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ACCESS TO SANITATION AND SAFE WATER:
GLOBAL PARTNERSHIPS AND LOCAL ACTIONS

Removal of fluoride from rural drinking water sources using geomaterials from Ghana

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This paper presents preliminary findings on the fluoride removal capability of some Ghanaian geomaterials and their potentials of being used to develop, design replicable easy-to-manage rural community based fluoride removal system. Batch experiments were performed on geomaterials (laterite and bauxite tailings) with raw fluoride-contaminated water (10.31 mg/l) from a borehole to determine their potentiality of removing excess fluoride from rural drinking water supplies. The raw bauxite tailings showed the higher removal capacity. Further experiments were conducted using heat-treated bauxite tailings. The results indicate that optimum fluoride removal is attained when the bauxite is heated to 600°C but removal capacity decreases with increased heating temperature. XRF analyses to determine chemical composition indicated Al_2O_3 , Fe_2O_3 and SiO_2 (silica) to be the most dominant compounds in that order.

Introduction

Access to adequate safe drinking water is a great challenge for rural communities in Ghana especially those in the Northern Region. As a result water-borne and water-related diseases such as guinea worm (*Dracunculus medenesis*), trachoma, typhoid fever, diarrheas etc. are prevalent in the rural communities.

Thus the Conrad N. Hilton Foundation (CNHF) and World Vision United States (WVUS) have provided financial support for the drilling of over 2000 boreholes fitted with handpumps to rural communities, educational and health institutions since 1991. Over 600 of these boreholes are located in the Northern Region. One hundred and fifty (151) of these boreholes have been detected to contain fluoride concentrations greater than the World Health Organization (WHO) drinking water guideline limit of 1.50mg/L. Approximately 50% of the affected boreholes contain fluoride less than 5.0mg/L. Also several boreholes in the Upper Regions have been detected to contain elevated fluoride concentrations (Apambire et al, 1997). Even though fluoride is a vital micronutrient for human physiological development and growth, excess intake of it can lead to both visible and non-visible debilitating diseases. The visible symptoms include dental fluorosis and skeletal fluorosis. Non-visible diseases include kidney and lung disorders, brittle skeletal system etc.

As a short-term measure, F- removal systems have been imported from Bangladesh and are being installed on the affected boreholes. These treatment systems are expensive to acquire and as well maintain. To ensure continuous safe drinking supply to the communities at minimum cost, it has become necessary to identify and develop affordable and sustainable treatment systems. To this end, initial studies have been conducted to identify appropriate locally available geomaterial for F- removal.

Some studies have been carried out using some natural geomaterials (Samson, 1952; Romo, 1957; Bower and Hatcher, 1967; Choi and Chen, 1979; Farrah and Pickering, 1986; Farrah et al., 1987; Wang and Reardon, 2001; çengelöglu et al 2002; Wang et al, 2002; Coetzee et al, 2003; Mohapatra et al, 2004). Others have used activated alumina (Hao and Huang, 1986; Lounici et al, 1997; Ku and Chiou, 2002). Almost all of these studies have used laboratory prepared aqueous solutions and the results have shown that optimum F- removal can be achieved within a pH range of 5 – 6.5. Such F- treatment systems can operate efficiently in poor rural communities in developing countries if additional units for buffer solutions to maintain the right pH range are provided. Skilled personnel to monitor such systems will also be required. This will impose extra cost for the communities.

Materials and procedure

Two experiments were carried out to first determine the F-removal capacities of laterite and bauxite and secondly to evaluate the effect of heat treatment on the F-removal capacity of the most efficient geomaterials.

Seven (7) laterite samples (LT) were collected from near fluoride-contaminated boreholes in the West Mamprusi (Kunkwa # 1-LTKK and Litcha-LTL), Gushiegu (Zogu-LTZ, Kanbonaazie-LTKB, Maaga-LTM and Yishie-LTY), and Savelugu-Nanton (Kadia-LTKD) Districts. The bauxite tailings (BXT) were collected from the Ghana Bauxite Mining Company Limited at Awaso in Ghana.

