pellets, though it must be noted that the pellet:BC ratio of the St. Mary's filter is 1.7 to 1. Pellets with a high release of calcium and phosphate result in a very large uptake capacity (CP-EHR, around 6.5 mg F/g).

It must be pointed out that the CP method is still in development and that, though we know from preliminary experiments that a higher pellet:BC ratio and a slow flow rate increase uptake capacity, we do not yet have the field data to demonstrate the effect of these two parameters. The pellet:BC ratio of the community filters ranges from 1.2 - 1.9, while that of the laboratory experiments is 3. The flow rate in the community filters is generally below 2 eBV/d, while that of the laboratory columns is greater than 3 eBV/d.

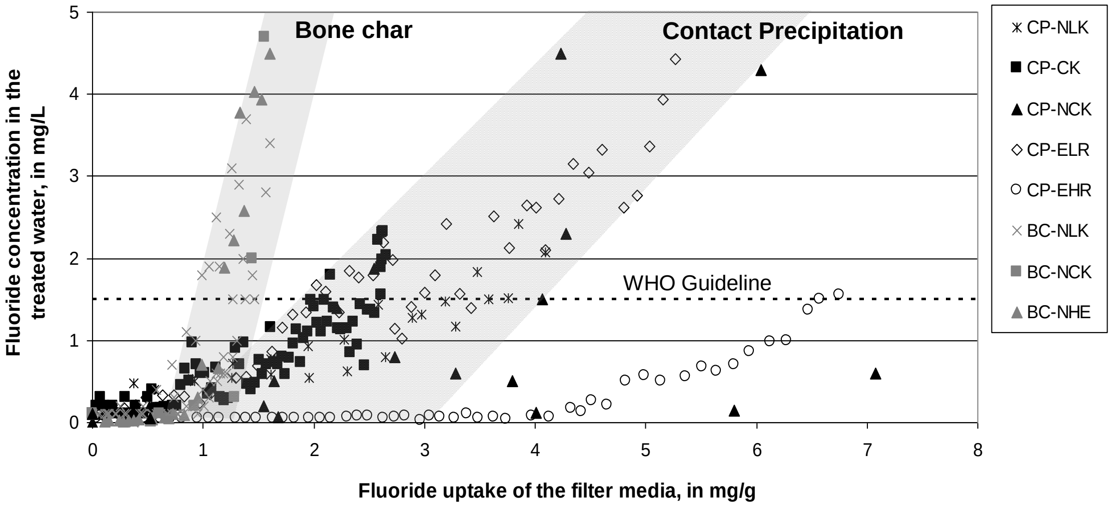

Figure 1. Fluoride uptake capacity of CP column experiments at CDN and Eawag, field tests on CP community filters maintained by CDN in Kenya (black symbols), and BC column experiments at CDN, field tests on BC community filters maintained by CDN in Kenya and BC household filters maintained by OSHO in Ethiopia (grey symbols)

Comparison of filter performance

On average the results show that the current CP filters have a filter lifetime 2.5 longer than BC filters. However, while the fluoride uptake capacity of the BC filters are very similar, even under different operating conditions, that of the CP filters appears to depend more strongly on a number of factors. These most likely include the pellet quality, pellet:BC ratio and flow rate, all factors that contribute to the calcium and phosphate concentrations available for fluoride coprecipitation within the filter columns.

Filter uptake capacity has an influence on the cost of treated water. In order to assess the relative costs of BC and CP filters it is necessary to compare the costs of the filter materials with the amount of water that can be treated. The price for calcium-phosphate pellets produced and sold by CDN is higher than the price for bone char. However the cost of CP-treated water is lower than that of the BC filters because of the longer filter life (CDN, personal communication). With a raw water concentration of 5 mg F/L, water treated with the CP filters costs 2.50 USD/m^3, while that treated in BC filters costs around 4.20 USD/m^3. In this costing only the filter material is considered.

Conclusion and outlook

The currently available results show that the uptake capacity of the BC filters is reproducible, irrespective of filter conditions. There is a greater variability in uptake capacity for the CP filters, probably because the filter function is more complex. The greater volume of water that can be treated by CP filters offsets the costs of the filter material making CP the preferred option from an economic point of view. Further work on the optimisation of the CP filters including pellet production and optimal operating conditions is planned.

Acknowledgements

The authors would like to extend special thanks to Peter Jacobsen who initiated the defluoridation programme at CDN We thank Hermann Mönch (Eawag) for analytical support and CDN's workshop team for the production of filter material and field support.

References

CDN, Mueller K. and Jacobsen P. (2007) *CDN's experiences in producing bone char.* Technical report, pp.10. http://www.wrq.eawag.ch

Dahi, E. (1996) *Contact precipitation for defluoridation of water*. In: Proceedings, 22nd WEDC Conference, New Delhi, India, pp. 262-265.

Samuel E., Mattle *M.J.*, Lem *F. (2009)*, *Household Water Treatment: Defluoridation of Drinking Water by Using Bone Char Technology in Ethiopia.* . In: Proceedings, 34th WEDC Conference, Addis Ababa, Ethiopia.

Fawell J., Bailey K., Chilton J., Dahi E., Fewtrell L. Magara Y. (2006) *Fluoride in Drinking Water* L. Fewtrell & J. Bartram (Eds.) IWA Publishing, London, 134 pp.

Korir H., Mueller M., Korir L., Kubai J., Wanja E., Wanjiku N., Waweru J. Mattle M., Osterwalder L. Johnson C.A. (2009) *The development of bone char-based filters for the removal of fluoride from drinking water.* In: Proceedings, 34th WEDC Conference, Addis Ababa, Ethiopia.

Johnston R.B., Edosa T., Osterwalder L. (2011) *Measuring use of household drinking water filters: field experiences from Ethiopia.* In: Proceedings, 35th WEDC Conference, Loughborough, U.K..

Larsen M.J., Pearce E.I.F. (1999) *Partial Defluoridation of Drinking Water Using Fluorapatite Precipitation*. Caries Research 26 (1), pp. 22-28.

Mueller K., Johnson C. A., Meierhofer R., and Wegelin M. (2006) *Fluoride removal in developing countries: State-of-the art of defluoridation techniques in East Africa*. In: Sandec News, No. 7, pp. 12-13.

NEERI- UNICEF (2008) *Integrated Fluorosis Mitigation, Guidance Manual.* http://neeri.res.in/pdf/integrated.pdf

UNESCO (2008) Ground water briefing: *Trace elements in groundwater and public health*. http://www.unesco.org/water/third_wwf/groundwater_health.pdf (status 29.2.2008)

Keywords

fluoride, defluoridation, water treatment, bone char, contact precipitation

Contact details

Name of Principal Author
Address
Tel:
Email:
www:

Name of Second Author
Address
Tel:
Email:
www: