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Bio removal of Fluoride from Water by Different Bio adsorbents

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Abstract: Fluoride is the major inorganic pollutant of natural origin found in the ground water. Water is a considerable channel of fluoride intake by living organisms. Flouride ions enter into water bodies naturally by the process of dissolution of rock minerals at a gradual pace. Considerably high amount of flouride ions escaping into the water by means of various applications such as excessive use of phosphate fertilizers and pesticides, sewage sludge in agricultural practices thus leading to the remarkably high concentrations. Fluoride is two edge sword. In small doses it prevents tooth decay and in higher doses it causes fluorosis.Its permissible limit is 1.5 ppm.Due to high toxicity of fluoride, there is urgent need to remove fluoride. This paper provides information about various bioadsorbents used for removal of fluoride from water.
Keywords: Fluoride, Adsorbent, Langmuir, Freundlich, Kinetics.

I. INTRODUCTION

Flourine(F), the 13th most abundant element of halogen family is one of the most reactive of all elements. It is also the most electronegative element in the periodic table and thus has a strong tendency to be in its ionic form , by gaining electrons in solutions [1]. Naturally it is found in rocks, soil and fresh water. Weathering of fluoride containing rocks like topaz, fluorite, fluorspar, cryolite, fluorapatite etc and soils leads to leaching of fluoride ions into ground water [2]. Flourides in the form of salts with monovalent cations i.e. NaF and KF are water soluble but salts of fluoride with divalent cations such as CaF_2 are insoluble in water . The pathway of fluorides in natural aquatic streams is mainly dependent on the geological conditions of rocks such as decomposition, dissociation and subsequent dissolution with considerably longer retention times that lead to the leaching of fluoride ions into water bodies [3]. Various industrial processes such as glass and ceramic production, semiconductor manufacturing and electroplating etc. further adds remarkably high amounts of fluoride in aquatic streams[4].

Permissible limits of Fluoride Permissible limits of fluoride ions in potable water assigned by various health organizations are as given in table.

Prescribed permissible Limits of Fluoride ions in Potable Water by Various Health Organizations

Name of the Health Organization	Permissible limits of fluoride ion (mg/L)
World Health Organization WHO (International standard of drinking water)	0.6–1.5
US Public Health Standards	0.8
The Committee on Public Health Engineering Manual and Code of practice, Government of India	1.0
Indian Council of Medical Research (ICMR)	1.0
Bureau of Indian Standards (BIS)	0.6–1.5

Although numerous available conventional methods have various advantages but due to inherent limitations, there is an urgent need to shift from synthetic, chemical based and cost intensive options towards environmental friendly and techno-economically viable alternatives. In recent years biosorption has emerged as most suitable technique for the removal of fluoride ions due to convenient operational conditions, low cost, minimum chemical/biological sludge and regeneration properties.Various Agricultural waste products have been used as bioadsorbents to remove fluoride from water. The main merits of agricultural waste materials are low cost, high efficacy, minimum sludge, no additional nutrient/chemical requirement, no temperature specific conditions and regeneration/recover of biosorbents.

II. BIOADSORPTION

Biosorption is a physiochemical process that occurs naturally in certain biomass which allows it to bind contaminants onto its cellulose structure. It is eco-friendly process.Biomass can be living organism or dead biological material. Different parts of agricultural materials such as leaves, bark, stem, roots, peels and seeds etc. in natural form and with certain chemical, thermal and physical modifications are used to enhance the removal efficiency and binding capacity for fluoride ions. These biodegradable materials are available in enormous amount in nature and are inexpensive and environmentally friendly. The use of agricultural waste materials for removal of fluoride ions is as discussed below.

A. Usage Of Agricultural Waste Materials In Natural Form

Jamode et.al. (2004) assessed the suitability of inexpensive and easily available leaves of neem (Azadirachta indica), peepal (Ficus religiosa) and Khair (Acacia catechu willd) trees for effectively remediation of fluoride-contaminated water. The study concluded approximately 98% removal of fluoride ions within 180 min at 29 ± 0.5°C with adsorbent dose of is 10 g/L [5].

