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REMOVAL OF FLUORIDE FROM DRINKING WATER: AN OVERVIEW

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Abstract: Fluoride (F^-) is an essential element for building teeth. Excessive F^- has detrimental effects on human health. Various efforts have been made by researchers in the field of F^- removal from drinking water and several technologies have been suggested, each having its own advantages and limitations. This paper has a broad overview of methods for removal of F^- from drinking water. Their strength and limitations have also been studied, compared and summarized here. It has been concluded that the method used should be site specific as each has its own advantage and disadvantage.

Keywords: Adsorption Methods; Defluoridation; Activated Alumina.



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INTRODUCTION

F⁻ is the 13th most abundant element on Earth. F⁻ intake is beneficial for us within the limit of 1 mg/L while it becomes hazardous when its concentration exceeds 1.5 mg/L [1], as the maximum permissible limit of F⁻ in water is 1.5 mg/L by WHO and ICMR [2,3]. Excess intake of F⁻ can lead to diseases like cancer, infertility, brain damage, thyroid disorder [4, 5]. It may also interfere with DNA synthesis and metabolism of carbohydrate, proteins, lipids, vitamins and minerals [6, 7]. Detrimental effect of prolonged consumption of excessive F⁻ concentration is known as fluorosis. That may be of three kinds – skeletal, non-skeletal and dental fluorosis. Various parts of the world are having elevated F⁻ concentration in ground water [8-17]. In India more than 16 states are facing acute fluorosis problems [18-21]. In Rajasthan 16 districts have been confirmed as F⁻ affected areas, having F⁻ more than the permissible limit [22-35]. Ground water becomes F⁻ contaminated due to natural or anthropogenic activities. Rajasthan's groundwater has high F⁻ concentration because of its geological formation that consists of crystalline basement rocks especially granite. These contain low Calcium and relatively high concentration of F⁻ bearing minerals [36] that can be leached out into the ground water [37-39]. Various industries viz. glass & ceramic production, electroplating, semiconductor manufacturing, brick & iron works etc. also contribute to F⁻ pollution [40-42]. In many areas there is no source of drinking water other than the groundwater highly contaminated with F⁻. People have to use that F⁻ contaminated water for drinking and other purposes. In that case a suitable F⁻ removal method is the only way to escape from manifestation of fluorosis.

Various techniques are used for water treatment depending upon nature of impurities viz. screening, flocculation, sedimentation, floatation, stripping neutralisation, adsorption, ion exchange, rootzone technology, ozonation/ oxidation by H₂O₂, electrolytic deposition [43]. Water purification technologies for excess F⁻ removal fall under defluoridation techniques. They are based on precipitation [44-48], ion exchange [49-53] or on adsorption [54]. Reverse osmosis [55,56] and electrodialysis [57] have also been investigated for F⁻ removal. Many of these cannot be utilized conveniently at wide level because of their limitations as operational cost, maintenance, secondary pollution etc. authors reviewed and concluded membrane process is expensive to install and maintain, electrochemical techniques are energy expensive, coagulation is not much worthy. Among various these methods adsorption process is the most commonly and widely used. Various adsorbents have been derived and modified by the researchers for defluoridation of water and satisfactory results have been observed. This review comprises such adsorbents and the relevant results regarding defluoridation of water.

