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DEFLUORIDATION OF WATER BY LOW COST ADSORBENT

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Abstract : India is among nation higher in percentage suffer from fluorosis through consumption of groundwater. Fluoride content in natural water has become a major issue in major parts of the world and should be in 0.6 to 1.5 mg/l. Investigations in the removal of fluoride content have been carried in various techniques. Process of removing of excess fluoride content is known as Defluorination. Banana Peel as adsorbent were used.
This study focuses on reducing fluoride levels in water to make it safe for drinking by using naturally available, low-cost adsorbents as an environmentally sustainable solution. The investigation includes examining how factors such as adsorption duration, fluoride concentration, and varying adsorbent doses at a controlled temperature influence the removal process..

***Keywords* - Defluoration, low cost adsorbent, Time study, pH study, various method use, Various use of chemical.**

I. INTRODUCTION

The quality of drinking water is likely to become a major concern in the future due to the rising levels of pollution in water bodies [1]. One such contaminant is fluoride, which poses significant risks to living organisms, especially humans [2]. While fluoride is beneficial in small amounts—contributing to bone development and protecting against dental cavities—excessive intake can lead to the deterioration of tooth enamel, a condition known as fluorosis. Fluoride can enter aquatic systems naturally through the weathering of fluoride-rich minerals, as well as through human activities such as industrial discharge [3]. This issue is particularly serious in tropical countries like India, Kenya, Senegal, and Tanzania. The most effective way to address this problem is through defluoridation. Various methods exist for removing fluoride, such as precipitation-coagulation, membrane filtration, ion exchange, and adsorption. However, the precipitation–coagulation technique produces a significant volume of sludge and may also eliminate other undesirable substances. Membrane-based techniques, while effective, are costly and prone to fouling, which is difficult to avoid. Adsorption methods offer distinct advantages, such as simplicity and reduced water usage. This review compiles an extensive range of literature, and an analysis of approximately 200 recent studies shows that low-cost techniques have demonstrated significant potential for fluoride removal.

Table 1. Effects of concentration of fluorine [4]

concentration of fluorine (mg/l)	Effects
<1.0	Reduces dental caries
1.0 - 1.5	A marginal risk of fluorosis
1.5 - 3.0	Risk of dental fluorosis
3.0 - 10.0	Skeletal fluorosis with an adverse change in bone st
>10.0	Crippling and skeletal fluorosis

Fluoride plays an important role as a micronutrient when present in small amounts, aiding in bone development and the prevention of tooth decay. However, high levels of fluoride consumption can lead to dental fluorosis—characterized by enamel damage—and Fluoride contamination in water systems has been linked to numerous serious health conditions, including skeletal disorders like osteoporosis, joint ailments, nerve system impairment, several types of cancer, reproductive health issues, Alzheimer’s disease, and problems related to the thyroid gland.

This contamination originates from both human-related activities—such as emissions from industries and the use of fertilizers in agriculture—as well as natural geological processes. Fluoride is naturally present in most water sources, with its concentration in groundwater largely determined by the surrounding rock formations, especially those that contain high levels of calcium minerals. An overview of the physical and chemical properties of fluoride compounds is provided in Table 2.

In numerous regions worldwide, brackish water contains fluoride levels exceeding the World Health Organization's recommended limit of 1.5 mg/L. In certain areas, concentrations rise above 5 mg/L, and in extreme cases, can reach as high as 20 mg/L. At present, more than 35 countries have identified elevated fluoride in drinking water, emphasizing the widespread nature of this environmental and health issue.

Various methods of fluoride removal

The selection of an appropriate defluoridation method should take into account local environmental conditions, economic feasibility, community awareness, the practicality of implementation, availability of necessary materials, and the potential for reusing spent treatment media. Preference is generally given to techniques that utilize locally accessible and cost-effective materials as fluoride-removal agents. Currently, a wide range of defluoridation technologies is available, each based on different operational principles, including precipitation, ion exchange, reverse osmosis, Donnan dialysis, electrodialysis, nanofiltration, membrane-based processes, electrocoagulation, and adsorption using various types of adsorbents..