Murugan and Subramanian (2006) used tamarind seed for removal of fluoride ions from water solutions batch sorption studies considering various process parameters such as pH, agitation time and initial fluoride concentrationand revealed that maximum fluoride removal was 90% achieved at pH 7.0, defluoridation process follows first order kinetics and Langmuir adsorption isotherm [6].

According to Alagumuthu and coworkers (2010) the removal of fluoride ions was studied from the water using Cynodon dactylon as bioadsorbent. The maximum removal of fluoride ions was found to be 83.77% in batch mode studies. Various process parameters that were kept in consideration while performing the studies were pH, contact time, initial ion concentration and agitation speed etc. The adsorption studies followed Redlich-Peterson isotherm as well as Langmuir isotherms [7].

Fluoride adsorption characteristics of eggshell was studied by Bhaumik et. al. (2011) . The maximum adsorption was achieved in the range of pH 2.0-6.0. The investigators achieved around 94% removal of fluoride at initial ions concentration of 5 mg/L at optimum adsorbent dose of 2.4 g/100 ml in 120 minutes. Experimental data provided best fit with the Langmuir isotherm model and the adsorption kinetics followed pseudo-second-order kinetic model [8].

Vardhan and Karthikeyan (2011) inspected the adosrption of fluoride by using Rice husk rich in floristic fiber, protein and various functional groups such as carboxyl, hydroxy and amidogen, etc. making adsorption effective possible. Maximum 83% fluoride removal efficacy was achieved at equilibrium and studies showed good fit of Langmuir adsorption model [9].

Jenish and Methodis (2011) investigated defluoridation studies by using waste tea leaves after surface modification by reducing the size in the range of 250-500 μm. The study revealed that experimental conditions like optimum adsorbent dose (12g/L), initial fluoride concentration (5 mg/L) at pH 6.0 and contact time 150 minutes resulted into 91% fluoride removal [10].

Bhagyashree and coworkers (2012)investigated the effectiveness of babool bark as adsorbent for fluoride removal in batch mode. Potentially high removal efficiency was achieved under controlled process parameters such as adsorbent dose (5g/L), initial ion concentration (5 mg/L), pH 6-8 and contact time (8 hours). The equilibrium data fitted to Langmuir isotherm as compared with Freundlich isotherm and pseudo-second-order kinetic model fitted well as compared to pseudo first-order model [11].

Patil et.al. (2012)conducted experiments to investigate the efficiency of various natural adsorbents such as Mangrove plant leaf powder (MPLP), Almond tree bark powder (ATBP), Pineapple peel powder (PPP), Chiku leaf powder (CLP), Toor plant leaf powder (TPLP) and Coconut coir pith (CCP) for fluoride removal. Studies included the effect of pH, contact time, adsorbent dose and initial metal ion concentration to remove fluoride ions from the aqueous solutions using batch studies. Uptake of fluoride ions by adsorbents at equilibrium was found to be in the order of MPLP > CCP > TPLP > CLP > PPP > ATBP. The optimum contact time for all the adsorbents was 60 minute with adsorbent dose of 10 g/L for initial fluoride concentration of 5ppm. Percentage removal at pH 2 was found to be very high [12].

Valencia-Leal et. al. (2012) used the Guava seeds (Psidium Guajava) as low cost biosorbent for the removal of fluoride ions from aqueous solutions. Maximum adsorption was found to be occurred between pH 5.0 to 8.0. The Langmuir model best described the isotherm's experimental data. [13].

