

## Preparation of Fly Ash Based Zeolite for Fluoride Removal

**L. Panda and B.B. Kar\***

School of Applied Sciences, KIIT University, Bhubaneswar (India)  
✉ karpublications@gmail.com

*Received March 20, 2017; revised and accepted August 6, 2018*

**Abstract:** Fluoride contamination of drinking water is a worldwide phenomenon and scientists are working relentlessly to find ways to remove fluoride from drinking water. Out of the different methods employed for removal of fluoride from drinking water, adsorption process is the most suitable because in this process the adsorbent is regenerated. In the present study fly ash is used as the raw material, which is treated with alkali (NaOH) to form NaP1 zeolite. This zeolite is then subjected to characterization by standard procedures. It is found that the synthesized zeolite has more crystalline character than the raw fly ash and has also residual positive charge on its surface. The synthesized zeolite is employed for removal of fluoride under varying pH, contact time, initial concentration of fluoride, temperature and adsorbent dose etc. The adsorption data is then put into Freundlich and Langmuir Isotherm. It is found that the equilibrium data for removal of fluoride by adsorption onto synthesized zeolite fits better into the Langmuir isotherm than the Freundlich isotherm.

**Key Words:** Fly ash, zeolite adsorption, adsorbent dose, Freundlich isotherm, Langmuir isotherm.

### Introduction

Removal of fluoride from drinking water is a major challenge the world over and more challenging is the development of cost effective and simple techniques for removal of fluoride from drinking water. The conventional methods employed for removal of fluoride from drinking water are:

1. Precipitation method based on addition of chemicals to water
2. Adsorption Method in which fluoride is removed by adsorption on a suitable adsorbent
3. Ion exchange reactions on some suitable substrate
4. Membrane process (Reverse osmosis and Nano filtration)
5. Electro dialysis

In precipitation process, precipitation with calcium and aluminum ions is one of the commonly used processes to remove fluoride from contaminated water and it can reduce the level of fluoride to approximately 2 mg/l. However, large amount of fluoride-containing sludge is generated and the same needs further treatment and suitable disposal. The electrolysis and membrane processes are quite effective but are too expensive and require regular regeneration of the ion exchange bed and cleaning and scaling of the membrane. Out of all these processes the adsorption process is considered to be the most suitable one because of its simplicity and cost effectiveness (Subhasini et al., 2012). Again the adsorbent used is capable of regeneration and reuse (Gu et al., 2000). The different adsorbents used for removal of fluoride from ground water by various researchers include  $\text{Fe}_3\text{O}_4\text{Al}(\text{OH})_3$  magnetic nano particles (Ma

\*Corresponding Author

et al., 2011), high alumina content bauxite (Lavecchia et al., 2012), bone charcoal as biosorbent (Ma et al., 2011), alum (Goswami et al., 2006), natural materials (Gandhi et al., 2015), mesoporous alumina (Lee et al., 2010), bagasse dust, aluminium treated bagasse fly ash, bone powder and shell powder (Gupta et al., 2014), microwave assisted activated carbon derived from Acacia Auriculiforms scrap wood (Dutta et al., 2012), chalk powder (Gandhi et al., 2015), Al(III) modified calcium hydroxyl apatite (Nie et al., 2012), natural lignite (Piekos et al., 1999), lime stone slurry impregnated fly ash (Grutzeck et al., 1997), modified fly ash adsorbent (Goswami, 2006) etc. The degree of removal of fluoride differ from adsorbent to adsorbent. Adsorption with activated alumina successfully removes fluoride from drinking water. However, its efficiency largely depends upon the pH of water and gives different values at different pH. Again aluminum ions are found to enter water during treatment (Subhasini et al., 2012).

Against this backdrop, it would be a wonderful idea to think of an adsorbent containing two or more such adsorbents. Such an adsorbent is coal fly ash which is a major industrial solid waste from coal powered thermal power plants. This by-product is produced as a fine residue carried off in the flue gases with relatively uniform particle size distribution. The major constituents of fly ash are silica ( $\text{SiO}_2$ ), alumina ( $\text{Al}_2\text{O}_3$ ), iron oxides, calcium oxide and residual carbon. The fine particles and the large surface area with some amount of unburnt carbon, makes it as a good and inexpensive adsorbent (Rongsayamanont and Sopajaree, 2007). Thus employing fly ash for defluoridation of water can be considered as a multi adsorbent therapy.

In India majority of power plants being coal based, disposal of huge amount of fly ash from these units poses serious challenges. Of the total amount of fly ash generated, a small fraction is used as raw material for concrete manufacturing, the manufacture of pozzolonic cements, readymade hollow blocks and asbestos sheets and in road embankment and agricultural purposes. The rest of the fly ash is simply dumped on the landfill sites. More that 90 million tons of fly ash is being generated annually in India with 65,000 acres of land occupied by fly ash ponds. Without proper disposal options, such a huge amount of fly ash poses a great threat to the environment.

### Types of Fly Ash

There are two types of fly ash as defined by American Society for Testing Materials (ASTM).

#### Class F Fly Ash

It is formed by burning of harder, older anthracite and bituminous coal. It is pozzolanic in nature and contains less than 20% of lime ( $\text{CaO}$ ). It requires a cementing agent like Portland cement, quick lime or hydrated lime in presence of water to react and form cementitious compounds. Alternatively the addition of a chemical activator such as sodium silicate (water glass) to Class F fly ash leads to the formation of a geopolymer.

