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A Review of Various Techniques for Removal of Fluoride from Water

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Abstract

Water is one of the most important elements for all forms of life. Pure water is scarce and is not easily available at all. There are many resources which contaminates the water and one such contaminant is fluoride. Smaller amount of fluoride is beneficial for human beings, but excess amount of fluoride intake causes fluorosis such as dental fluorosis, bone fluorosis etc. and adverse effect on IQ of child. According to IS 10500-2012 the permissible limit of fluoride is 1.0 – 1.5 mg/litre and detection range is given by IS 14543 –2016 (0.05 – 1.0 mg/litre). This review article aims at different techniques used for removal of fluoride from water. These techniques include coagulation – precipitation, membrane separation process, ion exchange, adsorption techniques and so on. Among all these techniques adsorption techniques are more efficient. Now – a –days, bio-sorption method is very effective and include low-cost adsorbents such as rice husk, bone char, fruit peels and so on. This paper discusses various defluoridation techniques used in India.

Keywords: *water, contamination, fluoride, fluoride removal, defluoridation, defluoridation techniques, adsorption*

1. Introduction

As we all know water is the basic need for the human life as it is useful for different purposes. And if we see the history, the human civilization always evolved near various water bodies. Now-a-days, due to increase in industrialization, the major water bodies or rivers and surface water source are highly polluted with multiple pollutants due to which water cannot be consumed for any purpose without treating it [1]. Water is contaminated by various chemicals in which fluoride is one of it. Fluoride is the part of our food cycle and it majorly enters in our body via water. Fluoride is a component of our food chain, and it primarily enters our bodies through water. Fluoride enters water bodies through industries that produce aluminium, nickel, and other metals, which dump their waste directly into bodies of water. Fluoride can be formed in water if there is sewage present. The analysis of fluoride concentration is important because fluoride ions are present in almost all media at low concentrations. Fluoride is important in drinking water at low concentrations because it prevents dental caries, but excessive amounts can cause dental fluorosis and skeletal fluorosis. The WHO recommends that fluoride concentrations not exceed 1.5 mg/l. The only source that is less contaminated and may contain less fluoride is groundwater. However, as the level of ground water drops day by day, there is a greater chance that it will reach geologically fluoride-rich rock, increasing fluoride concentration

in water. The presence of excess fluoride can also cause neurological disorders, gastrointestinal disorders, and other problems, according to some researchers. As a result, purifying water before use is highly recommended. Because groundwater is the only and major source of drinking water in many villages in India, the problem of fluoride is primarily a rural one, and because of poverty, they cannot afford to treat groundwater or surface water. The only option left is to purify the surface water. Without being in a sticky situation, it is highly recommended to conduct research on defluoridation techniques in order to develop a cost-effective and simple method for defluoridating water that is present in excess of the permissible limit and causing harm to human health, and to ensure that clean water is readily available to all. As a result, this paper presents a review of various defluoridation techniques of water [2].

1.1. Fluoride Chemistry

Fluorine is the most electronegative and reactive element in the periodic table, with nine protons in its nucleus. Because of its high reactivity, it is a common element that does not exist in its elemental state in nature. As a result, this odourless pale yellow-green gas does not occur in its natural state, but rather forms ionic states or compounds with other chemicals in minerals. It makes up around 0.3 g/kg of the Earth's crust and is found in the form of fluorides in a variety of minerals, the most common of which are fluorspar, cryolite, and fluorapatite. HF (hydrogen fluoride) is a colourless, pungent liquid or gas with a boiling point of 19.5 degrees Celsius. It is highly soluble in water, forming hydrofluoric acid as a result. Sodium fluoride (NaF) is a colourless to white solid with a mild water solubility [3]. The fluoride ion has an oxidation state of -1. Since the fluoride ion is a Lewis base, hydrogen fluoride, its conjugated acid, is a weak acid in water. It has a higher acidity than anhydrous acetic acid, however. Aqueous media have basic characters due to the basicity of fluoride ions. Fluoride forms water-soluble complexes with polyvalent metal ions such as Mg^{2+}, Ca^{2+}, Al^{3+}, and Fe^{3+} depending on the pH of the medium, which distinguishes it from most other halides. Fluoride enters the body primarily through the gastrointestinal tract and is rapidly consumed in the stomach. The rate at which fluoride is absorbed from the stomach is proportional to the acidity of the contents. However, many other factors, such as the solubility of the ingested fluoride compound, affect the rate of absorption [9].