Kamble (2012) studied the defluoridation capability of fresh leaves, dry leaves and stem of Basil (Tulsi leaves; Ocimum sanctum family Lamiaceae). The maximum removal of 94% (by fresh basil leaves), 75% (fresh basil stem), 78% (dry leaves) and 74% (dry stem) achieved from 5 ppm of fluoride solution under optimized conditions of pH, adsorbent dose, rotation speed, contact time and initial concentration of solution [14].

Ramanjaneyulu and coworkers (2013) observed the adsorption capacity of Tamarindus indica (Tamarind) fruit shell to remove fluoride ions from drinking water. The effect of controlling parameters of adsorption like pH, adsorbent dose, contact time and initial sorbate concentration on the removal efficiency was studied and optimum values for maximum uptake were found. Tamarind fruit shell exhibited highest fluoride removal efficiency of about 85% at pH 2, initial fluorine concentration of 3 mg/L, contact time of 90 min. adsorbent dosage of 2g/100 ml and maintaining temperature of 307 K. The obtained data were fitted to Langmuir and Freundlich isotherms [15].

Jain and Gupta (2013)used bioadsorbents such as seed powder of Guava (Psidium Guajava) (GL). Neem Bark (Azadirachta Indica) (NB), Neem leaf powder (NL) and Rice Husk (RH) to remove fluoride from water. The experimental results indicate that adsorption kinetics follow first order rate mechanism for Rice Husk (RH), leaf powder of Guava (GL) and Neem Bark (NB), but the above remaining adsorbents followed second order rate mechanism, finally adsorbents well fitted with Langmuir and Freundlich models in fluoride adsorption [16].

Shyam and Kalwania (2013) have studied the fluoride removal capability of a Khimp plant (Leptadenia pyrotechnica) stem powder, having sufficient positive (calcium) ions that adsorbed the negatively charged fluoride ions. The fluoride removal mechanism was mainly governed by precipitation and adsorption (CaF_2) onto khimp powder. The maximum fluoride removal of 97% was achieved at pH 6.7±0.1 with an adsorbent dosage of 6.0 g/L of biomass with a contact period of 60 minutes. Equilibrium adsorption data obeyed both Langmuir and Freundlich isotherms[17].

Rayappan et. al. (2014) have investigated potential of Cissus Quadrangularis (CQ) powder for removal of fluoride from water in batch process. The fluoride removal of 90% was obtained at 10 mg/50 ml dosage of CQ adsorbent for 60 minutes of contact time and 120 rpm shaking speed. The optimal pH for maximum fluoride removal was 7.0. The Langmuir and Freundlich adsorption isotherms were fitted well as per the study [18].

Tomar et. al.(2014) have reported that the adsorption of fluoride by using Citrus limonum leaf. The optimum pH was 2 and there was maximum removal of 70%. Experimental data fitted into Langmuir and Freundlich isotherm models [19].

Investigations carried out by Dwivedi et. al. (2014) on the bioadsorption of fluoride from aqueous solution by peepal leaves using batch study experiments revealed that maximum fluoride removal was found to be at equilibrium pH of 7.0 with optimum adsorbent dose (10g/L), temperature (30°C), time (45 min) and initial concentration (20 ppm)[20].

Bharali and Bhattacharyya (2014) reported the utilization of Devdaru (Polyalthia longifolia) leaf powder for defluoridation of aqueous solutions. The bioadsorbent was found to be highly effective at pH 7.0 and maximum fluoride ion removal was found to be 77 %. Surface adsorption and intra- particle diffusion studies were also carried out [21].

Bharali and Bhattacharyya (2014) have also used Silikha (Terminalia Chebula) leaf powder for defluoridation of aqueous solutions. The fluoride removal efficiency of 74% was obtained at the natural pH of 6.8 and 303 K temperature. Studies revealed that the defluoridation process fitted well with the pseudo-second-order kinetic model. The equilibrium time of 120 minutes for removal of fluoride ions indicated the high degree of affinity for fluoride sorption [22].