1. IonExchange: While ion exchange resins are capable of effectively removing fluoride and can be regenerated for repeated use, their high cost often limits their practicality for widespread implementation. One of the key disadvantages of this method is the production of a large amount of fluoride-rich waste during the regeneration process, which requires careful and proper disposal to avoid secondary pollution. In addition, the performance of ion exchange systems can be significantly reduced in the presence of other anions such as sulfates, nitrates, phosphates, and carbonates, which compete with fluoride ions [12, 11]. Research by Samadi et al. indicated that the highest fluoride removal efficiency achieved was 13.7 mg per gram of resin at a neutral pH of 7 [9]. Another study documented an adsorption capacity of up to 15.77 grams of fluoride per kilogram of resin. [10]

2. Precipitation/Coagulation: This method integrates substances such as aluminium salts, lime, and bleaching agents into conventional water treatment systems. The core mechanism involves the binding of fluoride ions to flocculated particles, which are subsequently removed through settling or filtration. Coagulation stands out as an economically viable option for fluoride removal in financially constrained regions, where more advanced technologies like reverse osmosis are often unaffordable due to their high installation and maintenance costs [13].

In contrast, precipitation processes are less favored because of several disadvantages. These include high expenses associated with chemicals, the generation of sludge containing toxic aluminium-fluoride complexes, the need for batch processing, limited scalability, unpleasant taste in treated water, and elevated levels of residual aluminium [6]. A prominent example of a precipitation-based approach is the Nalgonda method, which utilizes a combination of aluminium-based coagulants (such as aluminium sulphate or aluminium chloride) and lime to achieve fluoride removal through flocculation, sedimentation, and filtration. This technique is widely adopted due to its simplicity and cost-effectiveness, particularly in rural and semi-urban areas [14].

In a study by Kumar et al., fluoride was successfully extracted from acidic waste solutions derived from low-grade molybdenite ores containing alumino-silicates [15]. Another investigation identified that the most efficient fluoride removal occurred when 300 mg/L of alum was applied at pH 6 for a duration of 45 minutes. [16].

3. Nanofiltration(NF): Nanofiltration is a highly efficient membrane-based method for reducing fluoride levels in water, thanks to its selective separation capabilities and uniquely engineered membrane structure [6]. As a newer development among membrane filtration technologies, NF stands out for its ability to operate under relatively low pressure, consume less energy, and maintain higher flow rates while still achieving effective contaminant removal.

One of the main benefits of NF is its reduced sensitivity to the presence of competing ions, which can interfere with other treatment methods. Additionally, nanofiltration membranes are capable of filtering out a wide range of substances, including suspended solids, inorganic compounds, organic trace pollutants, pesticides, and microorganisms, making it a comprehensive solution for improving overall water quality.

4. Reverse Osmosis (RO):- Reverse osmosis (RO) is a physical filtration method where pressure is applied to feed water, pushing it through a semi-permeable membrane to remove anions. Operating under high pressure, RO offers superior removal of dissolved solids by rejecting ions based on their size and charge. Unlike natural osmosis, RO uses hydraulic pressure applied to the concentrated side of a solution, forcing the solvent to pass through the membrane toward the dilute side, effectively moving against the concentration gradient. A mechanical pump is used to generate the pressure required to surpass the natural osmotic pressure. This technique not only eliminates dissolved and particulate impurities but is also widely used for desalinating seawater by removing salts[12].

Ndiaye et al. used the reverse osmosis (RO) technique to remove fluoride from industrial wastewater and discovered that fluoride ion rejection consistently exceeded 98%, as long as the RO membrane was fully regenerated after each experimental run.

5. Nanoparticles(NPs): Nanotechnology, which deals with materials sized between 1 and 100 nanometers, has become increasingly important in developing advanced water purification solutions [6]. Among the various emerging techniques, the application of nanoparticles (NPs) for fluoride removal has shown remarkable potential due to their distinct advantages.

These nanoscale materials possess exceptional attributes such as an expansive surface area, high chemical reactivity, superior catalytic activity, and a large number of active adsorption sites. Their effectiveness in fluoride removal is largely due to their nanoscale features, including elevated surface energy and the availability of multiple reactive valence states [4].