Review:**Adsorption using Alumina and calcium based materials:**

Many studies have been conducted using Alumina [58-61] as an adsorbent. Researchers [62] studied fluoride removal from different solutions (0.1-1.0mM) using amorphous $\text{Al}(\text{OH})_3$ and alumina (Al_2O_3), varying pH from 3-8 and found that most of the $\text{Al}(\text{OH})_3$ formed AlF complexes and get dissolved at $\text{pH} < 6$ and total $\text{F}^-:\text{Al}$ ratio > 2.5 . Maximum fluoride uptake found in pH range 5.5-6.5. At lower pH it decreases while at higher pH (6-8) it decreases rapidly due to displacement of fluoride from solid by OH^- . The fluoride uptake varied in accordance with Langmuir model at fixed pH (5-7.5). Less fluoride was converted by Gibbsite by the same reaction. Bahena et.al [63] studied the effect of zeta potential on adsorption of fluoride by $\alpha\text{-Al}_2\text{O}_3$ and observed maximum fluoride removal between pH 5-6 at 25°C . Adsorption varied with Langmuir isotherm model. The point of zero charge (pzc) of Al_2O_3 was obtained at pH 9.2 at 20°C . In presence of fluoride zeta potential get reversed towards more acidic pH. Thus fluoride ion replaces OH^- ions from the positively charged surfaces and adsorbed by H-bonding ($\text{pH} \geq \text{pzc}$). Studies regarding regeneration have also been conducted [64]. At higher flow rate alumina (Grade OA-25) gets saturated earlier. Same results obtained at higher fluoride concentration. This saturation decreases the fluoride removal. Regeneration increases the efficiency upto 85% again. In spite of regeneration there is a marginal decrease in the fluoride removal capacity of the alumina studied. Adsorption capacities of untreated hydrated alumina (UHA) and thermally treated hydrated alumina (THA) for fluoride removal from aqueous solution have been compared [65]. It is found that rise in thermal treatment temp. upto 200° cause an increase in fluoride adsorption efficiency, but on further increasing the temperature it decreases. High defluoridation efficiency was obtained with in a pH range of 4.0-9.0. Adsorption varied in accordance with Freundlich isotherm model. Wasay et.al [66] modified alumina to enhance the fluoride removal capacity by impregnating La(III) and Y(III) to alumina. The order of selective removal was observed as – fluoride $>$ phosphate $>$ arsenate $>$ selenites. The adsorption capacity for alumina impregnated with Lanthanum hydroxide [67] was found 0.350mM/g, whereas the same for the original alumina was 0.170- 0.190mM/g. The mechanism involves ion exchange between OH^- and anion. Modification has also been done impregnating Copper oxide [68], Calcium oxide (CaO) and Manganese oxide (MnO_2) [69,70], using different techniques. The Langmuir sorption capacity of fluoride was found 7.22m/g for copper oxide incorporated alumina. It was found that at same concentration Cao-AA works 5-10 times better than the $\text{MnO}_2\text{-AA}$.

Calcium has good affinity for fluoride. So fluoride removal has also been conducted using calcium salts as an adsorbent [71-73]. The Langmuir adsorption capacity of limestone was

observed 43.10 mg/g, whereas for Aluminum hydroxide impregnated limestone was 84.03 mg/g.

Adsorption using iron based materials:

Iron based materials have also been studied for fluoride removal [74-78]. Fluoride adsorption of Hydrous Ferric Oxide (HFO) has been studied by Dey et.al [79]. Highest adsorption density for fluoride is found to be at pH 4.0. It was observed that arsenite, arsenate, phosphate and sulphate show strong interfering effect in removing fluoride. Freundlich isotherm was followed by the adsorption. Granular Ferric Hydroxide (GFH) was also used for defluoridation by Kumar et.al [80] and Streat et.al [81]. The adsorption was found to be strongly dependent on pH. Mechanism follows ion exchange process.

Polypyrrole/ Fe_3O_4 magnetic nanocomposites [82], Fe(II)/Ti(IV) sulphate bimetallic oxide adsorbent [83], iron rich lactrite [84] have also been investigated as adsorbent for fluoride removal from water.

Adsorption using other metal based materials:

Various synthetic sorbents for fluoride removal using two or more multi metal oxides/hydroxides have been developed by researchers. Biswas et.al [85] prepared synthetic hydrous iron(III)- chromium(III) bimetal mixed oxide (HICMO). Maximum defluoridation was occurred at pH-3.0. It was found nearly constant in pH range 5.0-7.0. Chang et.al [86] applied superparamagnetic Zirconia material ($\text{ZrO}_2/\text{SiO}_2/\text{Fe}_3\text{O}_4$), for fluoride removal. Meixnerite and its calcinations product were used for the same purpose by Guo et.al [87]. Zhongzhi et.al [88] investigated fluoride removal with the help of Cerium based adsorbent (CTA). Freundlich isotherm was followed by the adsorbent. Mohapatra et.al [89] suggested fluoride removal by metal oxyhydroxide. The surface oxygen on metal oxyhydroxides helps in adsorption of different cations and anions. The property was used by the authors with refractory grade bauxite, feed bauxite and manganese ore. The process was exothermic and two step ligand exchange reaction. Biswas et.al [90] prepared synthetic iron (III)-tin(IV) mixed oxide (HITMO) for fluoride removal. The adsorption capacity of HITMO was found constant in pH range 5.0-7.5. Another synthetic adsorbent Hydrated iron(III)- aluminium(III)-Chromium(III) (HIACMO) [91] ternary mixed oxide was also synthesized by the same workers for defluoridation. Sundaram et.al [92] used Magnesia (MgO) and Magnesia/Chitosan (MgOC) composite for fluoride removal from aqueous solution. Remarkably higher defluoridation capacity was observed in case of MgOC Composite. Different influencing factors have also been studied. Increase in fluoride concentration causes an increase in the capacity of fluoride removal with both MgO and MgOC. Freundlich isotherm was followed by the process. Kang et.al [93] studied calcined