#### Class C Fly Ash

It is formed by burning of younger lignite or sub-bituminous coal. In addition to having pozzolanic characters it also has some self cementing characters. In the presence of water Class C fly ash will harden and gain strength over time. It contains more than 20% of lime. Unlike the F class fly ash it does not require an activator. Alkali and sulphate contents are generally higher in class C fly ash (Rosa et al., 1992).

#### Zeolite from Fly Ash

Zeolites are crystalline, micro porous, aluminosilicate minerals commonly used as commercial adsorbents and crystals. The possibility of using waste coal fly ash in synthesizing zeolite molecular sieves is very much attractive for its widespread applications in diversified fields. In fact high content of reactive materials like aluminosilicate makes fly ash an interesting starting material for the synthesis of zeolite (Rosa et al., 1992). Converting fly ash into zeolites not only eliminates the disposal problems, but also turns an otherwise waste material into a marketable commodity.

#### Structure of Zeolites

Generally zeolites are polymers built from tetrahedral  $\text{TO}_4$  units where T is  $\text{Si}^{4+}$  or  $\text{Al}^{3+}$  ion, each oxygen atom being shared by two T atoms (Rosa et al., 1992). The primary building units of zeolites are the tetrahedral and the secondary building units are the geometric arrangements of the tetrahedral. The secondary building units may be simple polyhedra such as cubes, hexagonal prisms or cubo-octahedral. The structures can be formed by repeating secondary building units. This is depicted in Figure 1.

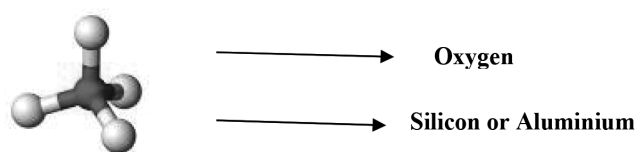


Figure 1: Primary building units of zeolites.

Zeolites can be synthesized from coal fly ash, by hydrothermal treatment in alkaline solutions, using the alkali NaOH or KOH. Volcanic ashes can be modified into zeolites in nature. But natural processes being slow, it takes years for the conversion. Now a days zeolites can be hydrothermally synthesized in the laboratory within hours or days (Grutzeck et al., 1997). The properties of synthesized zeolites largely depend upon the shape, fineness, particle size distribution, density and composition of fly ash particles used. There is wide variation in the physical properties and chemical composition of coal fly ash depending upon the source of coal and operational procedure. This makes fly ash more versatile product for use and thus, we get a large many types of zeolites which differ significantly in their cation exchange capacity and adsorption properties. Basing on the difference in cation exchange and adsorption properties, zeolites find variety of applications. The important parameters in the preparation of the zeolite are the alkaline condition, fusion temperature and the  $\text{SiO}_2/\text{Al}_2\text{O}_3$  ratio of the fly ash.

### Aims & Objectives of the Present Study

The aims and objectives of the present study are:

- (i) Synthesis of zeolite from fly ash
- (ii) Characterisation of the synthesised zeolite
- (iii) Application of the synthesised zeolite as an adsorbent for removal of fluoride from drinking water

Thus, attempt has been made to convert the dumped fly ash as a significant resource for zeolite production. Such secondary utilization of the wastes supports activities aimed at lithosphere protection being consistent with the guidelines of so-called balanced development.

### Zeolite Synthesis

#### Material Methods and Procedure

Coal fly ash required for synthesis of zeolite is collected from National Thermal Power Corporation, Kaniha, Odisha. All other chemicals are of AR grade. NaOH was used as alkali for modification of fly ash into zeolite. The coal fly ash was added to 1M NaOH solution to prepare fly ash slurry, with solid to liquid ratio being 2:7. The mixture was agitated in a 500ml volumetric flask fitted with reflux condenser. The reaction was carried out under atmospheric pressure and at  $110^\circ\text{C}$ . The reaction time for zeolite synthesis is 96 hours. The flow diagram of the synthesis is shown in Figure 2.

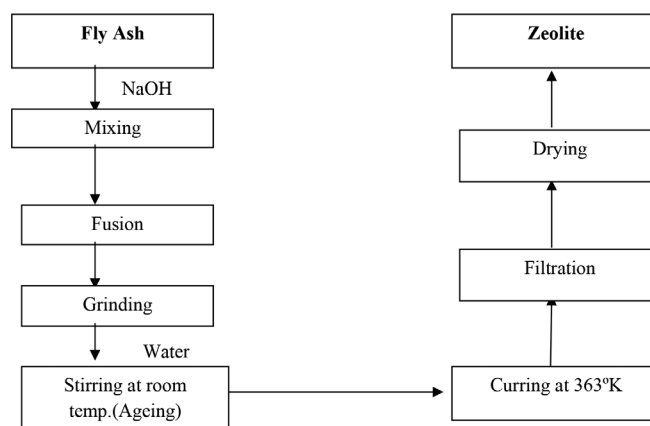


Figure 2: Flow diagram of zeolite synthesis.

Chemical composition of different constituents in fly ash and the synthesized zeolite is measured by X-ray Fluorescence Analyzer. Cation exchange capacity was measured by standard methods. Surface structure was observed by Scanning Electron Microscope and surface area was analyzed by using BET nitrogen sorption micrometrics. Crystalline structure was determined by X-ray diffraction equipment (Phillips, 1830). Particle size is analysed by Laser Particle size Analyser (Malvern Instrument Master sizer) and specific gravity by Pycnometer Bottle.