For instance, calcium oxide (CaO) nanoparticles demonstrated a fluoride removal efficiency of 92% within 30 minutes using a concentration of 0.6 g/L. According to Jokar et al., a polyaniline/Fe_3O_4 nanocomposite achieved adsorption capacities of 97.48 mg/g at pH 4 and 78.56 mg/g at pH 7 after 4 hours of treatment. Likewise, nano-magnesium oxide (MgO) removed up to 90% of fluoride at the same dosage. In another study, Bazrafshan et al. reported that copper oxide (CuO) nanoparticles removed over 89% of fluoride, with a maximum capacity reaching 357 mg of fluoride per gram. Additionally, aluminum oxide/carbon nanotube composites exhibited an adsorption capacity of 28.7 mg/g at pH 6.[24].

6] Adsorption Method:- Adsorption refers to the process by which substances from a gas or liquid phase adhere to the surface of a solid material. In this context, the substance being attached is known as the adsorbate, which typically includes contaminants or impurities. While adsorption occurs naturally, it has been engineered for practical applications such as removing hazardous pollutants or purifying drinking water. It's important not to confuse adsorption with absorption—the former involves molecules adhering to the surface of a material, whereas the latter entails the penetration of substances into the internal pores of the solid. Adsorption typically involves weak and reversible bonding, although certain compounds—especially those with color, taste, or odor—tend to bind more strongly. Activated carbon, for example, is known for effectively capturing chromogenic compounds, whose molecular structures absorb visible light frequencies, making them ideal for water purification [25].

Additionally, the kaolinite method demonstrated fluoride removal rates between 90% and 96% after 120 minutes of exposure [17].

Low Cost Adsorbent:-

1]Fly Ash:- In a study conducted by N. Gandhi and D. Sirisha, batch adsorption experiments were carried out to assess the effectiveness of various low-cost adsorbents for removing fluoride from water and wastewater. The materials tested included concrete, ragi seed powder, red soil, horse gram seed powder, orange peel powder, chalk powder, pineapple peel powder, and multani mitti. The optimal contact time for fluoride removal generally ranged from 20 to 30 minutes, depending on the concentration of fluoride. As the contact time increased, the fluoride adsorption capacity also improved. However, once the adsorbent reached its saturation point, no additional fluoride could be removed. The required contact time varied between adsorbents, depending on their unique properties. Similarly, increasing the adsorbent dosage led to a higher fluoride removal rate, but once saturation was achieved, further increases in dosage did not result in any additional fluoride removal.

[26].

2] The excessive presence of fluoride in drinking water has become a major concern due to its association with fluorosis, which affects the teeth and bones. This global issue has led to significant research into methods for fluoride removal. A study by P.D. Nemade and A. Vasudeva Rao investigated the effectiveness of low-cost adsorbents in removing fluoride from water. The research focused on several factors, such as contact time, pH levels, adsorbent dosage, and fluoride concentration, to understand their impact on removal efficiency.

The study revealed that contact time played a crucial role in fluoride removal. It was found that most fluoride removal occurred within the first two hours of exposure to the adsorbent, with minimal further removal after this period. The adsorbents tested included fly ash, brick powder, wood charcoal, animal bone charcoal, and fish bone charcoal, all of which were evaluated using batch adsorption experiments.

Key findings of the study include:

1. Contact Time: The removal efficiency was highest within the first two hours, and longer contact times did not significantly increase the removal of fluoride.
2. pH: The pH level of the solution influenced the fluoride adsorption process, with different adsorbents showing varying levels of effectiveness at different pH values.
3. Adsorbent Dosage: The amount of adsorbent used was directly related to the fluoride removal capacity. Larger dosages generally led to more fluoride being removed, but only to a certain extent.
4. Fluoride Concentration: The fluoride concentration in the water also affected the efficiency of the adsorbents, with higher concentrations requiring more adsorbent to achieve effective removal.

The study concludes that materials like fly ash, brick powder, and charcoal (derived from animal and fish bones) show promise as affordable and effective solutions for fluoride removal in drinking water, particularly in regions where more expensive treatment methods are not feasible.

This research highlights the importance of understanding the relationship between key factors and adsorbent performance to develop cost-effective and efficient water purification techniques.

[27].