magnesia with pullulan (cMgOP) composite for fluoride removal. It was found that its defluoridation capacity was 10 times higher than that of MgO.

Liu et.al [94] prepared Al-Ce hybrid adsorbent and studied it for defluoridation. Its maximum adsorption capacity was 91.4 mg/g at 25°C that was observed at pH- 6.0. Sujana et.al [95] studied amorphous iron and aluminium hydroxide for fluoride removal. Different molar ratio composition of Fe: Al was used in the study. The optimum pH was found to be 4.5 with molar ratio 1:0, 3:1 and 2:1. Garmes et.al [96] conducted defluoridation studies using hybrid process combining adsorption and Donnan dialysis. Defluoridation was found to be independent of pH and ionic strength of the sample water. Specified anion exchange membranes were used to eliminate anions from the sample water. Gopal et.al[97] used Magnesium titanate for defluoridation the defluoridation capacity was found to be 0.029 mg/g at 4 mg/L initial fluoride concentration. Defluoridation increases with increase in initial concentration of fluoride. Other influencing parameters like temperature, adsorbent dose etc. were also studied. The process followed Langmuir adsorption isotherm.

Wu et.al [98] prepared a trimetal oxide (Fe-Al-Ce) having examined its adsorption quality. It was found that adsorbent showed high adsorption capacity over a wide pH range 5.5-7.0. On increasing pH fluoride removal decreases due to the repulsion of fluoride ion and competition effect of OH⁻ ions. Wajima et.al [99] studied fluoride removal by gel like hydroxide derived adsorbents. Evident fluoride removal was observed even at low concentration of fluoride. Jamasbian et.al [100] reported bauxite as an adsorbent for defluoridation of water. The adsorbent were analysed by XRD, FTIR and SEM-EDX. First order kinetics was followed by the adsorption. Sivsankar et.al [101] reported that Manganese dioxide improves defluoridation capacity of earthenware (<300µm). Defluoridation increases with increase in added Manganese di oxide. Static experiments were conducted at pH 5-11. Effect of other ions was also studied. Reduction in fluoride removal was higher in presence of sulphate ion. Aluminiumtitanate (AT) and Bismuth aluminate (BA) were also explored for fluoride removal by Karthikeyan and Elango [102]. Their specific properties make them more suitable for defluoridation. Defluoridation capacity for AT and BA was observed 0.85 and 1.55 mg/g respectively at 4.0 mg/L fluoride concentration. Adsorbent was analysed by FTIR and XRD technology before and after adsorption. It was observed that greater defluoridation occurs at acidic pH range. Deng et.al [103] studied Mn-Ce oxide adsorbent for fluoride removal. Defluoridation capacity of powdered and granular adsorbent was 79.5 and 45.5 mg/g respectively.

Adsorption using carbon based materials:

As activated charcoal is known as a good adsorbent, sorbents based on carbon have also been explored by the researchers for defluoridation [104-108]. Janardhana et.al [109] studied water

defluoridation using Zirconium ion impregnated activated charcoal (ZIAC). The adsorption capacity of ZIAC was 3.5 times higher to that of activated charcoal. Fluoride removal using fishbone charcoal was studied by Bhargav and Killedar [110]. They found that ratio of attained equilibrium sorbate concentration to the initial sorbate concentration and the fluoride removal capacity inversely varied with the sorbent mass input rate. Yan Hui Li et.al [111] reported fluoride adsorption using amorphous Al_2O_3 supported on carbon nanotubes ($\text{Al}_2\text{O}_3/\text{CNTs}$) and observed that maximum fluoride removal occurs at pH range 5.0-9.0. The adsorption capacity for $\text{Al}_2\text{O}_3/\text{CNTs}$ was found to be about 4 times higher than that of $\gamma\text{-Al}_2\text{O}_3$ at equilibrium fluoride concentration 12 mg/L. The same workers also used aligned carbon nanotubes (ACNTs) [112] for fluoride removal. ACNTs were prepared by catalytic decomposition of xylene using ferrocene as catalyst. The highest fluoride removal (14.5 mg/g) occurred at pH- 7. Kinetics experiment showed that it was a fast adsorption process and reaches to equilibrium in about 180 min. Multi-walled carbon nanotubes (MWCNTs) was also used for fluoride removal by Ansari et.al [113]. Zhang et.al [114] studied defluoridation by graphene.