### Results and Discussion

Comparison between the properties of coal fly ash and synthesized zeolite is depicted in Table 1.

Table 1: Analysis of fly ash and synthesized zeolite

Major constituents (in % of weight)/Properties	Coal fly ash	Synthesized zeolite
$\text{SiO}_2$	53.20	42.10
$\text{Al}_2\text{O}_3$	24.67	21.67
$\text{Fe}_2\text{O}_3$	10.25	9.30
CaO	3.68	3.14
$\text{Na}_2\text{O}$	1.79	5.45
MgO	2.6	2.13
$\text{K}_2\text{O}$	2.54	1.82
$\text{TiO}_2$	0.42	0.38
$\text{P}_2\text{O}_5$	0.18	0.16
LOI	0.64	13.82
BET ( $\text{m}^2/\text{g}$ )	2.13	56.14
CEC (meq per gram)	0.07	2.49
Avg particle size (in micron)	$16.38 \pm 0.09$	$63.54 \pm 2.12$
Specific gravity	2.26	2.39

The images here show the structure of powder form of raw fly ash (Figure 3) along with the microscopic structure of raw fly ash and synthesized zeolite (Figure 4).

The original FA particles had a smooth surface as the surface is covered by an aluminosilicate glass phase. After the formation of zeolite the surface becomes rough due to deposition of the zeolite. The amount of  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  in zeolites is lower than that of FA. This may be attributed to the fact that dissolution of aluminosilicate during the glass phase in alkaline solution during the treatment and then reaction of alumino and silicate ions to form an aluminosilicate gel is a pre-requirement for zeolite synthesis. The gel covers the outer surface

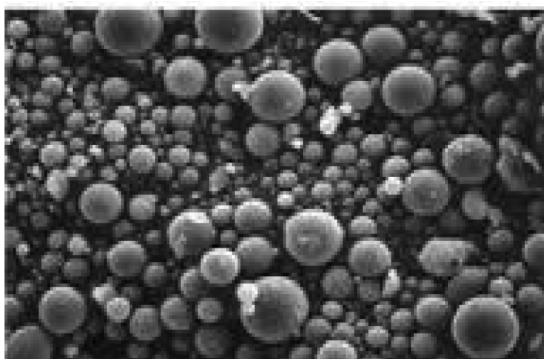


Figure 3: Microscopic structure of raw fly ash.

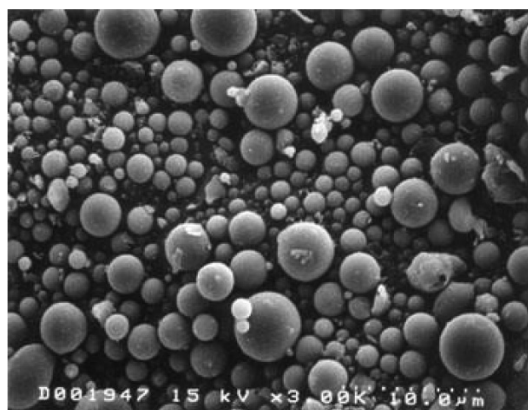


Figure 4: Comparative microscopic structure of raw fly ash and zeolite

of FA and so aluminate ions and silicate ions are not supplied from FA due to the covering of the surface. An increase in  $\text{Na}_2\text{O}$  content of the product is caused by capture of  $\text{Na}^+$  ions to neutralize the minus charge on aluminate in zeolite structure when zeolite is formed. This indicates that these impurities were dissolved in the alkaline solution during alkaline treatment. Moreover the particle size of the zeolites are increased compared to FA due to change in its structure wherein more spaces have developed within the structure and this resulted in increase of surface area and ion exchange capacity of the synthesized product (Woolard et al., 2000).

From the above data it is seen that the fly ash is a typical class F type consisting of finally divided micro-metre sized fly ash sphere, small amount of quartz and mullite. The synthesized zeolite is sintered at elevated temperature and the change in the structure of the zeolite is watched. It is observed that as the temperature is raised there is a gradual change from amorphous phase to crystalline phase. This is corroborated from the X-ray diffraction data. Thus the percentage of crystallinity in the synthesized product increases, which serves our purpose of adsorption better than the raw fly ash due to its crystalline framework. Figure 5 shows the X-ray diffraction data of raw fly ash. There are small peaks which can be attributed to small amount of quartz and mullite and the small humps are due to the presence of amorphous materials. The small humps due to amorphous materials in fly ash are gradually eliminated in the process of zeolitization.

### Thermal Stability of the Synthesized Zeolite

The synthesized zeolite was subjected to heating at various temperatures in range from  $400^\circ\text{C}$ - $1000^\circ\text{C}$  for two hours each in muffle furnace. The change in the structure of the zeolite is observed at different

