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Eco-Friendly Agricultural Biomass-based Adsorbents for Removing Fluoride from Drinking Water: A Review of their Performance and Real-World Challenges

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***Abstract*— Removal of fluoride from groundwater remains a serious concern for the environment and health, especially in developing nations where groundwater is the primary source of drinking water. Excess fluoride in groundwater can cause dental and bone disorders, as well as other health problems, which is why there is a need for cost-effective and long-term solutions for the removal of fluoride. This review examines the current developments in the removal of fluoride using low-cost adsorbents prepared from agricultural biomass. Adsorbents such as activated bagasse carbon, sawdust, wheat straw, and rice husk have been found to possess a strong potential for fluoride adsorption, especially in water with a pH close to neutrality, as is found in natural conditions. The efficiency of these adsorbents typically varies between 40% and 94%, depending on several conditions such as pH, contact time, temperature, presence of other ions, and dosage of the adsorbent. Although these methods have been found to be effective in the laboratory, their practicality on a large scale and in the long term is still limited. The review discusses how these regeneration of these adsorbents, their evaluation on a larger scale, and their application in real-life settings.**

***Index Terms*— Adsorption, Carbon, Defluorination, Fluoride, Water.**

I. Introduction

The fluoride in drinking water is a significant concern in the environment and health globally, particularly in for potable water. A certain quantity of fluoride, ranging from 0.5 to 1.0 milligrams per liter of water, is essential in preventing tooth decay, but excess levels of fluoride can result in severe health issues. Fluoride in excess can cause dental fluorosis, which affects teeth, and skeletal fluorosis, which impacts bones. Moreover, it can also cause other health issues, including nervous disorders, kidney failure, and developmental abnormalities in children. The World Health Organization recommends the permissible limit of fluoride to be 1.5 mg/L, but in reality, the level of fluoride in groundwater in many regions is significantly higher than that Conventional technologies [1,2,3,4]. However, these technologies are often expensive, use large quantities of chemicals, are difficult to handle, generate waste, and are not efficient in varying water conditions. Therefore, these technologies are not suitable for small-scale rural areas. Adsorption has become a more attractive alternative because it is simpler, less expensive, requires fewer chemicals, and is easier to control. However, most of the adsorbents that are currently marketed are most effective in acidic water (pH 3 to 5), which is not very suitable for water treatment [5].

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Because of this, scientists are now turning to materials derived from agro-waste and plant wastes such as bagasse, rice husk, sawdust, coconut shell, groundnut husk, and wheat straw [6].These materials have good surface properties and functional groups that make them efficient fluoride removers [7]. Using agricultural by-products addresses two issues simultaneously: waste management and water quality improvement. Different processes such as acid or base treatment, heating, and the addition of metals can be used to remove the fluoride capacity of these materials by increasing their surface area and binding sites [8].
Although many laboratory studies have already demonstrated the effectiveness of these materials, there is not much research that integrates the major findings, limitations, and potential for scaling up [9,10,11].This review hopes to examine the effectiveness of these agricultural-based adsorbents in removing fluoride, how their performance varies depending on different conditions, and what factors are currently hindering their widespread use [12,13,14].

II. Materials and Methodology

A. Preparation of Sawdust and Wheat Straw

The Sawdust and wheat straw treated is used to extract fluoride from water. Wheat straw obtained from Triticum species, and sawdust is collected from Indian Rosewood (Dalbergia sissoo). These materials are gathered locally and cleaning to get rid of any dirt, dust, or impurities. The material is allowed to dry in the sun to lower moisture content [15,16]. The powder material is used to improve surface area, which is used for successful adsorption. Formaldehyde is used for strengthen structural strength and removing coloring and soluble chemicals from the fine biomass. A 1% formaldehyde solution is prepared, and the added to biomass at a weight-to-volume ratio of 1:5. The mixture is then kept at 50°C for four hours. The procedure allowed the formaldehyde to connect with the lignin and phenolic groups in the biomass, increasing the adsorbents' longevity, decreasing their solubility in water, and preventing breaking down during use [17]. The filtered material is carefully washed with distilled water to eliminate any residual formaldehyde and other soluble chemicals [18].The washed samples is then dried with 80°C in oven for 24 hours “Fig. 1”. Thus the material become thermally stable with consistent moisture levels. The dried biomass is then crushed again to ensure a consistent texture and sieved from 20 to 50 mesh. The procedure is used to make material homogenous and suitable for use in adsorption tests [19,20]. Finally, the manufactured sawdust and wheat straw adsorbents were stored in sealed, moisture-free containers to prevent contamination and preserve their porosity and adsorption properties for the subsequent studies [21].