A gram (1.0g) of each of the crushed ($\approx 2\text{mm}$) untreated laterite and bauxite tailings were weighed into 50ml top screw tubes and then filled with 50ml of raw F- contaminated borehole water (Mang, WVI 1667) with initial F- concentration of 10.31mg/L and pH 8.11. The tubes were fixed to Barnstead/Thermolyne Lab-quake shaker and allowed to spin for 24hours and the decanted after standing for 10minutes. The supernatant was filtered and the pH, temperature and fluoride concentration (in mV) measured. Total Ionic Strength Adjustment Buffer III (5ml) was to each of the filtrates prior to measuring the F- concentration with an Orion Ionplus Fluoride electrode connected to a Beckman (225 pH/Temperature/mV) meter. A set of seven portions of the bauxite over a temperature range of 300-900C at temperature interval of 1000C. The samples were then crushed and sieved (BXT Series). Another set of the bauxite tailings was crushed and heated (SNJ series) over the same temperature range and intervals. One gram (1.0g), 1.50g, 2.0g, 2.5g, 3.0g and 3.5g of each of the heated bauxite were measured into top screw tubes and taken through the same process as above. To be sure that the bauxite is F--free, 1.0g of the unheated bauxite was weighed into a 50ml screen tap tube and filled with 50ml of de-ionized water and allowed to spin for 24hours. The chemical composition of the laterites and bauxite tailings was determined by X-ray fluoresce analyses.

Results and discussion

Fluoride adsorption

All the raw geomaterials show varying capacities of fluoride removal with the bauxite tailings having the highest removal capacity (35.4%) (*Figure 1*). The order of removal capacity is BXT>LTZ>LTL>LTKB>LTKK>LTM>LTY.

Further experiments were conducted on heated bauxite tailings since it showed a relatively higher F- reduction. A general increase in F- removal is observed with increased sorbent mass and temperature. The BXT series show F- reduction from 10.31g/l (raw water F- concentration) to below 1.50mg/l (i.e. WHO drinking water guideline limit) for sorbent mass range between 2.5g and 3.5g and a corresponding temperature range of between 5000C and 7000C. Optimum F- removal is obtained with 3.0g of sorbent at a temperature of 6000C (*Figure 2* & *Table 1*). On the otherhand the SNJ Series show F- reduction to below 1.50mg/l with sorbent mass between 1.5g and 3.5g. The corresponding temperature range for this reduction is 7000C and 8000C. The optimum removal is also obtained with 3.5g of sorbent at 7000C (*Figure 3*).

By comparison, the SNJ Series show better F- reduction capacity than the BXT Series. The BXT Series shows a relatively broader heating temperature range (5000C to 7000C) than SNJ Series. In contrast, the SNJ Series show a much broader sorbent mass range (1.5g-3.5g) for reducing F- to below 1.50mg/l than BXT Series. This suggests that a minimum of 1.5g of the SNJ Series (i.e. to 7000C) can remove 89.4% (i.e. 9.21mg/l F) of raw water F- concentration of 10.31mg/l to 1.1mg/l (i.e. below WHO limit of 1.5mg/l) (*Table 1*). Even greater quantities (e.g. 3.5g) of the SNJ Series is capable of better removing 92.7% (9.51mg/l) of the initial F- concentration of 10.31mg/l to 0.8mg/l. Therefore household water filters can possibly be produced if the appropriate ceramic ingredients (e.g. clay) are combined with crushed and heated (7000C) bauxite in the right proportions. Such filters can be used for both microbial and F- removal. For borehole-site F- removal, larger quantities of the bauxite tailings granules can be used as filtration media.

X-ray refraction (XRF) analysis of the unheated bauxite and the various laterites shows that Al_2O_3 , Fe_2O_3 and SiO_2 (silica) are the most dominant compounds (*Table 2*). The XRF also indicates that the bauxite contains the highest Al_2O_3 and the least Fe_2O_3 and SiO_2 content. The high fluoride removal capacity of bauxite compared to the various laterites can be attributed to the high Al_2O_3 (74.8%) content. On the other hand the removal capacities of the laterites can be attributed to the Fe_2O_3 contents (*Figure 4*).

pH

Generally there is an increase in pH for all samples with increase in heating temperature. The BXT series show increase of less than 1 pH unit for samples heated below 400°C and above 800°C. Similarly the SNJ series show pH increase of less than 1 unit for samples heated below 600°C. The highest pH increases are noticed with samples heated to 700°C and 800°C for BXT series and SNJ series respectively. These temperatures

at which the pH increases are highest mark the temperatures at which fluoride removal by the two types of heated-treated bauxite begins to decline. The pH increases with increase in fluoride sorption may be due to anion-exchange between the F⁻ ions and hydroxyl group on the geomaterials (Bower and Hatcher, 1967; Romo, 1954; Romo and Roy, 1957; Samson, 1952).

Conclusions and further work

Some bauxite tailings from Ghana are capable of reducing F⁻ from ≤ 10.31 mg/l in water to less than 1.50 mg/l by using crushed bauxite tailings (≈ 2 mm) that is heated to about 700 °C. Next steps to this experiment will be field-testing at both household and borehole-site to determine the breakthrough point. Drinking water filters producers will be contacted to explore the potential of producing affordable systems for fluoride removal.