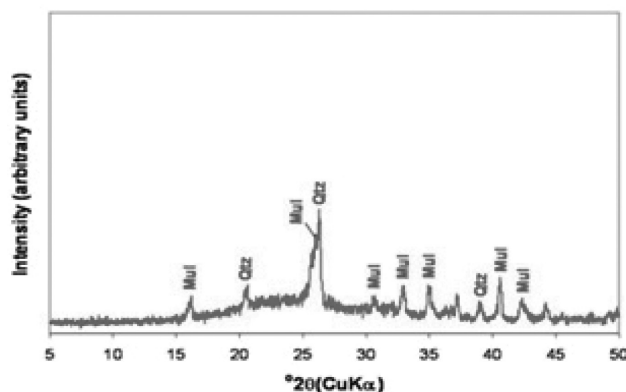


Figure 5: XRD pattern of FA and its SEM image. (Qtz, quartz; Mul, mullite)



temperatures. Thermal stability of the synthesized zeolite increases as the fusion temperature rises, but up to a certain temperature and then shows a decreasing trend. The synthesized zeolite loses its crystallinity beyond 700°C and the crystalline structure almost disappears above 800°C. As the temperature rises the amorphous material present in the zeolite melts, thus increasing the percentage of crystalline character in the synthesized zeolite. Crystalline zeolites are more resistive to heat than amorphous materials due to geometrical structure of the crystalline framework. Thermal stability depends upon the silica/alumina ratio. It is seen that the metal exchange efficiency is considerably reduced as the temperature of the synthesized zeolite is increased. Thus at high temperature, the absorption capacity of the synthesized zeolite is almost zero. The reason may be due to the loss of hydroxyl groups by condensation and also due to non-existence of interstitial  $H_2O$  molecules. Thus at high temperature the synthesized zeolite can be better utilized as an adsorbent rather than as a metal exchanger.

#### IR Spectrum of Fly Ash and Synthesized Zeolite

Figure 7 shows the IR spectrum of fly ash and synthesized zeolite. From the figures we see a broad peak in the region of  $3600-3200\text{ cm}^{-1}$ . This may be assigned to the presence of anorthite and adherent  $H_2O$  molecules (Maurice et al., 2009).

We can also see another broad peak in the region  $1200-800\text{ cm}^{-1}$  that may be attributed to  $SiO_4$  asymmetric and symmetric vibrations (Grutzeck et al., 1996). The multiple peaks below  $1100\text{ cm}^{-1}$  may be

due to the presence of various types of metal–oxygen linkages in fly ash as well as in the synthesized zeolite.

#### Chemical Stability

Chemical stability of synthesized zeolite was examined in several mineral acids like HCl,  $HNO_3$ ,  $H_2SO_4$ , alkalis and also in organic solvents. 100 ml of the solvent is taken in conical flask and 1 gm synthesized zeolite is added to it and the resultant mixture is left for one day at 25°C with continuous shaking. The synthesized zeolite is found to be quite stable in various acids and mixed solvents and comparatively less stable in alkalis. The order of stability in different medium as observed from the experiment is summarized below:

Mineral acids :  $HNO_3 > HCl > H_2SO_4$ .

Alkalis :  $KOH > NaOH$  and

Mixed solvents : Benzene > Acetone > (Acetone + Nitric acids) > (Acetone + KOH)

#### Application of the Synthesized Zeolite for Adsorption of Fluoride from Drinking Water

##### Factors Affecting the Adsorption of Fluoride

The surface of most zeolites is negatively charged due to isomorphic substitution of  $Al^{3+}$  for  $Si^{4+}$ . For using zeolites in anionic adsorption like removal of  $F^-$ , their surfaces should be modified for making them positively charged. Surface of the zeolites is modified by using an aqueous salt solution of the modifying metal. Among the different salts used for surface modification,  $Al^{3+}$  was particularly found to create adsorption media with high

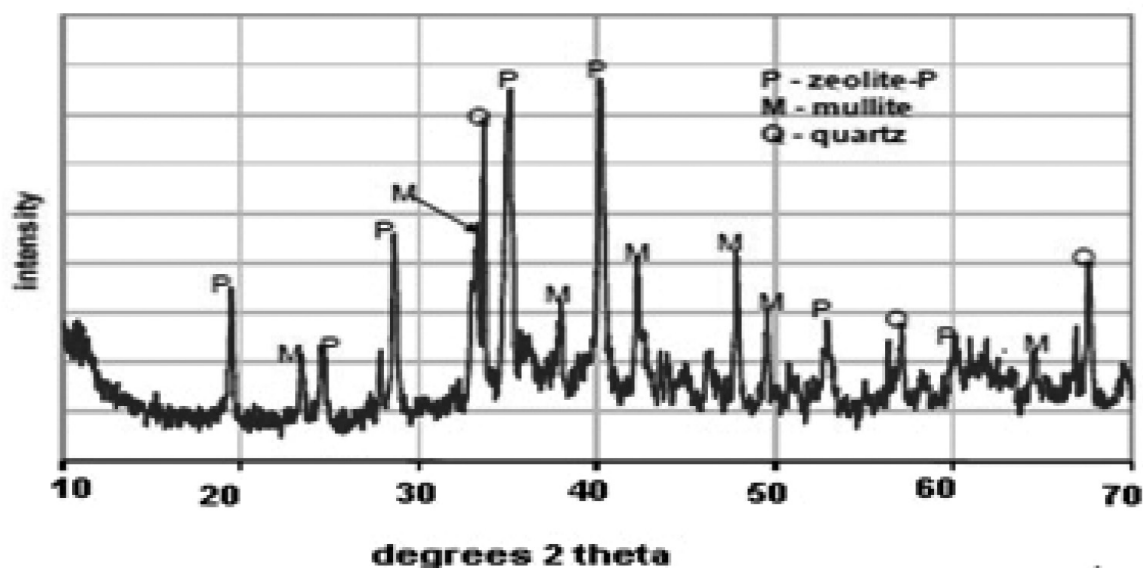


Figure 6: XRD pattern of synthesized zeolite. (Qtz, quartz; Mul, mullite)