B. Preparation of Activated Bagasse Carbon

A local sugarcane juice vendor provided the sugarcane bagasse. It was sun-dried after being cleaned in pure water. Sulfuric acid was combined with dried sugarcane bagasse and heated to 150 °C for a full day in an air oven. Before steeping in a 1% sodium bicarbonate solution for the entire night, the heated material was cleaned with filtered water to get rid of any remaining acid [22,23]. The material was screened to 20-50 mesh ASTM after being baked for a full day at 105 °C “Fig. 1”.

C. Preparation of Rice Husk Carbon

Figure 1. Process for adsorbent carbon

The rice husk is made free from the dust, soil particles, and soluble impurities, then the rice husk is meticulously cleaned with distilled water. Making sure that all surface moisture was eliminated, the cleaned husk was spread out in a dust-free, open space and drying in the sun was carried for two days. Following sun-drying, the material is gently powder using a mechanical grinder [24,25]. The powder material is then stored in an airtight polyethylene container for use as an unaltered adsorbent. Modified rice husk is prepared with combing 500 mL of 0.1 mol dm^{-3} hydrochloric acid (HCl) with 250 g of powdered rice husk [26].The mixture is then heated to 110 °C for 20 minutes with constant stirring to promote acid activation and for removal of any mineral components that might obstruct adsorption "Fig. 1". A Buchner funnel is used to vacuum-filter the heated acid-treated rice husk slurry. To cast aside of extra acid, the solid residue is washed with distilled water until it reached a neutral pH (pH = 7). The HCl is used to modified rice husk that is obtained by air-drying the cleaned adsorbent for 48 hours. The additional characterizated and fluoride adsorption tests, the both generated adsorbents, acid-modified and unmodified is stored in hygienic, airtight containers [27].

III. Result and Discussion

A. Effect of absorption with time

The three adsorbents that were considered in relation to the adsorption capacity is the function of efficiency of fluoride removal with increased contact time (from 15min to 105min) include bagasse carbon, sawdust, and wheat straw. The data shows that all adsorbents required time to adsorb, with efficiency improving as the contact time increased. The efficiency of bagasse carbon was highest in removing the contaminants. The efficiency level of removing the contaminant started from 45% at 15 minutes to nearly 80% efficiency at 105 minutes with a steep curve initially for 60 minutes, after which it decayed. This reveals that the equilibrium was nearly reached.

The moderate efficiency of raw saw dust adsorption increased gradually from 46% in 15 minutes to 68% in 105 minutes. Although the affinity of these adsorbents is lower than that of bagasse carbon, an increase in affinity indicates the continuous presence of available adsorption sites. The least efficient adsorbent was raw wheat straw. With an average slower adsorption rate and early stabilization, there was a relative increase in efficiency from 25% at 15 min to 53% at 105 minutes "Fig. 2".

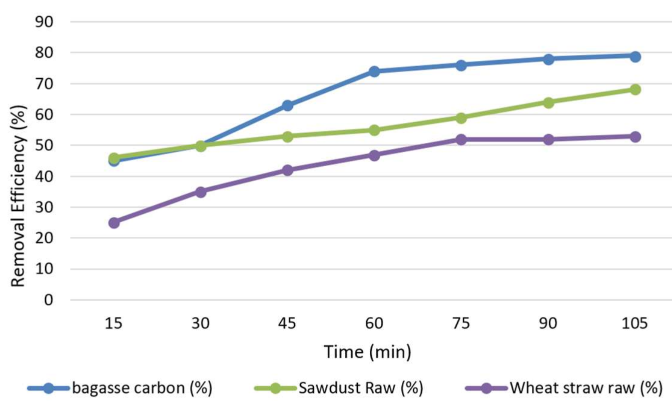

Figure 2. Effect of absorption with time

B. Effect of pH on Adsorption

Bagasse carbon, raw sawdust, and raw wheat samples were tested for effect of pH on fluoride removal capacity using each adsorbent separately. Results clearly show that adsorption capacity of all adsorbents alters depending on pH values. Relative removal percentage of all adsorbents varies in the following manner: The lower interaction between the fluoride ions and the surface of the adsorbent resulted in a relatively poor efficiency of the removal of the fluoride ions in the lower levels of pH. There was an increase in the removal of the fluoride ions with the increase in the levels of pH.

