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Removal of Fluoride Ions from Aqueous Solution using Water Hyacinth Biomass as a Low-Cost Adsorbent

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ABSTRACT
Batch experimental technique was used to remove fluoride ions from aqueous solution using water hyacinth biomass as a low cost adsorbent under different experimental parameters. Stem fractions of water hyacinth (*Eichhornia crassipes)* were air dried for 8 days and in the oven for 24 hours at 110 ^{0}C and allowed to cool in a desiccator. They were ground into powder and sieved into various particle sizes and used in fluoride removal experiments.100 ml of solution containing known amounts of fluoride ion was added to 1g of water hyacinth powder in a beaker, stirred and allowed to stand for predetermined times. The solution was filtered and the fluoride ion concentration in the filtrate was determined using ion selective electrode. The pH of the solution was maintained at 6.2 throughout the experiments. The adsorptive properties of fluoride ion were influenced by contact time, the adsorbent dosage and the particle size of the adsorbent. Water hyacinth powder effectively removed fluoride ion from aqueous solution.

Introduction

Contamination of water by fluoride ion is of concern due its human health effects especially at elevated concentrations. However, at low levels fluoride is essential for bones and dental enamel formation in humans and animals. Some water systems are known to contain naturally occurring fluoride and hence must be treated to comply with fluoride limits in drinking water. In Kenya, Kenya Bureau of Standards (KEBS) has set a limit of 1.5mg/l for fluoride [1]. Water is an essential commodity for life, hence at the water treatment points, fluoride is added to water (1mg/L) to help reduce tooth decay which is one of the usefulness of fluoride. In the environment fluoride compounds include fluorspar, cryolite and fluorapatite. Fluorspar is known to contain the highest percentage of fluoride by weight as calcium fluoride (CaF_2). According to UNICEF report [2], a good number of people living in developing countries have no access to safe drinking water.

The removal of fluoride ions from water requires a suitable and cost effective method. The removal methods that have been adopted include membrane filtration [3], nanofiltration [4] ion exchange [5], electrocoagulation, flotation [6], precipitation [7] and adsorption [8]. Adsorption is an effective method that is used in the removal of fluoride [9]. Water hyacinth (Eichhornia crassipes) is currently a menace in many water bodies in Kenya [10] and has interfered with many activities in Lake Victoria especially fishing, hence its use as a low cost adsorbent to remove fluoride from water would be quite beneficial. More so, water in many parts of Rift Valley part of Kenya is contaminated with fluoride. The objective of this study was therefore to determine the effectiveness of Dry Powdered Water hyacinth Biomass (DPWHB) as a low cost adsorbent in the removal of fluoride from aqueous solution with the intention of applying the technique to domestic water. Water hyacinth is a cheap and low cost material that is available for many rural communities in Kenya, who live in the regions where drinking water has high fluoride levels. Some of the fluoride compounds are quite soluble in water hence fluoride can be present in surface and groundwater in a completely dissociated fluoride ion [11; 12].

Health effect of fluoride in water

Fluoride is rarely found in its elemental state and instead exists in inorganic form and in rare cases organic fluoride (F^-). In the body, fluoride is found mostly as calcium fluoride especially in the teeth and bones. It protects the teeth from demineralization brought about by acid released when the bacteria in the mouth digest starch and release acid. The acid erodes the teeth and causes damage.

The effects of fluoride on the skeletal structure are based on the ion exchange reactions between hydroxide and fluoride ions in the calcium hydroxyl-phosphate which forms the primary composition of the skeletal structure. The exchange of ions results in the formation of a more acid-resistant structure (fluorapatite). The ion exchange reaction during the process occurs according to the following equation (1).

$$Ca_5(PO_4)_3OH + F^- \rightarrow Ca_5(PO_4)_3F + OH^- \quad (1)$$

The excessive uptake of fluorides will go beyond the exchange of hydroxyl ions with fluoride ions or exchange of phosphate ion with fluoride. This results in the formation of calcium decafluoride which is a very brittle material that cannot function as a skeletal structure. Equation (2) explains the formation of decafluoride in the presence of excess fluorides.

$$Ca_5(PO_4)_3F + 9F^- \rightarrow Ca_5F_{10} + 3PO_4^{3-} \quad (2)$$

Health effects of fluoride include: fluorosis, muscle atrophy, reduced hemoglobin content, distortion of red blood cells shape, rashes on the skin, abdominal pains, reduced immunity, urinary tract failure and tingling sensation in toes/fingers amongst others [13].

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Table 1. Percentage fluoride adsorbed and adsorption capacity at different particle sizes.