2. Defluoridation

In 1998, the Rajiv Gandhi National Drinking Water Mission (RGNDWM) released a survey report revealing that residents of 8700 villages are drinking ground water polluted with excessive fluoride (1.0 to 48.0 mg/L), putting their health at risk. The simplest and cheapest solution for this problem is DEFLUORIDATION, which means lowering the concentration of fluoride in ground water. There are many methods available for determining the concentration of fluoride in water such as SPADN'S method, Alizarin visual method and so on [11].

3. Defluoridation Techniques

Various strategies for removing fluoride from water have been studied extensively in the past years after fluoride was discovered to be the source of fluorosis. These techniques include adsorption techniques, Nalgonda technique, reverse osmosis and so on. Each method has their advantages and disadvantages under certain conditions. All these methods are explained briefly along with their merits and demerits.

3.1. Adsorption Technique

Adsorption is a commonly used process for defluoridation that relies on adsorbate in fluid diffusing to the surface when they are bonded to the adsorbent or held by their weak intermolecular forces. While several techniques or methods have successfully reduced fluoride concentrations in water to appropriate levels, the adsorption technique holds a significant position in defluoridation of water due to its lower cost and ease of access. Previously, many scientists were attempting to discover more low-cost defluoridation techniques, but many researchers have continued to investigate low-cost defluoridation techniques [5]. A wide range of adsorbents that are effective at removing fluoride from water have been used. Bio-adsorbents and chemical adsorbents are the two main forms of adsorbents that can be used in the adsorption process.

3.1.1. Bio - Adsorbents

Bio adsorbents are less time consuming to prepare and are widely available. This adsorption technique is mostly used in rural areas of India, as it is very cost-effective. The different bio adsorbents are used such as fruit peels, fly ash, fish bone, coffee husk, bone char, nut shell, clay minerals, etc. The reported bio adsorbents are described below;

Fruit Peel Adsorbent:

Because of their low cost, availability, environmentally stability and high adsorption efficiency/capability, fruit peel has piqued interest as potential candidate for removing contaminants from aqueous solution or water having fluoride content exceeding acceptable limit. Different fruit peels are used as bio adsorbent such as banana peel, lemon peel, orange peel, etc.

Banana Peel:

Among various fruit peels, banana peel is the major waste in many countries including India. Banana peel shows high capacity of defluoridation. It is a low cost, effective and economical method. It is eco-friendly and gives efficiency up to 90% for removal of fluoride. This method is not applicable over wide pH range, adsorption increases with increasing pH and in a pH range of 1-7. Banana peels can be collected from vendors or sellers. After extracting the peels, wash them with distilled water and dry them for 12 hours in a hot air oven at 50°C. After that, the peels were dried and cut into small pieces before being placed back in the oven for another 24 hours at 60°C. The dried banana peel is then ground into powder in a blender [6].

Advantages:

1. Simple design
2. Low investment in terms of both initial cost and land cost. Hence, can be used in rural areas easily.
3. It is applicable in removal of fluoride even at low concentration.
4. Lack of sludge production
5. High efficiency and high productivity of fluoride removal and can remove fluoride up to 90%.
6. Needs less maintenance.

Disadvantages:

1. This approach is only effective up to a certain pH level.
2. This method does not kill bacteria.

3.1.2. Chemical Adsorbent

There are various chemical adsorbents available in market such as activated alumina, activated charcoal / carbon, magnesia, calcite, synthetic tricalcium phosphate etc.

Activated alumina

It is a porous and highly adsorptive filter media produced by processing aluminium ore. Aluminium oxide in granulated form is another name for it. Activated alumina removes a variety of pollutants, including excessive arsenic and selenium, that often coexist with fluoride. To stay reliable, the medium must be cleaned on a regular basis with an appropriate regenerate such as alum or acid. Activated alumina has been used as an important adsorbent in a variety of applications, including point-of-use. The key disadvantage of activated alumina is that its adsorption efficiency is highest at low pH, and pollutants such as arsenates must be peroxidised to arsenates before being adsorbent. In addition, supplementary treatment methods will be needed to minimise levels of other health-related pollutants [4]. Flushing activated alumina with a 4 percent sodium hydroxide solution removes fluoride from the alumina surface, allowing it to be regenerated. After that, the alumina surface is flushed with acid to re-establish a positive charge. Adsorption on activated alumina has the drawback that the pH must be on the acid side of 7, and dissolution of any aluminium oxide/hydroxide is unavoidable, releasing poisonous aluminium ions. At pH 6.5, activated alumina was found to be 92.6 percent effective in removing fluoride from water.