Mohammad and Majumdar (2014) investigated the feasibility of two low cost agricultural waste adsorbents namely: banana peel and groundnut shell for defluoridation of water at optimized pH range. The banana peel and groundnut shells showed removal efficiency of 94.34% and 89.9 respectively at doses of 14 and 12 gm/L respectively. Mechanism followed in adsorption kinetics was found to be pseudo- second order reaction and further surface adsorption and intra- particle diffusion contributed in the rate determining step[23].

Mann et. al. (2014) studied the adsorption behavior of saw dust to remove fluoride ions from water streams by carrying out the batch adsorption studies and observed that the maximum adsorption occurs at pH 7.0 at contact time of 120 min. and the fluoride removal achieved was 70% and the equilibrium data best fitted into Langmuir equation [24].

Kumari et al. (2015) used Sal (Shorea Robusta) leaf powder of particle sizes 0.3 and 1.0 mm for defluoridation of water using different particle sizes. They found that the fluoride ion removal efficiency by paticle size 0.3 mm was more than particle size of 1.0 mm. The fluoride removal percentage of 0.3 mm and 1.0 mm sized particles of Sal powder was 63.6% and 25.8% respectively at pH of 7.5 and adsorbent dose of 1 g per 50 ml solution. The adsorption process obeyed Freundlich isotherm model [25].

Islamudin et.al. (2016) investigated the removal of fluoride ions from drinking water by coconut husk as natural adsorbent. The biosorbent was found successful in removal of fluoride ions from aqueous solution of 0.7 mg/l fluoride concentration with about 86% removal efficiency at 323 K temperature. It was also observed that the adsorption was pH dependent with maximum adsorption achieved at optimized pH 5.0 [26].

Patil et.al. (2016) studied the process of biosorption by using bark of Phyllanthus Emblica (Amla) with the object of defluoridation from samples of aqueous medium. Batch experiment studies were performed for identifying the removal capacity of fluoride ions by using this bioadsorbent. The study was performed under the influence of various experimental conditions such as pH of aqueous solution (2.0 to 10), initial fluoride concentration (3–20 mg/L) and adsorbent dose (0.5 to 5.0g/L) Results indicated significant removal efficiency under optimized process parameters [27].

Nusrat Ali et. al .(2016) studied the adsorption of fluoride ions from waste waters by using an easily available and effective agricultural waste materials that is sugarcane bagasse. The experiments concluded 84% fluoride ion removal efficiency at pH 7.0 and 323K temperature [28].

Gandhi et al (2016) studied adsorption of fluoride ions from water by using Horse Gram (Macrotyloma uniflorum) seed powder. Under optimum dosage of 0.8 gm/L and contact time of 30 minutes the adsorbent showed significant results. Data was found to follow Freundlich adsorption isotherm and followed pseudo second order kinetics [29].

Mereta (2017) studied the removal of fluoride by using seeds of cabbage tree (Moringa stenopetala). The maximum floride ion sorption capacity was found to be 1.32 $mg.g^{-1}$ of dry weight of Moringa seeds at a biomass dosage of 2g L^{-1}, pH 7.0, initial fluoride ion concentration of 10 mg. L^{-1} and a contact time of 60 min. The fluoride level was reduced from 10 to 3.4 mg L^{-1} in water solutions. The adsorption equlibrium data was fitted well to Langmuir as well as Freundlich adsorption models [30].

Gayathri G. et al (2017) studied the removal of fluoride by using amla powder, coconut shell powder, turmeric powder. By use of amla powder fluoride conc. was decreased from 2.5mg/l to 1.4mg/l.By use of turmeric powder fluoride conc. was decreased from 2.5mg/l to 1.6mg/l. By use of coconut shell powder fluoride conc. was decreased from 2.5mg/l to 1.9mg/l. So among all amla powder was found to be more effective[31].

Sharma et al (2018) studied the removal of fluoride by using Aegle marmelous(Bilva patra). Maximum adsorption was found at pH 7. It was observed that with the dose 1.01gm/100ml and contact time of 300 min there was 68% fluoride removal[32].