Particle size (µm)	Initial concentration C_o mg/L	Final concentration C_t mg/L	Concentration change $(C_o - C_t)$ mg/L	%fluoride adsorbed $\frac{(Co-Ct)}{Co}$ x 100	Adsorption capacity $\frac{(Co-Ct)}{m}$ x V
≤250	10	5.87	4.13	41.3	$\frac{(10-5.87)}{1}$ x 0.1 = 0.413 mg/g
250-710	10	7.28	2.72	27.2	$\frac{(10-7.28)}{1}$ x 0.1 = 0.272 mg/g
710-1400	10	9.28	0.72	7.2	$\frac{(10-9.28)}{1}$ x 0.1 = 0.072 mg/g

Materials and Methods

Many water bodies in Kenya are occupied by water hyacinth which has become a menace to water activities (Figure 1).

Preparation of water hyacinth adsorbent

Water hyacinth biomass was collected from Lake Victoria and stems were chopped into smaller sizes. They were dried in the sun for 8 days and then dried in the oven at 110ºC for 24 hours to remove the moisture completely. The dry samples were then crushed to powder using pestle and motor. The samples were sieved through ≤250µm, 710µm, and 1400µm particle sizes. The various particle sizes were placed in air tight plastic bottles and stored for subsequent use in the study.

Adsorption studies for removal of fluoride from aqueous solution

Batch experiments were carried out by adding 100 mL of the stock solution containing known amount of fluoride to a measured mass of powdered water hyacinth biomass placed in a series of beakers at room temperature. The mixtures were stirred at the beginning to homogenize the solutions.

Figure 1. Water hyacinth on Lake Victoria, Kisumu County.

The mixtures were left to stand for predetermined times and then the samples were filtered through Whatman filter paper. The filtrate was then analyzed for the presence of fluoride ion using ion selective electrode. The adsorption studies were done at constant pH of 6.2 throughout the experiment.

The effect of particle size on fluoride removal

100ml of 10 mg/l of fluoride solution was added to 1g powdered water hyacinth of various sizes (≤250 µm, 250-710 and 710-1400 µm) in a beaker, stirred and left to stand for 120 minutes. The solution was filtered into 200ml beakers and the fluoride ion concentration analyzed for each of the particle sizes using the ion selective electrode. The pH of the aqueous solution was maintained at 6.2 throughout the experiment.

Effect of the amount of adsorbent on fluoride removal

Various amounts of powdered water hyacinth was taken (0.1, 0.2, 0.4, 0. 8, 1.5, 2.0, 2.5 and 3.0 g) and 100 ml of the 10 mg/l of the fluoride added. The experimental procedure was the same as in the previous one and the pH of the aqueous solution was kept at 6.2 throughout the experiment.

Effect of contact time on fluoride removal

0.1g of ≤250 µm DPWHB was placed in 100 mL beaker, and 100 mL of 10mg/L fluoride solution was added, stirred and left to stand. Fluoride concentration was taken after every 30 minutes for 4 hours. The working pH was 6.2.

Results and Discussion

Effect of particle size

The percentage of fluoride adsorbed and adsorption capacity at different particle sizes were computed and recorded as in Table 1.

C_o = 10 mg/L; C_t = new concentration after adsorption; m = mass of powdered water hyacinth; V = 0.1L (100 mL).

The % of fluoride adsorbed by the various particle sizes as represented in Table 1 showed that the smaller particles (≤250 µm) removed high amount of fluoride which could be attributed to the large surface area for adsorption provided by the smaller particles. The study revealed that the percentage of fluoride removed decreased with increasing particle size from ≤250 µm to 710-1400 µm which is clearly shown in Figure 2.

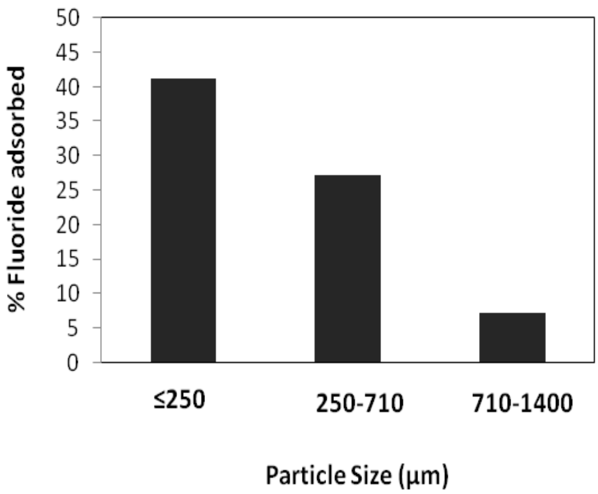

Figure 2. Effect of particle size on fluoride removal from aqueous solution.