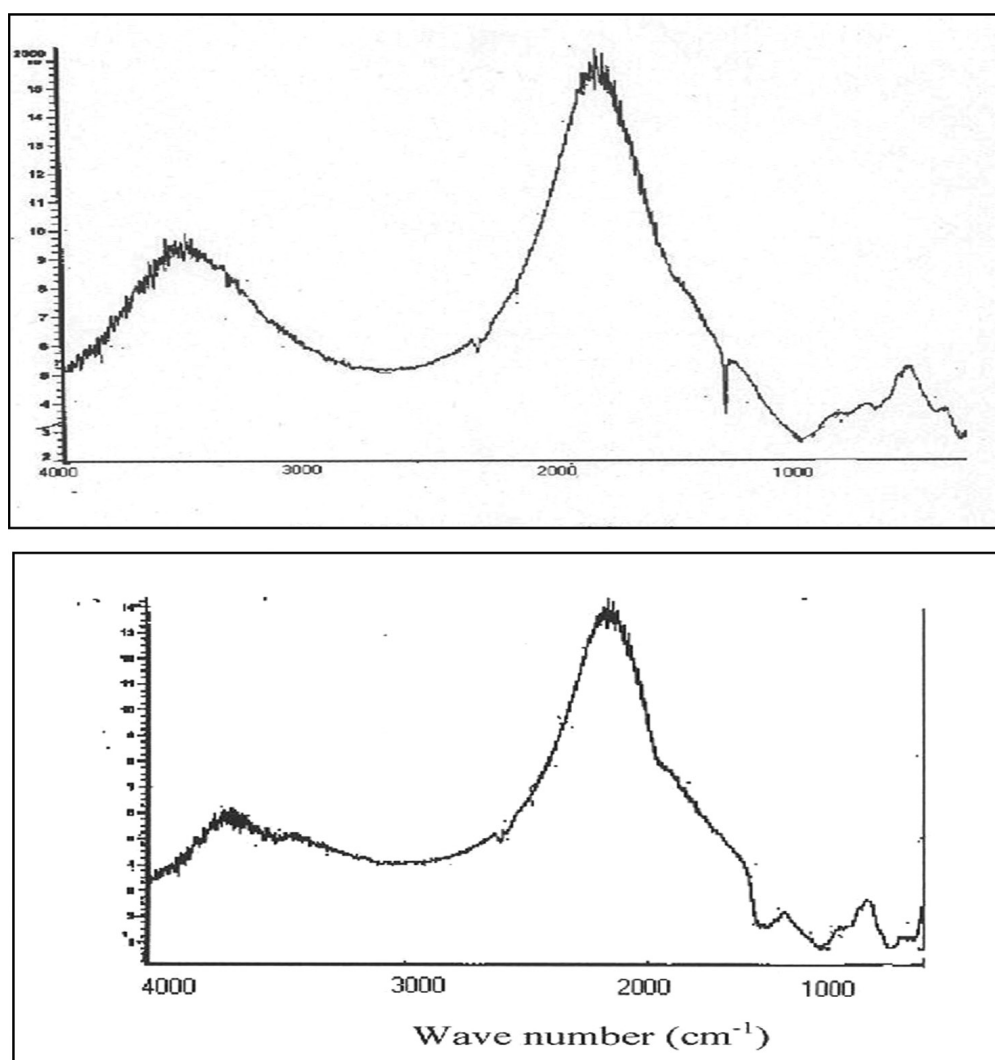
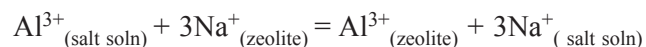


Figure 7: IR spectrum of fly ash and synthesized zeolite.

capacity and specificity for fluoride. The  $\text{Na}^+$ -bound zeolite is exchanged with  $\text{Al}^{3+}$  from aqueous solution creating a surface-modified zeolite adsorption media suitable for fluoride adsorption. The reaction proceeds as follows:



The mechanism of fluoride sorption is by ion exchange and inner-sphere complexation (Maurice et al., 2009). In order to increase the adsorption capacity of synthetic zeolite for the uptake of fluoride, the same is added with 1% NaOH at room temperature and then treated with 2% aluminium sulphate to prepare the zeolite slurry with solid to liquid ratio 1:1. The slurry is left undisturbed at room temperature for one day, then washed with distilled water repeatedly and then dried. The effect of major parameters like pH of the solution, contact time, the dose of the adsorbent, and initial

concentration of fluoride on the removal percentage of fluoride ions on the surface modified zeolite are studied from the kinetic point of view.

### Effect of pH

Adsorption of fluoride onto the zeolite depends upon the pH of the aqueous solution. To judge the effect of pH the experiment is carried out at different pH values like 2, 4, 6, 8, 10 etc. pH is maintained at the required level by addition of  $\text{HNO}_3$  or NaOH to 1000 ml of the prepared solution. The effect of pH on the percentage of fluoride adsorption is shown in Figure 8. The adsorption capacity initially increases slowly and then decreases regularly with increasing pH which is indicative of the stability of the  $\text{CaF}^+$  ion at low pH value. In the initial stage, the formation of weak hydrofluoric acid retards the pace of fluoride adsorption and hence the slow rise in the curve (Subhasini et al., 2012). Optimum