Gebrewold et al (2018) studied the removal of fluoride by using rice husk and corn cob. The effect of pH , contact time, initial fluoride conc. and adsorbent dose on adsorption capacity was studied. Removal efficiency of 91% and 89% was achieved by rice husk and corn cob respectively. Adsorption data and kinetic model fitted well into Langmuir isotherm and Pseudo-second order kinetics respectively[33].

B. Usage of Agricultural Waste Materials After Chemical Modification

Parmar et. al. (2006) have compared the defluoridation competence of natural and aluminium chloride and calcium chloride treated powdered corn cob as an adsorbent to remove fluoride ions. Calcium treated corn cob was found to be more effective than aluminium treated corn cob powder under optimum conditions of pH and contact time. Maximum fluoride uptake was achieved in 90 to 120 minutes. Freundlich model was best fitted to experimental data [34].

Alagumuthu et. al.(2010) studied the adsorption of fluoride by zirconium impregnated cashew nut shell carbon (ZICNSC). Experimental data showed that 80.33% fluoride removal was obtained at optimum pH 7.0. Further pseudo-second order equation was applied to the studies and was found fitted well [35].

Kai et.al.(2011) reported the capability of Zirconium loaded garlic peels as a substrate to remove fluoride ions from aqueous streams. Under optimized process parameters the biosorbent showed remarkable results. The optimum pH for maximum fluoride uptake was found 2-4. The kinetic study showed that experimental data was well fitted by pseudo-second-order rate equation [36].

Ganvir et. al. (2011)studied the defluoridation from water by using Aluminium hydroxide coated rice husk ash as an adsorbent. The maximum fluoride removal was attained at pH 5. The data followed the Freundlich isotherm and pseudo second order kinetic model [37].

Hanumantharao et. al. (2011)explored the potential of defluoridation of water through batch adsorption dynamics and equilirbium studies at room temperature by using an adsorbent Acacia Farnesiana Carbonized Material. They have identified that adsorption of fluoride was attained between the pH range of 6.50 to 7.00 and maximum adsorption was noticed around pH of 6.90. Fluoride adsorption follows the Freundlich isotherm [38].

Joshi et. al. (2012) studied the adsorption of fluoride onto Zirconyl-Impregnated activated carbon prepared from Lapsi Seed Stone. The optimum pH for adsorption of fluoride was observed at pH 3-4, and minimum contact time for the maximum defluoridation was found to be 180 min. The Langmuir and Freundlich isotherm were used to describe adsorption equilibrium [39].

Bhagawati et. al.(2012) has used activated carbon prepared from an agricultural waste almond shells with KOH activation for the removal of fluoride from aquatic solutions. Maximum removal efficiency was found to be 68% under optimized conditions of biosorbent dose, contact time, pH, stirring speed and temperature [40].

Sadasivan et al. (2012)studied the defluoridation of water by using Phosphoric acid activated Vetiver root. Batch sorptive defluoridation was conducted under variable experimental conditions such as pH, agitation time, dose of adsorbent and particle size.

Maximum defluoridation of 80% was achieved at pH 6. The surface and sorption characteristics were analyzed using SEM techniques. The equilibrium data obtained fitted well with Langmuir and Freundlich both isotherms [41].

Yadav et.al.(2013) studied the removal of fluoride ions from aqueous solutions and groundwater by using activated bagasse carbon (ABC), saw dust raw (SDR) and wheat straw raw (WSR). The performance was compared with commercially available activated carbon (CAC). The CAC, ABC, SDR and WSR removed 57.6, 56.4, 49.8 and 40.2% of fluoride ions respectively from aqueous solution of 5 mg L^{-1} at pH 6.0 with contact time of 60 min [42].