Effects of adsorbent amount on fluoride removal

The amount of adsorbent was varied (0.1 to 3.0g) while the fluoride concentration added was kept constant (10 mg/l). The % of fluoride adsorbed and adsorption capacity were calculated as reported in Table 2. The contact time was kept at 2 hours. The particle size used was ≤250 µm in all the cases.

The study showed that the efficiency of adsorbent to remove fluoride significantly increased with the amount of the water hyacinth biomass (Table 2).

Table 2. Percentage fluoride adsorbed and adsorption capacity using different amounts of adsorbent.

Mass of DPWHB (g)	**Initial concentration C_o** mg/L	**Final concentration C_t** mg/L	**Concentration change (C_o -C_t)** mg/L	**%fluoride adsorbed $\frac{(Co-Ct)}{Co}$ x 100**	**Adsorption capacity $\frac{(Co-Ct)}{m}$ x V** (mg/g)
0.1	10	9.09	0.91	9.1	0.91
0.2	10	8.73	1.27	12.7	0.64
0.3	10	8.43	1.57	15.7	0.52
0.4	10	7.79	2.21	22.1	0.55
0.8	10	7.58	2.42	24.2	0.38
1.0	10	7.34	2.66	26.6	0.27
1.5	10	6.48	3.52	35.2	0.23
2	10	5.8	4.2	42.0	0.21
2.5	10	5.7	4.3	43.0	0.17
3.0	10	5.7	4.3	43.0	0.14

C_o = 10 mg/L; C_t = new concentration after adsorption; m = mass of DBWHB; V = 0.1L

Table 3. Percentage of fluoride adsorbed and adsorption capacity at different contact times.

Time (min)	**Initial concentration C_o** mg/L	**Final concentration C_t** mg/L	**Concentration change (C_o -C_t)** mg/L	%fluoride adsorbed $\frac{(Co-Ct)}{Co}$ x 100	Adsorption capacity $\frac{(Co-Ct)}{m}$ x V **(**mg/g)
30	10	8.15	1.85	18.5	0.185 mg/g
60	10	7.84	2.16	21.6	0.216 mg/g
90	10	7.62	2.38	23.8	0.238 mg/g
120	10	7.42	2.58	25.8	0.258 mg/g
150	10	6.5	3.5	35.0	0.350 mg/g
180	10	6.48	3.52	35.2	0.352 mg/g

Effect of contact time on fluoride removal

The % fluoride adsorbed over a series of times was calculated when the concentration of fluoride was kept constant (10 mg/L) and particle size was ≤250μm.The computed results for the adsorbed fluoride are shown in Table 3. The study revealed that the amount (%) of fluoride adsorbed on the water hyacinth biomass increased as the time of contact increased. More fluoride was being removed as the time increased. However, Figure 3 showed that the adsorbed fluoride reached some maximum point after which it levelled off.

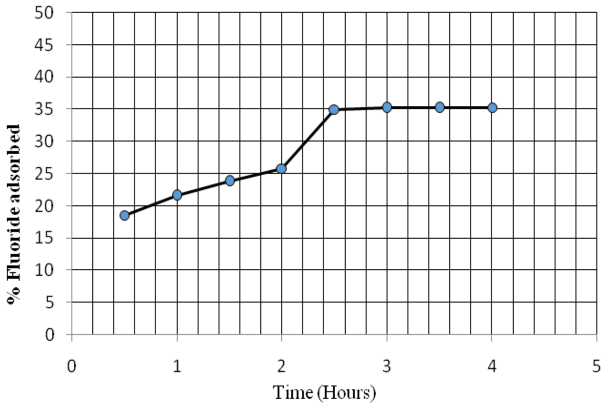

Figure 3. Describes the percentage of fluoride removed against contact time.

The observed increase, followed by a plateau is attributed to the fact that at the beginning, all active sites of the adsorbent are free and therefore fluoride ions are adsorbed at a faster rate. However, after 2 hours (Figure 3), the amount of fluoride adsorbed levelled off. This was due to drop in fluoride concentration and saturation of the active adsorbent sites [14].

Conclusion

The amount of fluoride adsorbed and adsorption capacity decreased with increased particle size of the water hyacinth biomass. As the mass of adsorbent increased, the amount of fluoride adsorbed increased and the adsorption capacity decreased. The amount of fluoride adsorbed and adsorption capacity increased with contact time. However, it was observed that after reaching a maximum, the adsorption formed a plateau. The study showed that dry powdered water hyacinth biomass could be used as a low cost adsorbent to remove fluoride from domestic water. The use of dry powdered water hyacinth biomass (DPWHB) as an adsorbent for fluoride in water would help reduce the menace of water hyacinth in dams and Lakes in Kenya.

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