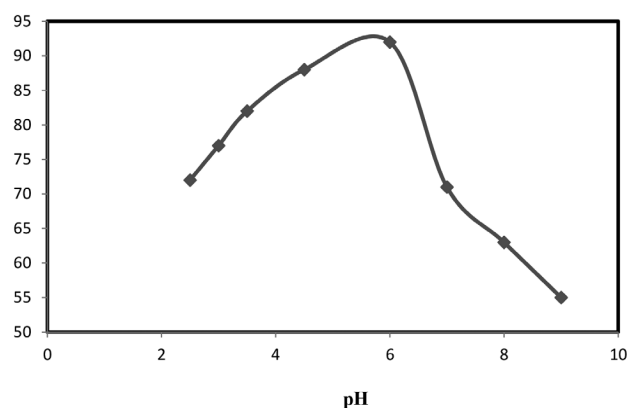


Figure 8: Effect of pH on fluoride adsorption.

adsorption efficiency of more than 90% is recorded around pH 6. One of the major factors may be that at acidic pH the  $H^+$  ion concentration is high and this neutralizes the negatively charged environment on the adsorbent surface and thus repulsion to fluoride ions due to the negatively charged environment is reduced. As the pH increases beyond 6, the concentration of  $H^+$  ion decreases and that of the hydroxyl ions increases. Increase in hydroxyl ions ( $OH^-$ ) concentration acts as a shield for the incoming fluoride ions to the adsorbent surface. Thus, it renders the surface inactive for the negatively charged  $F^-$  ion. Thus pH 6, where maximum % of fluoride adsorption is recorded, is taken as the optimal pH for removal of fluoride.

#### Effect of Adsorbent Dose

The amount of zeolite material was varied between 2 and 24 gm/l with the pH being maintained at 2. The effect of adsorbent dose on adsorption capacity is represented in Figure 9.

It is seen that adsorption increases with the increase in the amount of adsorbent. This is attributed to the increase in the surface area available for fluoride adsorption. Increase in amount of zeolite increases the number of active sites and hence the enhanced rate of adsorption.

#### Effect of Contact Time

The effect of contact time between the adsorbent surface and the adsorbate was recorded by varying the same at constant pH and fixed adsorbent dose. The findings are shown in Figure 10.

It is seen that the fluoride adsorption shows an upward trend with the initial increase in contact time and after a few minutes the process of adsorption reaches its equilibrium and the rate becomes constant.

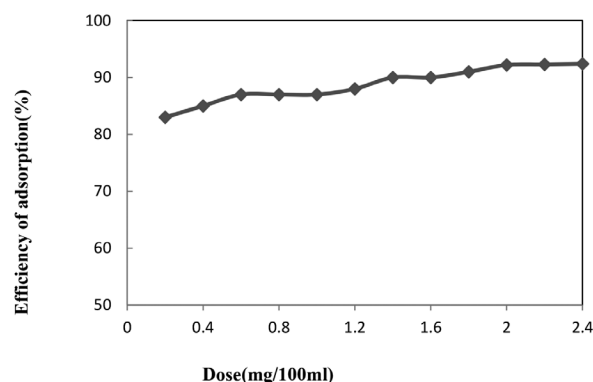


Figure 9: Effect of adsorbent dose on fluoride adsorption.

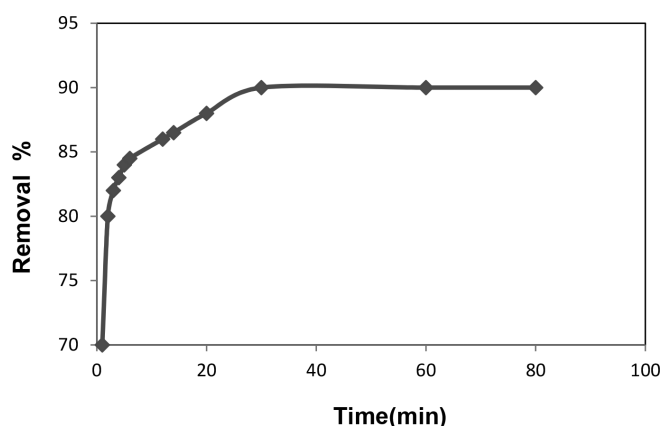


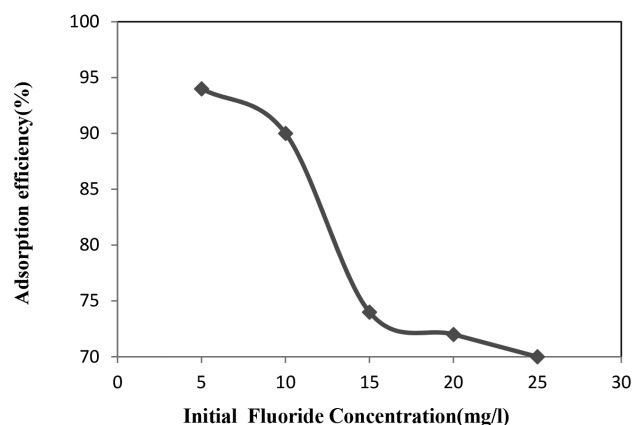
Figure 10: Effect of contact time on fluoride adsorption.

Initially all the adsorbent sites are vacant and the intake of fluoride is rapid, which is seen from the steep rise in the adsorption curve. But after some time the fluoride uptake decreases due to the saturated active sites on the adsorbent surface. When the equilibrium is reached, the fluoride uptake becomes zero and the curve becomes asymptotic. From the above figure it is seen that the equilibrium is reached at 30 minutes.

#### Effect of Initial Fluoride Concentration

The effect of initial concentration of fluoride ion on sorption capacity is studied by varying the same at constant pH, fixed adsorbent dose and fixed contact time. The findings are represented in Figure 11.