Rajan and Alagumuthu (2013) have studied the fluoride removal capacity of Zirconium impregnated walnut shell carbon (ZIWSC) and compared to natural walnut shell carbon (WSC). The fluoride removal of ZIWSC and WSC were found 94% and 81% at pH 3 respectively. The Langmuir maximum adsorption capacity of ZIWSC was 3.19 mg/g at 303 K for optimum condition at 180 minutes of contact time [43] .

Mise and Gurani (2014) have used chemically activated carbon prepared from Phoenix dactylifera (date palm) seeds at room temperature for removal of fluoride from water. Maximum fluoride removal was at pH 7.0 and optimum contact time was 40 minutes [44].

Marappan et. al. (2015) prepared chemically activated cotton nut shells carbon by different chemicals and was put in use for the removal of fluoride ions from aqueous solutions. Effects of adsorption time, adsorbent dose, pH of the solution, initial concentration of fluoride, and temperature of the solution were studied with equilibrium, thermodynamics and kinetics of the adsorption process [45].

Bashir et. al. (2015) synthesized chemically modified kernel-shell based bioadsorbents for removal of fluoride ions from waste water. Chemically modified palm kernel shells (CMPKS) showed effective adsorption property with maximum adsorption capacity of 2.35 and 2.01 mg/g at pH 6.0 and pH 7.0 respectively. Langmuir and Freundlich isotherms were studied along with pseudo first and second order kinetics mdoels, as well as intraparticle diffusion study indicated the probability of chemisorption. SEM showed drastic changes in surface morphology with projections and porous surface. FT-IR analysis also verified the presence of hydroxyl and amine group on the bioadsorbent [46].

Mondal et. al (2015) produced Aluminum impregnated coconut fiber ash (AICFA) for removal of fluoride from water. Adsorption kinetic indicated that the adsorption equilibrium was achieved within 60 min of process with removal efficiency of 98% at optimized pH of 12. Further adsorption process followed the pseudo- second order kinetic model. The Langmuir isotherm model could fit the experimental data. [47].

C. Usage of Agricultural Waste Materials After Thermal Modifications

Kumar et. al.(2008) have studied the defluoridation capacity of thermally activated neem (Azadirachta indica) leaves carbon (ANC) and thermally activated kikar (Acacia Arabica) leaves carbon (AKC) adsorbents. Batch experiments were done to see the fluoride removal properties. The optimum pH was found to be 6 for both adsorbents. The optimum dose was found to be 0.5g/100ml for ANC and 0.7g/100ml for AKC. The optimum time was found to be one hour for both the adsorbents. The adsorption process obeyed Freundlich adsorption isotherm [48].

Alagumuthu et. al. (2010) produced Zirconium impregnated groundnut shell carbon (ZIGNSC) to remove fluoride from water. Thermodynamic studies showed that fluoride adsorption increases with increase in entropy and is endothermic process. The kinetic data obtained from adsorption obeyed pseudo-second order equation. The equilibrium time for removal of fluoride ions was 180 min. The fluoride saturation capacity of ZIGNSC was 1.26 mg F^{-}/g at room temperature [49].

Chakrabarty and Sharma (2011) have investigated the defluoridation capability of thermal treated betel nut coir charcoal (BNC) powder at 200-300°C for 2-3 hours in a muffle furnace. The fluoride removal of 92% to 70% was achieved from aqueous solution of 2-10 mg/L fluoride concentration at 25°C. Adsorption equilibrium was achieved within 180 minutes. The optimum pH for maximum removal efficiency was accomplished at pH 6.0. The isotherm was fitted well for both Langmuir and Freundlich isotherms. The kinetic study revealed that result obeyed pseudo-second order for adsorption [50].

Chakrabarty and Sharma (2012) also studied the adsorption capacity of neem charcoal to remove the fluoride ions from water. The biosorbent was found significantly successful in removal of fluoride ions from aqueous solution of 10 mg/L fluoride concentration with about 94% efficiency. Biosorption equilibrium was achieved within 180 minutes. It was observed that the adsorption was pH dependent and maximum adsorption achieved at pH 5.0. Both Langmuir and Freundlich isotherm models fits well to the adsorption [51].