3] Saravanan Ramasamy et al. (2025):-

Banana peels (BP), orange peels (OP), lemon peels (LP) and groundnut shell (GS)

The research work focused in this study is to develop and apply an economical, novel method for removal of fluoride content from contaminated water sources by using natural bio adsorbents. Batch adsorption studies were carried out. This study explores the viability of four biomass-derived adsorbents that are cost effective namely: banana peels (BP), orange peels (OP), lemon peels (LP) and groundnut shell (GS). initial fluoride concentration (range within 10–50 mg/L) were explored to understand their impact on adsorption from that observation 20mg/l has carried out. The peak adsorption was fall down at pH levels of 5 for lemon peel and 7 for orange peel, banana peel, and groundnut shell respectively, within 1.5 hours. The removal rates for LP, BP, GS and OP were 48.36 %, 79.8 %, 72.38 % and 39.19 % respectively. The optimal contact times for BP, GS, OP and LP were found to be 69 minutes, 44 minutes, 66 minutes and 76 minutes respectively, with doses of 12 g/l, 16 g/l, 14g/l and 12 g/l.

4]Stanslaus G. Mtavangu et al. (2022):-

The study describes the biogenic cockle (Anadara granosa) shells for the defluoridation of drinking water. Batch adsorption experiments were conducted using the Box-Behnken design (BBD) with parameters like adsorbent dose, initial fluoride concentration, contact time, reaction temperature, and pH. The interaction effects of adsorbent dose and initial fluoride concentration on fluoride removal efficiency are shown in at 12.25 h, 318 K, pH 7. The efficiency of fluoride removal improved from 71.19% to 98.64% as the adsorbent dosage increased from 3 g/L to 10 g/L, given an initial fluoride concentration of around 45 mg/L. However, beyond this concentration, the removal efficiency started to decline. Optimum adsorbent dose, temperature, time and initial concentration were found 6 g/L, 333 K, 12.25 h and 20 ppm respectively. Maximum specific uptake obtained from Langmuir isotherm is found to be 15.19 mg/g.

5] Milind Girkar et al. (2024)-

This study investigated the potential use of chemically modified sugarcane bagasse biochar as a new adsorbent for removing fluoride ions from groundwater. Defluoridation process was conducted using a novel column. From making of filtration unit to found removal efficiency and analyse the cost has been done. They studied with water sample in regions of Maharashtra, including Yavatmal, Nanded, and Latur districts. The groundwater samples had a moderate fluoride concentration, measuring 4.44 mg/l (ranging from 0.87 to 6.37 mg/l). After the treatment, fluoride concentration found to be in between 0.35 to 1.12 mg/l. The authors reported that the adsorbent can undergo up to five adsorption-desorption cycles with minimal loss of efficiency, allowing for regeneration and reuse. The packed bed column with continuous flow method proved highly efficient and cost-effective with the approximate cost of 1 litre of water is 0.25 Indian rupees, for removing fluoride from groundwater.

6] Mohamed E. Mahmoud et al. (2024) :-

Investigated the adsorption of Fluoride using avocado seeds as adsorbent. An effective nano-biosorbent is made by combination of three constituents, cobalt-iron layered double hydroxide (Co/Fe-LDHs), avocado kernel seeds biochar and carboxymethyl cellulose (CMC) as an example of biodegradable natural polymers. Adsorptive capture of fluoride ion was conducted under various experimental conditions such as pH, dosage, concentration of fluoride ion, contact time and reaction temperature. The pH variation (1–7) for fluoride (20, 40 and 60 mg/L) by using 10 mg of adsorbent at 30 0C and 120 rpm at 30 min stirring time. The maximum adsorption was achieved at pH 1 and 7 and minimum at pH 3. Experimental data showed the minimum adsorptive capturing values of fluoride ion were identified using 5mg of dose as 82.7, 76.5 and 69.1 % for 20, 40 and 60 mg/L respectively. It is evident that a gradual increase in the adsorptive capturing of fluoride ion was accomplished upon increase the dose of adsorbent. For instance, the above listed values were highly enhanced to reach 100, 96.0 and 90.9 %, respectively by applying 100 mg of the adsorbent. Time study (1, 10, 20, 30, 45, 60, 75, 105 and 125 min) with the fluoride concentration of 30, 40, 50, 60, 70, 80 and 90 mg/L has showed A gradual increase in adsorptive capturing of fluoride ion to 100.0, 99.04, 98.31, 97.31,97.25, 96.83 and 96.24 %, respectively at 125 min. The fluoride capturing capacity was 100, 98.7 and 97.9 % extraction at 60 0C using 20, 40 and 60 mg/L.