This is attributed to the favourable surface charge of the adsorbent, which increases the efficiency of the removal of the fluoride ions. Compared to the other two adsorbents, the removal efficiency of bagasse carbon was least and gradually increased with the increase in pH, but it was always much lower than the other two adsorbents. The removal efficiency of raw sawdust had an average adsorption capacity and a steady increase with the increase in pH value "Fig. 3". Raw wheat straw had the highest adsorption capacity among all adsorbents and a significant increase of fluoride removal capacity with increasing pH value. This research has demonstrated that fluoride adsorption is more preferred under basic pH and conditions, and raw wheat straw is the best adsorbent medium compared to other adsorbents.

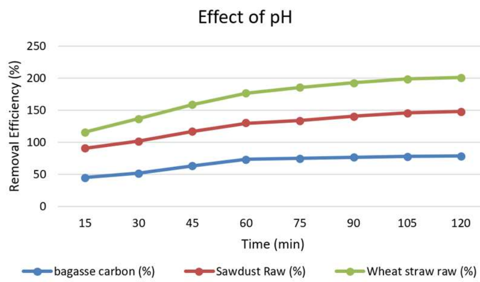

Figure 3. Effect of pH on Adsorption

C. Effect of Contact Time on Adsorption

The role of time in contact for removal efficiency was performed for raw sawdust, raw wheat straw, and bagasse carbon. The results showed an growth in removal efficiency due to the increase in the progress of the adsorption process up to the near achievement of the equilibrium state for the three adsorbents. The removal efficiency of the bagasse carbon was reduced by 45% for the first contact time, which later rose to 65% for the maximum contact time. It can be noted that the removal of contaminants was slower for the material compared to others. The capacity of adsorption of sawdust was higher than the bagasse carbon. The removal efficiency of the contaminant increased from 75% to 125% as the contact time increased from initial to maximum. The rate of increase of the removal efficiency of the contaminant was faster in the initial period, followed by steady increments, indicating steady usage of the adsorption capacity. The efficiency of raw wheat straw was the highest in the removal of the adsorbate. The efficiency level rose from 95% in the initial state to a range of 170-175% efficiency at the point of maximum contact “Fig. 4”. The rate of rise in efficiency was faster for lower contact times that gradually diminished. Generally, the trend for the degree of efficiency for adsorption was: wheat straw raw > sawdust raw > bagasse carbon. The findings supported that with the increase in contact time, there would be enhancement in efficiency for adsorption, and that efficiency for the raw wheat straw would be highest among all.

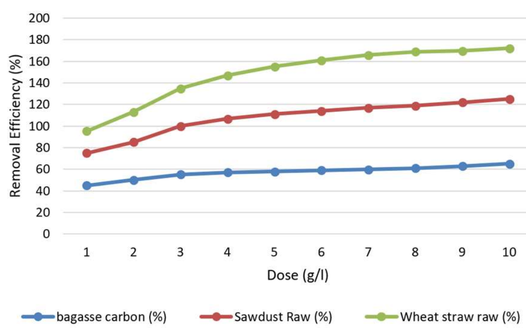

Figure 4. Effect of contact time on Adsorption

IV. CONCLUSION

The adsorption capacity of bagasse carbon, sawdust, and wheat straw for fluoride ion removal was investigated for contact times between 15 and 105 minutes and at different pH levels. Fluoride ion adsorption capacity increased with time for all adsorbents, showing the progressive use of active sites and eventually reaching equilibrium. The removal efficiency of bagasse carbon increased rapidly with time and reached saturation, followed by sawdust, which showed moderate and consistent adsorption. Wheat straw had the lowest time-based removal efficiency, indicating the least number of binding sites. pH played a crucial role in determining the efficiency of adsorption, and higher pH values were more favourable for the removal of fluoride ions for all adsorbents. At lower pH values, the removal efficiency was low due to the repulsive forces between the surface charges of the adsorbents and the fluoride ions. As the pH values increased, the electrostatic attraction between the fluoride ions and the adsorbent surfaces increased, resulting in higher removal efficiencies. Among the adsorbents, wheat straw had the highest removal efficiency at all pH values, followed by sawdust, and bagasse carbon had the lowest removal efficiency at lower pH values.

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