Adsorption using natural materials:

A number of natural materials have been used as adsorbent for the removal of fluoride from water. Morges et.al [115] explored fired clay chips for the same purpose. At pH 9 and 3 the maximum fluoride removal was 80% and 90% respectively. Montmorillonite clay [116,117] has also been evaluated for defluoridation. Fluoride uptake decreases with increase in pH due to negative charge of the surface. Algerian [118], bentonite[119,120], tunisian[121], south african[122], laterite[123-125], kaolinite[126,127] are various types of clay that have been used for fluoride removal from water. The efficacy of coal based sorbents has also been evaluated for defluoridation [128]. Subramanian et.al [129] reported defluoridation using three kinds of tamarind seed viz. pristine(PriTS), purified(PurTS) and polyanniline(Pani). Fluoride adsorption capacity of PriTs and PurTS has been found to increase on being 50% pani coated. Maximum fluoride removal was occurred at pH-7.

Onygo et.al [130] explored zeolite F-9 as fluoride adsorbent. Zeolite – F9 was having surface active sites created with Al^{+3} , La^{+3} . Al^{+3} based zeolite removes fluoride through an ion exchange mechanism. While La^{+3} exchanged zeolite follows physical adsorption for fluoride removal. It was found that first one is preferable to La^{+3} exchange zeolite.

Adsorption using Biomaterials:

Various biomaterials like chitin, chitosan derivatives, algal and fungal biomasses have also been examined by many researchers. Chitin and Chitosan was studied by Kamble et.al [131] for the removal of fluoride from water. 20% La-chitosan showed higher fluoride removal capacity than the chitin and simple chitosan. Fluoride adsorption was found maximum at pH-6.7. Anions like

carbonates and bicarbonates showed a negative effect on fluoride adsorption. Vishwnathan et.al [132-136] studied chitosan beads modified by introducing groups like $-NH_3$, $-COOH$, for fluoride removal which showed maximum fluoride removal capacity at pH-7. Protonated cum carboxylated chitosan beads have been found more efficient for fluoride removal than bare chitosan beads. Banisal et.al [137] prepared La incorporated chitosan beads (LCB) for defluoridation. Maximum adsorption capacity was observed at pH-5. 98% fluoride was found to be removed at 10% La incorporation. LCB were also prepared by Thakre et.al [138] using its metal binding characteristics. The same property was used to develop Ti (III) incorporated chitosan by Jagtap et.al [139]. Maximum fluoride removal was observed at neutral pH with 15% Ti loading. The same workers [140] evaluated the performance of chitosan modified by Ti (IV) and Al (III) ions. They found that fluoride removal was independent of pH over a wide pH range (3-9). Regeneration was also done using alum. The maximum fluoride removal was found to observe at adsorbent dose 4g/L.

Various modifications have been done to make chitosan more efficient for fluoride removal [141,142]. Vishwnathan et.al [143] evaluated Hydrocalcite/ chitosan [HTCs] composites for fluoride removal. At acidic pH maximum fluoride removal was observed. The efficiency of fluoride removal for HTCs was found higher (1255 mgF⁻/Kg). Lakshminarayan et.al [144] compared the fluoride removal capacity of brushite calcite with grind neem and peepal leaves and found that biosorbent material was less efficient in fluoride as compared to brushite calcite. Alagumuthu et.al [145] investigated the ability of Cynodondactylon to remove fluoride from water. Activated carbon as derived from the species (commonly known as Bermuda grass) and utilized for defluoridation. Maximum fluoride removal (83.77%) was occurred at neutral pH with initial fluoride concentration 3.0 mg/L. Langmuir and Redlich-Peterson isotherms were followed by the process.