The percentage of fluoride adsorption is maximum at 5 mg/l and it gradually decreases till the concentration reaches 25 mg/l. The reason for the same may be attributed to the fact that when the amount of adsorbent remains reasonably constant, the total number of active sites on the surface is also restricted and with the increase in the initial concentration the percentage of fluoride removal decreases due to saturation of the active sites available thereon.



**Figure 11: Effect of initial fluoride concentration on fluoride adsorption.**

### Conclusions

Different techniques are available for removal of fluoride from water from the ancient days till the modern days. However finding a suitable method which is simple, cost effective, eco-friendly and suits the local conditions is a major challenge. In other words, the selection of treatment process should be site specific as per local needs and prevailing conditions as each technology has some limitations and no single process can serve the purpose in diverse conditions. As we know Odisha mainly depends on coal-based thermal power plants for its energy needs wherein fly ash is a major environmental pollutant without any suitable disposal mechanism. Against this backdrop, the choice of alkali activated coal fly ash geo-matrix (better called zeolites) serves the twin purposes of fly ash disposal and also converting an otherwise waste product into a marketable commodity.

The coal fly ash is digested with NaOH for modification of the same into zeolite. We know the original FA has a smooth surface. But after the formation of zeolite the surface becomes rough and porous. There is an increase in Na<sub>2</sub>O content of the synthesized zeolite due to capture of sodium ions from the alkaline treatment. This in turn makes an otherwise negative surface into a positive one, thus facilitating the adsorption of the negatively charged fluoride ion. Moreover the particle size of the zeolite is larger than the raw fly ash due to change in its structure wherein more spaces have developed within the structure and this resulted in increase of the surface area and ion exchange capacity of the synthesized zeolite. The synthesized zeolite is then characterized by X-ray diffraction and other structural analysis studies. The

synthesized zeolite is a NaP1 type zeolite and when subjected to temperature its mechanical and crystallinity increases up to 700°C and then decreases gradually due to breakdown of the crystalline structure.

Then the synthesized zeolite (NaP1) is applied as an adsorbent for removal of fluoride from drinking water with varying pH, adsorbent dose, temperature, initial concentration of fluoride, effect of contact time etc. Defluoridation of water by sorption is supposed to take place by both adsorption mechanism as well as ion exchange mechanism. During adsorption process, the fluoride ions get adsorbed onto the adsorbent surface and this process of adsorption is favoured at low pH, where the concentration of H<sup>+</sup> ion is high. The adsorbent surface thus becomes positively charged which in turn lures more fluoride ions towards the adsorbent through H<sup>+</sup> bonding and there is thus a significant increase in fluoride adsorption. As the pH increases surface slowly acquires negative charge, which would repel fluoride ions and hence the fluoride removal by electrostatic attraction is ruled out in alkaline medium. The adsorption of fluoride initially increases with time and when the process of adsorption reaches its equilibrium the rate becomes constant due to the saturation of the adsorbent surface. Again adsorption increases with the increase in the amount of adsorbent due to increase in the surface area. The removal may also be controlled by ion exchange with PO<sub>4</sub><sup>3-</sup> ion in addition to electrostatic attraction. Further the metal ions in the respective inorganic matrix of the zeolite can remove F<sup>-</sup> ion by means of both electrostatic interaction as well as complexation. The adsorption of fluoride onto the NaP1 zeolite obeys the general adsorption rules.

### References

- Dutta, M., Ray, T. and J.K. Basu (2012). Batch adsorption of fluoride ions onto microwave assisted activated carbon derived from Acacia Auriculiformis scrap wood. *Scholars Research Library Archives of Applied Science Research*, **4(1)**: 536-550.
- Fly ash resource centre, home page, Canaveral/ Launchpad/2095/fly ash/htm/2003.
- Gandhi, N., Sirisha, D. and K.B. Chandra Shekar (2015). Adsorption of fluoride from aqueous solution by using chalk powder. *World Journal of Pharmacy and Pharmaceutical Sciences*, **2(5)**: 3897-3914. Research Article (ISSN 2278 – 4357).
- Goswami, D. et al. (2006). Removal of fluoride from drinking water using a modified fly ash adsorbent. *Journal of Scientific and Industrial Research*, **65**: 77-79.