Advantages:

1. Widely used method.
2. Highly efficient up to 99 percent.
3. It also removes other ions such as arsenate, sulphate etc.
4. Produce high quality water.
5. Easy operation

Disadvantages:

1. Not applicable for wide pH range.
2. Issue regarding disposal of depleted adsorbents.
3. Further treatment is necessary after removal of fluoride.

3.2. Nalgonda Technique

This technique was developed by NEERI (National Environmental Engineering Research Institute), Nagpur in 1961. Nalgonda technique was created for household purpose. This is the first community defluoridation technique. The process can handle up to 20 litres of water in a single day. The chemicals added in this method are alum, lime and bleaching powder. The processes involve in this technique are rapid mixing, flocculation, sedimentation, filtration and disinfection. Alum is responsible for removal of fluoride from water. Fluoride removal is most effective when the pH range is 5.5 – 7.5 [8]. This technique is modified by using poly aluminium chloride instead of alum because it has higher efficiency and less cost. Poly aluminium hydroxy sulphate requires less flocculation time than alum [7].

Advantages:

1. Economical method.
2. Efficiently use at domestic level.

3. Regeneration of media is not required.
4. The chemicals used for this method are easily available.
5. Can be used to treat large amounts of water for community use.

Disadvantages:

1. Require talented labour.
2. Production of greater amount of sludge.
3. The pH of treated water must be carefully monitored.
4. To remove fluoride, a large amount of alum is required.
5. Only 18-33 percent of fluoride is removed in the form of precipitates, while 67-80 percent is converted to soluble toxic ions.
6. Time consuming method.

3.3. Membrane Filtration Process

Mainly there are two methods under membrane filtration process which can be used for removal of fluoride from water: 1) Reverse osmosis 2) Dialysis – Electrodialysis. These methods are extremely effective at removing fluoride, with a fluoride removal rate of 85 – 95 percent [10].

3.3.1. Reverse Osmosis

A reverse osmosis (RO) process extracts 85 – 90 percent of fluoride from water [8]. It is a physical mechanism that removes anions from water by forcing it through a semipermeable membrane under pressure. In reverse osmosis, an applied pressure is used to resolve osmotic pressure. As a result, the solute is trapped on the pressurised side of the membrane while the pure solvent is able to pass through. RO removes a wide range of dissolved and suspended organisms from water, including bacteria. RO is used in both industrial and potable water processing.

Advantages:

1. Systems for reverse osmosis are simple to design.
2. Low maintenance.
3. RO systems require less energy.
4. RO is very effective and rapid process.

Disadvantages:

1. RO is not suitable for rural areas.
2. After treatment of water, water becomes acidic and needs pH adjustment.
3. High operating cost.
4. Consumptions of chemical is high.
5. Require skilled labours.
6. Membranes must be well – maintained to avoid fouling.

3.3.2. Dialysis – Electrodialysis

In electrodialysis, ionic components are removed from aqueous solutions through ion exchange membranes under the electric driving force. It is similar to reverse osmosis (RO) except current is used instead of pressure to remove ionic contaminants [8]. The membranes used in this method allow the ions to move but not water [10]. With the help of this method fluoride levels in water can reduce below the standards given by WHO. It can de - fluoridate waters with as little as 3000 mg/litre. This method also reduces total dissolved salts (TDS) of water. It is commonly used in areas where cost is not an issue.

Advantages:

1. Cost of pre and post treatment is less.
2. More accurate.
3. Chance of contamination is less.
4. Rapid process.
5. Effective and acceptable technique.

Disadvantages:

1. Expensive and complicated process.
2. Large amount water gets wasted as brine.
3. Only removes ions, not organic matter.

4. Conclusion

This review article attempted to cover various methods for removing fluoride from ground water as well as from drinking water that have been used in the past. Various techniques for removal of fluoride includes adsorption, precipitation – Nalgonda technique, membrane filtration and so on have been reviewed in this paper along with their advantages and disadvantages. Out of all these method adsorption techniques are inexpensive, effective and produces high quality water. In this adsorption techniques both bio – adsorbents and chemical – adsorbents are reviewed. Thus, we can conclude that the studies in the field of defluoridation have been reviewed effectively.

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