Polyaniline/ chitosan (PANI/Ch) and Polypyrrole/chitosan (PPy/Ch) were also explored as adsorbent for defluoridation. It was found that PPy/Ch composite is more efficient than PANI/Ch composite for defluoridation [146]. Ramanaiah et.al [147] derived waste fungal biomass from laccase fermentation and explored its fluoride removal capacity. Fluoride removal was found to be greater at lower pH. Prajapat et.al [148] identified *Aspergillus penicilloides* and *Mucor racemosus* as potential biomaterial for defluoridation. The biomass obtained from the above two species was treated with Cu^{+2} and then studied for fluoride removal. Another study has been conducted using *Eichhorniacrassipes* (water hyacinth) by Sinha et.al [149]. They derived activated carbon from the species at two different temperatures. L-type at 300°C and H-type at 600°C. The H-type carbon was found to be more efficient than L-type carbon.

Mohal et.al [150] investigated algal *Spirogyra IO2* for defluoridation from water. The fluoride uptake decreases as the pH of the solution increases (2.0-10.5). Evident increase in fluoride

removal was found to observe at acidic pH due to the Protonated effect of surface functional groups.

Adsorption using Nanosorbents:

Nanotechnology has attracted evident attraction of researchers in last year's. Even for defluoridation many nano sorbents have been explored. Nano sized particles show good adsorption capacity because of their enhanced surface area. Li et.al [111,112] prepared carbon nanotubes and aligned carbon nanotubes which have been discussed earlier in carbon adsorbents. The same workers also modified CNTs with alumina and investigate for fluoride removal [151]. Highest adsorption capacity was found at 30% aluminium loading at 25°C in pH range 6-9.

Wang et.al [152] studied enhanced adsorption of fluoride with nanosized hydroxy apatite. Zhang et.al [153] investigated hydroxyl apatite nanoparticles for defluoridation. Phosphogypsum was utilized to prepare this adsorbent. It was found that remarkably good adsorption capacity was shown by the adsorbent. Wang et.al [154] conducted defluoridation experiments under various conditions using aluminium oxide hydroxide. The maximum defluoridation capacity was found to be 325mg/Kg. the pH_{pzc} was reported 7.8 fluoride removal increases with increasing pH upto 6.8 which was explained by XPS analysis.

Table: Adsorption Capacity, Adsorption isotherm & Kinetic models for different adsorbents

S.N	Adsorbent	Adsorption Capacity	Adsorption isotherm models	Kinetic models	Reference
1	Activated alumina(Grade OA-25)	1450 mg/kg	-	-	[64]
2	Aluminium hydroxide (hydrated alumina) (THA and UHA)	23.7 and 7.0 mg/g	-	-	[65]
3	Copper oxide coated alumina (COCA)	7.770 mg/g	Langmuir	Pseudo second order	[68]
4	Manganeseoxide-coated alumina	2.851 mg/g	Langmuir	Pseudo second order	[69]

5	Hydrous manganese oxide-coated alumina	7.09 mg/g	Langmuir	Pseudo first order & second order	[70]
6	Lime stone (LS) and aluminium Hydroxide impregnated lime stone (AILS)	43.10 mg/g and 84.03 mg/g	Freundlich	Pseudo first order	[71]
7	Quick lime	16.67 mg/g	Langmuir	First order	[73]
8	Fe/Al hydroxide	91.7 mg/g	Langmuir & Freundlich	Pseudo first order	[75]
9	Fe-Al-Ce nano adsorbent	2.22 mg/g/g	-	-	[76]
10	Stilbite zeolite modified with Fe(III)	2.31 mg/g	-	-	[77]
11	GC(FeSO ₄ .7H ₂ O), GC(Fe ₂ O ₃)	2.16, 1.70 mg	-	-	[78]
12	Granular ferric hydroxide (GFH)	7.0 mg/g	Langmuir	Pseudo first order	[80]
13	PPy/Fe ₃ O ₄ nanocomposite	17.6 – 22.3 mg/g	Langmuir & Freundlich	Pseudo second order	[82]
14	Fe—Ti oxide nano-adsorbent	47.0 mg/g	-	-	[83]
15	Superparamagnetic sorbent (ZrO ₂ /SiO ₂ /Fe ₃ O ₄)	14.7 mg/g/g	-	-	[86]
16	Calcined meixnerite	16.0 mg	-	-	[87]
17	Iron(III)-tin(IV) mixed oxide	10.47 mg/g	Langmuir	Pseudo second order	[90]
18	Hydrated iron(III)-aluminium(III)-	31.89 mg/g	Langmuir	Pseudo second order	[91]