Mondal et. al. (2012) studied the removal of fluoride using tea waste in ash form as adsorbent through batch studies. The authors reported that the adsorbent was efficient for the uptake of fluoride ions at pH 6 with contact time 180 minutes. Tea ash was found to be more efficient at an initial concentration of 5 mg/L and temperature 303 K. The authors also reported that the data well fitted with Langmuir adsorption isotherm. The adsorption process was observed to follow a pseudo-second-order kinetic model [52].

Hanumantharao et. al. (2012) reported the surface sorption characteristic of activated carbon prepared from the shells of Lagenarla Sicerala towards fluoride ion removal from aqueous streams under various operational parameters such as initial ion concentrations, (1.5–15 mg/L), agitation time (10-70 minutes) and pH (3-10). The experimental isotherms data was analyzed using Langmuir and Freundlich isotherm models. The data was best fitted with the Langmuir isotherm model. First order, pseudo-first order, second order, pseudo-second order kinetic equations, intra particle diffusion and pore diffusion models were applied to studies to examine the experimental data. It was found that the pseudo-second order kinetic equation described the data of F^- ion adsorption on adsorbent carbon adequately [53].

Yadav et. al. (2014)have studied the potential of activated charcoal powder derived from dry stems or timber of Aralu (Ailanthus exelsa) tree by charring the biomaterials at 100-200^0 C for about 3-4 hours in muffle furnace. The removal efficiency of 94% and 80% was achieved for 10 mg/l of initial fluoride concentration at pH 2 and 5 respectively at an adsorbent dose of 0.5 g/l. The adsorption process was rapid and removed 75% of fluoride within first 30 minutes and biosorption equilibrium was achieved within 180 minutes with 94% removal [54].

Jadhav et. al. (2014) studied adsorption of Maize husk fly ash as an adsorbent for removal of fluoride ions from aqueous streams. The equilibrium was attained in initial 120 min. Maximum removal efficiency was obtained at pH 2.0 and optimum adsorbent dose was found to be 2g/50ml. Maximum fluoride removal was 86% at optimum conditions. Freundlich and Langmuir isotherms were best fitted into data[55]

Anusha et. al. (2014) conducted a batch mode adsorption studies by adsorption process using activated carbon prepared from Bale fruit (Limonia acidissima) shells as adsorbent and the removal efficiency was determined by optimizing various process parameters such as adsorbent dosage, contact time, pH and initial ion concentration. The maximum removal efficacy was found to be more than 63% [56].

Kanaujia et.al. (2015) studied the elimination of fluoride ions from ground water by carbonised Punica granatum (CPGC). The equilibrium time for removal of fluoride ions was achieved in 75 min. The fluoride saturation capacity of CPGC was found to be 1.68 mg F^-/g at room temperature. The best fitting adsorption isotherm was Freundlich model[57].

Kalpana et. al. (2017) investigated the adsorption of fluoride ions from the aqueous solutions by using activated carbon of Bael shells. The batch adsorption experiments were carried out and studies revealed significantly fast removal efficiency. It was observed that at initial concentration of 4 mg/L, approximately 52% of fluoride ions were removed in 60 minutes of contact time with adsorbent dose of 2 g/L. The adsorption isotherm data fitted well into Langmuir isotherm [58].

III. CONCLUSION

Agricultural waste biomass is generated during the harvesting of agricultural and food crops, as a byproduct of various agro based industrial processes or as a waste material after processing. Agricultural waste biomass is mainly composed of cellulose, lignin and hemicellulose along with other components such as lipids, proteins, simple sugars, water, hydrocarbons and starch etc. So these Agricultural waste materials are good adsorbents for fluoride removal from water.

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