Table 1: Comparative fluoride removal capacities of SNJ series and BXT series

Solid	1.0g		1.5g		2.0g		2.5g		3.0g		3.5g	
	% F	F in	% F	F in	% F	F in	% F	F in	% F	F in	% F	F in
	Absorbed	Solution	Absorbed	Solution	Absorbed	Solution	Absorbed	Solution	Absorbed	Solution	Absorbed	Solution
SNJ 300	63.3	3.78	69.6	3.13	77.7	2.30	80.8	1.98	87.7	1.27	87.5	1.29
BXT 300	31.3	7.08	35.9	6.61	38.1	6.38	44	5.77	53.3	4.81	59	4.23
SNJ 400	48.2	5.34	50.5	5.10	58.3	4.30	61.1	4.01	68.5	3.25	70.2	3.07
BXT 400	44	5.77	57.8	4.35	62.8	3.84	74.5	2.63	78.8	2.19	78.2	2.25
SNJ 500	47.6	5.40	51.7	4.98	59.5	4.18	61.3	3.99	70.1	3.08	71	2.99
BXT 500	69.2	3.18	74.7	2.61	80.7	1.99	88.1	1.23	85.6	1.48	85.7	1.47
SNJ 600	72	2.89	76	2.47	74.5	2.63	78.5	2.22	85.2	1.53	85	1.55
BXT 600	70.4	3.05	78.6	2.21	81.8	1.88	86.4	1.40	88.7	1.17	87.2	1.32
SNJ 700	78.3	2.24	89.4	1.09	86.9	1.35	90.1	1.02	89.2	1.11	92.7	0.75
BXT 700	63.1	3.80	72.6	2.82	76.4	2.43	82.2	1.84	87	1.34	86.4	1.40
SNJ 800	75.3	2.55	82.2	1.84	82.3	1.82	86.4	1.40	87.4	1.30	91	0.93
BXT 800	54.6	4.68	67.2	3.38	71.8	2.91	80.4	2.02	82.4	1.81	81.8	1.88
SNJ 900	70.7	3.02	77.8	2.29	79	2.17	83.3	1.72	85	1.55	87.7	1.27
BXT 900	31.8	7.03	33.4	6.87	38.8	6.31	44.4	5.73	52.1	4.94	51.3	5.02

Table 2. Fluoride removal capacity - chemical composition relationship

Sample ID	F (mg/kg)	% Al ₂ O ₃	% SiO ₂	% Fe ₂ O ₃	LOI
BXT	182.5	74.78	1.55	18.64	1.00
LTZ	131.5	8.1	32.6	32.9	22.1
LTL	125.5	9.1	40.7	25.3	17.6
LTKB	117.5	6.7	36.3	35.2	16.5
LTKK	113.0	7.9	26.3	41.3	19.5
LTM	105.0	6.0	37.7	35.7	16.5
LTY	74.0	9.0	20.2	46.5	19.5