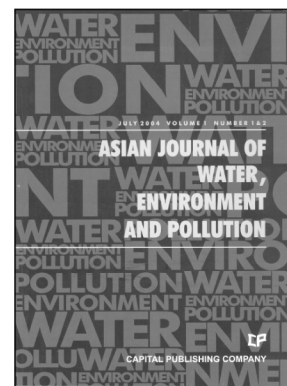


- Grutzeck, M.W. and D.D. Siemer (1997). Zeolites synthesized from class F fly ash and sodium aluminates slurry. *J. Am. Ceram. Soc.*, **80**: 2449-2453.
- Grutzeck, M.W. (1996). Zeolites synthesized from fly ash and cement kiln dust. *Ceram. Trans.*, 353-364.
- Gupta, N., Gupta, V., Singh, A.P. and R.P. Singh (2014). Defluoridation of Groundwater using Low Cost Adsorbent like Bagasse Dust, Aluminium Treated Bagasse Fly ash, Bone Powder and Shell Powder. *Bonfring International Journal of Industrial Engineering and Management Science*, **4**(2).
- Gu, B., Wang, L., Wang, S., Zhao, D., Rotberg, V.H. and R.C. Ewing (2000). Effect of  $H^+$  concentration on the Cs-exchange capacity of zeolite- NaY. *J. Mater. Chem.*, **10**: 2610-2616.
- Lavecchia, R., Medici, F., Piga, L. and Rinaldi G. Antonio (2012). Fluoride Removal from Water by Adsorption on a High Alumina Content Bauxite. *Chemical Engineering Transactions*, **26**: 124-129.
- Lee, G., Chen, C., Yang, S.T. and W.S. Ahn (2010). Enhanced adsorptive removal of fluoride using mesoporous alumina. *Microporous and Mesoporous Materials*, **127**: 152-156.
- Ma, W., Ya, F., Wang, R. and Y. Zhao (2011). Fluoride removal from drinking water by adsorption using bone char as a biosorbent. *International Journal of Environmental Technology and Management*, **9**(1): 59-69.
- Maurice, S. Onyango, Taile Yvonne Leswif, Aoyi Ochieng, Dalibor Kuchar, Fred O. Otieno and Hitoki Matsuda (2009). Breakthrough Analysis for Water Defluoridation Using Surface-Tailored Zeolite in a Fixed Bed Column. *Ind. Eng. Chem. Res.*, **48**: 931-937.
- Nie, Y., Hu, C. and C. Kong (2012). Enhanced fluoride adsorption using Al (III) modified calcium hydroxyapatite. *Journal of Hazardous Materials*, **234**: 194-199.
- Piekos, R. and S.P. Gdansk (1999). Fluoride uptake characteristics of Fly Ash. *Research Report, Fluoride*, **32**(1): 14-19.
- Rongsayamanont, C. and K. Sopajaree (2007). Modification of synthetic zeolite pellets from Lignite Fly ash A: The pelletization. World Coal Ash (WOCA) May 2007. Northern Kentucky, USA.
- Rosa, J.L., Kwan, S. and M.W. Grutzeck (1992). Zeolite formation in class F fly ash blended cement pastes. *J. Am. Ceram. Soc.*, **75**: 1574-1580.
- Rosa, J.L., Kwan S. and M.W. Grutzeck (1992). Self generating zeolite cement composites. *Mat. Res. Soc. Symp. Proc.*, **245**: 211-216.
- Srinivasan, A. and M.W. Grutzeck (1999). Adsorption of  $SO_2$  by zeolites synthesized from fly ash. *Environ. Sci. Technol.*, **3**: 1464-1469.
- Subhasini, V. et al. (2012). Defluoridation from Aqueous Solutions using Alum. *Chemical Science Transactions*, **1**(3): 552-559.
- Woolard, C.D., Petrus, K. and M. Horst (2000). The use of modified fly ash as adsorbent for lead. *Water SA*, **26**(4): 531-536.

## Advertisement

# Asian Journal of Water, Environment and Pollution

[www.iospress.com/asian-journal-of-water-environment-and-pollution](http://www.iospress.com/asian-journal-of-water-environment-and-pollution)



### Aims and Scope

Asia, as a whole region, faces severe stress on water availability, primarily due to high population density. Many regions of the continent face severe problems of water pollution on local as well as regional scale and these have to be tackled with a pan-Asian approach. However, the available literature on the subject is generally based on research done in Europe and North America. Therefore, there is an urgent and strong need for an Asian journal with its focus on the region and wherein the region specific problems are addressed in an intelligent manner. In Asia, besides water, there are several other issues related to environment, such as; global warming and its impact; intense land/use and shifting pattern of agriculture; issues related to fertilizer applications and pesticide residues in soil and water; and solid and liquid waste management particularly in industrial and urban areas.

Asia is also a region with intense mining activities whereby serious environmental problems related to land/use, loss of top soil, water pollution and acid mine drainage are faced by various communities.

Essentially, Asians are confronted with environmental problems on many fronts. Many pressing issues in the region interlink various aspects of environmental problems faced by population in this densely habited region in the world. Pollution is one such serious issue for many countries since there are many transnational water bodies that spread the pollutants across the entire region. Water, environment and pollution together constitute a three axial problem that all concerned people in the region would like to focus on.

### Editor-in-Chief

Prof. V. Subramanian  
Jawaharlal Nehru University  
Environmental Science  
Delhi, India  
Email: [subra@mail.jnu.ac.in](mailto:subra@mail.jnu.ac.in)

### Subscription Information 2018

ISSN 0972-9860

1 Volume, 4 issues (Volume 15)

Institutional subscription (online only):

US\$ 330 / €270

Institutional subscription (print only):

US\$ 386 / €314 (including postage and handling)

Institutional subscription (print and online):

US\$ 452 / €368 (including postage and handling)

Individual subscription (online only):

US\$ 95 / €75

IOS Press serves the information needs of scientific and medical communities worldwide. IOS Press now publishes more than 100 international journals and approximately 75 book titles each year on subjects ranging from computer sciences and mathematics to medicine and the natural sciences.

**IOS**  
Press

#### IOS Press

Nieuwe Hemweg 6B  
1013 BG Amsterdam  
The Netherlands  
Tel.: +31 20 688 3355  
Fax: +31 20 687 0019  
Email: [market@iospress.nl](mailto:market@iospress.nl)  
URL: [www.iospress.com](http://www.iospress.com)

#### IOS Press c/o Accucoms US, Inc.

For North America Sales and Customer Service  
West Point Commons  
1816 West Point Pike  
Suite 125  
Lansdale, PA 19446, USA  
Tel.: +1 215 393 5026  
Fax: +1 215 660 5042  
Email: [iospress@accucoms.com](mailto:iospress@accucoms.com)