2.2] Chemical Adsorbent:-

1] graphitic carbon nitride g-C3N40

g-C3N4 was synthesized by warming melamine powder at 550 ◦C for 4 h in a suppress heater. The gotten g-C3N4 was ground into a fine powder some time recently utilize. Commercially accessible AC powder with a molecule measure of 100–150 µm was secured from Sigma Aldrich. Sodium fluoride (NaF) was utilized as the fluoride source.

The g-C3N4-AC composites were synthesized by means of ultrasonic irradia- tion strategy. To begin with, 0.5 g of g-C3N4 was scattered in 200 mL water and ultrasonicated employing a test sonicator (Sonics VCX 750) at 40% adequacy for 15 min (5 s on/2 s off). Another, 1 g of AC powder was presented and ultrasonicated for 30 min to realize uniform stacking of

g-C3N4 on the AC surface. The g-C3N4-AC slurry gotten was dried overnight at 80 ◦C. For comparison, a physical blend of g-C3N4 and AC

was moreover arranged by basic pounding without ultrasonication. The dried composite and blend were ground tenderly and put away in air-tight con- tainers some time recently utilize.

The basic blend method and utilize of reasonable antecedents make this composite appropriate for decentralized drinking water treatment, particularly in creating locales influenced by tall fluoride levels. How- ever, a impediment of this consider is that the adsorption execution was assessed as it were beneath bunch conditions. Encourage ponders assessing the adsorption energy and column execution beneath nonstop stream conditions are required for viable applications. The recovery productivity can moreover be moved forward by optimizing the desorption conditions. Future work can moreover investigate altering the composite with other metal oxides or nanoparticles to advance upgrade the defluoridation capacity. Generally, the ultrasonically synthesized g-C3N4-AC composite appears guarantee as an successful and low-cost adsorbent for water defluoridation.

2] Clinoptilolite / zeolite Na-LSX Powder.

The ponder was utilized diverse materials, Chemicals and Reagents were utilized amid this ponder. For-instance Crusher (jaw, mortar and pestle) for Measure decrease No.16 work, Sifter (strainer test), Expository adjust, Hatchery shaker Vacuum channel, and Centrifuge. Chemicals and Reagents utilized for the think about were NaCl (decide the surface), Sodium fluoride, NaOH and HCl (alteration of pH), Clinoptilolite (adsorbent) refined water, HDTMA-Br, and Zeolite adjustment can be finished through different approaches, counting particle trade, in which the first zeolite's interchangeable cation is supplanted by Hexad Trimethyl ammonium bromide. The particle trade of Hexad Trimethyl ammonium bromide (HDTMA-Br) with clinoptilolite can be dispense with fluoride concentration from drinking water sources, due to this interaction. There's no any progressed treatment innovation or adjusted treatment innovation utilized for this range, and most of the analysts examined were centered on assurance fluoride concentration in day by day admissions in water supply sources. This have a negative suggestion on the wellbeing condition of the society living around that zone. The results of the consider were to evacuate abundance fluoride in drinking water, which is tall influences society's wellbeing by utilizing actually accessible fabric by basic adjustment with cationic surfactants.

Drinking water supply for the think about zone was exceedingly contaminated by fluoride concentration, which is amazingly over WHO rules. The altered Clinoptilolite was effectively conducted utilizing shifting HDTMA-Br doses (0.5, 1, 2, 5, 10, and 15) g/L, and utilized 10 mg/L of starting fluoride arrangement, this publicized that the fluoride evacuation potential of the Clinoptilolite Nano zeolite adjusted expanded with expanding HDTMA-Br dose. The efficiency of fluoride removal using modified zeolite was influenced by various operational factors, including the amount of adsorbent used, contact time, pH level, and the initial fluoride concentration.

Adsorbent Type	Mechanism	Cost	Efficiency	Reusability
Al/Fe oxides	Surface complexation	Medium	High	Moderate
Zr-based compounds	Ion exchange	Medium	Very High	High
Ion-exchange resins	Anion exchange	High	Very High	High
LDHs	Intercalation	Medium	High	High
Ca-based adsorbents	Precipitation	Low	Medium	Low

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