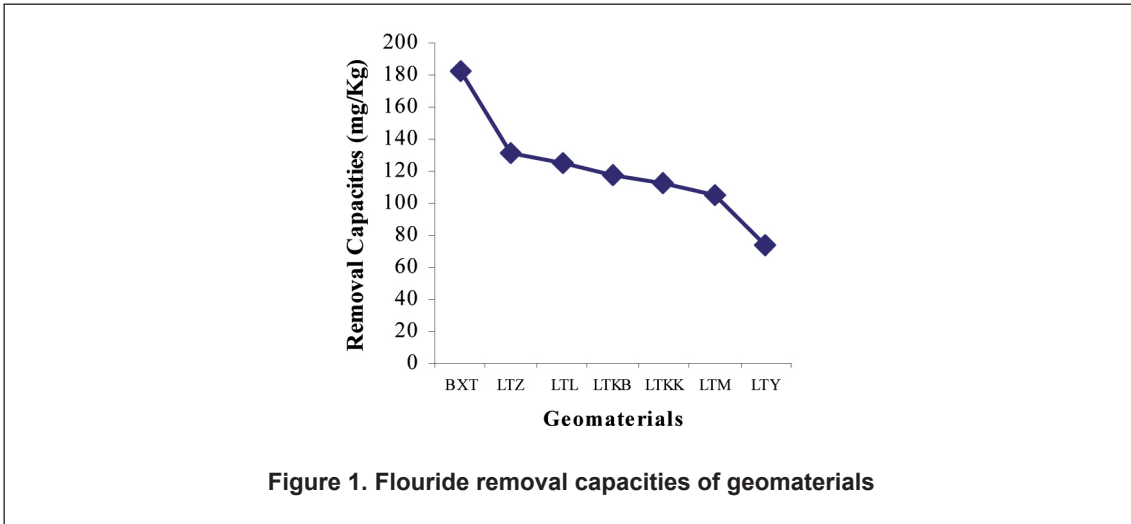


Figure 1. Fluoride removal capacities of geomaterials

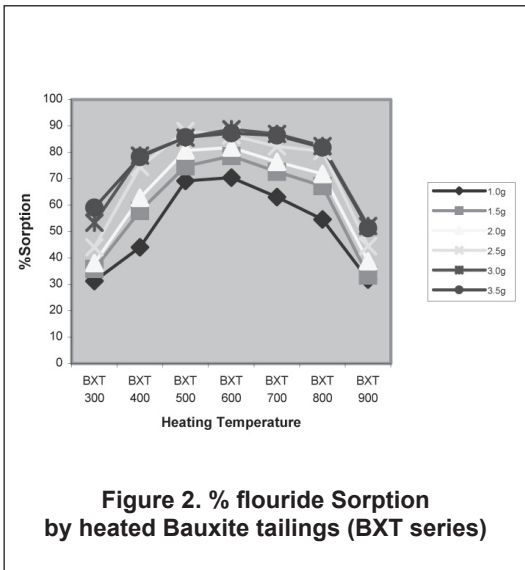


Figure 2. % fluoride Sorption by heated Bauxite tailings (BXT series)

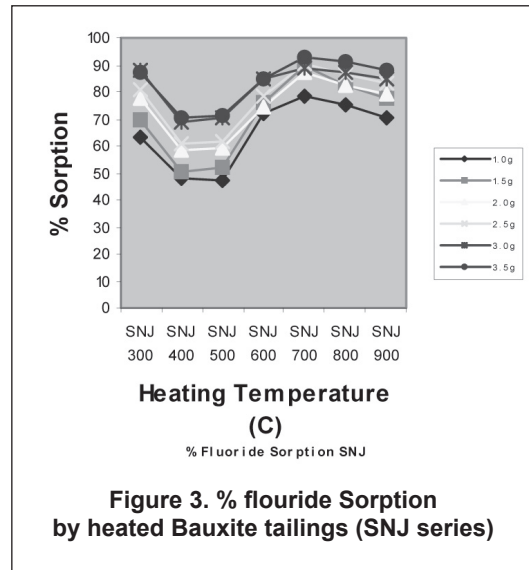


Figure 3. % fluoride Sorption by heated Bauxite tailings (SNJ series)