	chromium(III) ternary mixed oxide					
19	Magnesia, Magnesia/chitosan composite	2.2, 4.4mg/g	Freundlich	Pseudo second order		[92]
20	Al–Ce hybrid adsorbent	91.4 mg/g	Langmuir			[94]
21	Fe–Al mixed hydroxide (Molar ratio:1)	91.7mg/g	Langmuir & Freundlich	Pseudo first order		[95]
22	Magnesium Titanate	0.03mg/g	-	-		[97]
23	Fe–Al–Ce trimetal oxide	178mg/g	-	-		[98]
24	Aluminium titanate (AT) Bismuth aluminate (BA)	3.01mg/g 7.09mg/g	-	-		[102]
25	Al ₂ O ₃ /CNTs	28.7 mg/g	Freundlich	-		[111]
26	Aligned carbon nanotubes (CNTs)	4.5 mg/g	Freundlich	-		[112]
27	Fired clay chips	72–90%	-	-		[115]
28	Montmorillonite	0.263 mg/g	-	-		[116]
29	Montmorillonite Clay	1.485 mg/g	-	-		[117]
30	Algerian clay (montmorillonite) (with and without calcium)	1.013 mg/g and 1.324 mg/g	-	-		[118]
31	Magnesium Incorporated bentonite clay	2.26 mg/g	Langmuir	Pseudo first order		[119]
32	Chemically modified bentonite clay (10% La-	4.24 mg/g	Langmuir & Freundlich	Pseudo first order		[120]

	bentonite)					
33	Clay minerals	69.44–93.45 mg/g	-	-		[121]
34	Acid–base treated raw laterite (TL)	11.8 mg/g	-	-		[123]
35	Laterite	0.8461 mg/g	-	-		[124]
36	Acid activated kaolinite clay	0.0450 mg/g	-	-		[127]
37	Lignite (LN) Fine coke (FC) Bituminous coal (BC)	6.9–7.44 mg/g	-	-		[128]
38	Zeolite F-9 Al ³⁺ -exchanged zeolite F-9 La ³⁺ -exchanged zeolite F-9	28–41 mg/g	-	-		[130]
39	Fe(III) loaded carboxylated chitosan beads	4230 mg/kg	Freundlich	Pseudo second order		[134]
40	La(III) incorporated carboxylated chitosan beads	4711 mg/kg	Freundlich	Pseudo second order		[136]
41	Lanthanum incorporated chitosan beads	4.7 mg/g	Langmuir	Pseudo first order		[137]
42	La-incorporated chitosan beads Commercial activated alumina	4.7 mg/g	-	-		[138]
43	Titanium/chitosan Adsorbent	7.20 mg/g	-	-		[139]

44	Chitosan based mesoporous Ti-Al binary metal oxide supported beads	2.22 mg/g	-	-		[140]
45	Aluminium impregnated chitosan	1.73 mg/g	Freundlich	Pseudo order	first	[141]
46	Hydrotalcite Hydrotalcite/chitosan composites	1030 mg/kg 1255 mg/kg	-	-		[143]
47	PANi/Ch, PPy/Ch	5.9, 6.7	-	-		[146]
48	Eichhornia crassipes biomass and its carbonized form	0.523–1.54 mg/g	Freundlich	Pseudo order	first	[149]
49	Spirogyra IO2	1.272 mg/g	Langmuir	Pseudo order	first	[150]
50	nano-AlOOH	3259 mg/kg	Langmuir	Pseudo order	second order	[154]

CONCLUSION:

The paper comprises review of some methods regarding fluoride removal. On the basis this review following conclusion have been made:-

Activated alumina method is the best reported technology. It is expensive. Its performance is affected by the presence of other ions as sulphate, bicarbonates etc. the most important drawback about this method is that aluminum is dangerous to human health.

Similarly, although metal oxides are efficient in fluoride removal, they are very expensive. Natural materials are not so efficient for defluoridation with initial concentration and also have regeneration problems with them.

Biosorbents are ecofriendly adsorbents which have been explored for fluoride removal. They provide a technical answer to the fluoride problem. They are not much expensive but there are some difficulties with chitosan and its derivatives, thereby decreasing its adsorption capacity.

Nano adsorbents are recent discovery for fluoride removal on which the research is going on to make them more efficient.

It can also be concluded that the method should be selected site specifically, considering the local needs and conditions as each of the above methods has its own advantage and disadvantage.

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