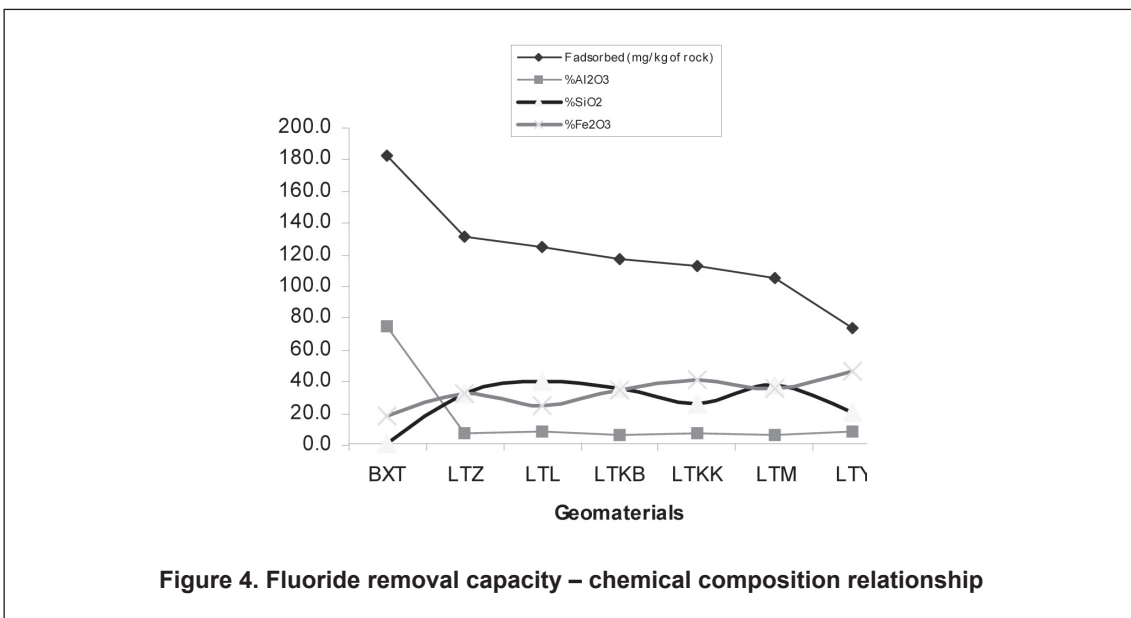


Figure 4. Fluoride removal capacity – chemical composition relationship

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References

- Apambire, W.B., Boyle, D.R and Michel, F. A (1997) *Geochemistry, genesis and health implications of fluoriferous groundwaters in the Upper Region of Ghana*. Environmental Geology. International Journal of Geosciences. Vol.33 No.1 pp.13-24.
- Bower, C. A and Hatcher, J.T (1967) *Adsorption of fluoride by soils and minerals*. Soil Science Vol. 103, No. 3, pp. 151-154.
- Çengelöglu, Y. Kir, E. and Ersöz, M. (2002) Removal of fluoride from aqueous solution by using red mud. Separation and Purification Technology. Vol. 28, pp. 81-86.
- Choi, W-W and Chen, K. Y (1979) *The removal of fluoride from waters by adsorption*. Water Technology/Quality: Journal American Water Works Association. pp. 562-571.
- Christoffersen, J., Christoffersen, M.R., Larsen, R and Møller, I. J (1991) *Regeneration by surface coating of bone char used for defluoridation of water*. Water Research Vol. 25, No. 2, pp. 227-229.
- Coetzee, P.P., Coetzee, L.L., Puka, R. and Mubenga, S. (2003) Characterisation of selected South African clays for defluoridation of natural waters. Water SA, Vol. 29, No. 3, pp. 331-338.
- Farrah, H. and Pickering, W. F. (1986) *Interaction of dilute fluoride solutions with hydrous iron oxides*. Australian Journal of Soil Research. Vol. 24, pp. 201-208.
- Farrah, H., Slavek, J. and Pickering, W.F (1987) *Fluoride interaction with hydrous aluminum oxides and alumina*. Australian Journal of Soil Research. Vol. 25, pp. 55-69.
- Hao, O. J. and Huang, C. P. (1986) *Adsorption characteristics of fluoride onto hydrous alumina*. Journal of Environmental Engineering (ASCE) Vol.112, pp. 1054-1069.
- Harrington, L.F., Cooper, E.M and Vasudevan, D (2003) *Fluoride sorption and associated aluminum release in variable charged soils*. Journal of Colloid and Interface Science 267: 302-313.
- Hiemstra, T. and Riemsdijk (2000) *Fluoride adsorption on goethite in relation to different types of surface sites*. Journal of Colloid and Interface Science. Vol. 225, pp. 94-104.
- Ku, Y and Chiou, H (2002). *The Adsorption of Fluoride Ion From Aqueous Solution by Activated Alumina*. Water, Air, and Soil Pollution 133: 349-360.
- Lounici, H., Addour, L., Belhocine, D., Grib, H., Nicolas, S., Bariou, B. (1997) *Study of a new technique for fluoride removal from water*. Desalination 114:241-251.
- Mohapatra, D., Mishra, D., Mishra, S.P., Chaudhury, G.R. and Das, R. P. (2004) *Use of oxide minerals to abate fluoride from water*. Journal of Colloid and Interface Science. Vol. 275, pp. 355-359.
- Nawlakhe, W.G and Bulusu, K. R. (1989) *Nalgonda technique- a process for removal of fluoride from drinking water*. Water Quality Bulletin. Vol. 14, pp. 218-220.
- Romo, L. A., and Roy, R. (1957) *Studies of the substitution of OH by F in various hydroxylic minerals*. American Mineralogist, Vol.42, pp. 165-177.
- Samson, H.R (1952) *Fluoride adsorption by clay minerals and hydrated aluminum*. Clay Minerals Bulletin Vol.1, pp. 266-271.
- Singh, R.P., Singh, Y., Swaroop, D. (2000) *Defluoridation of Groundwater in Agra City Using Low Cost Adsorbents*. Bulletin Environmental Contamination and Toxicology 65: 120-125.
- Wang, Y. and Reardon, E.J. (2001) *Activation and regeneration of a soil sorbent for defluoridation of drinking water*. Applied Geochemistry Vol.16, pp. 531-539.
- Wang, W., Li, R., Tan, J., Luo, K., Yang, L., Li, H. and Li, Y. (2002) *Adsorption and leaching of fluoride in soils of China*. Fluoride. Vol. 35 (2), pp. 122.
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