



## Review Paper

# Zeolite Synthesis Strategies from Coal Fly Ash: A Comprehensive Review of Literature

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## Abstract

*The ever increasing energy demand in developing world will result in sustainable increase in the fly ash generation, which will remain a cause of concern as far as its management is concerned. However, technological advance may prove to be effective in fly ash management as well as its possible utilization through the zeolites. The zeolites are known to possess many beneficial properties (such as ion-exchange property), however, its cost effective production using fly ash as a raw material has still not been standardized. In view of this, the present study (literature review) was carried out to understand the evolution of zeolite synthesis strategies adopted by different researchers. The literature clearly indicates that zeolite synthesis depends on physico-chemical properties of the raw material as well as reaction mixture. However, it also suggests that the current state of knowledge can be readily used for further advancement of the zeolite synthesis processes on commercial level using fly ash as the primary source of raw material.*

**Keywords:** Fly ash, management, zeolites, synthesis strategies, ion-exchange.

## Introduction

The rapidly growing energy demand in developing world in general and India in particular demands that high energy generation should be achieved. Though there are different ways to generate energy; historically, coal-based power generation has been predominant in India. Thermal power plant plays an important role in fulfilling the growing energy demand of the people<sup>1</sup>. Currently, coal-based thermal power installations in India contribute about 65% of the total installed capacity for electricity generation. Indian coals have very high ash content (25 and 45%) and typically, the coal with an ash content of 40% is widely used in the power plants of India. As a consequence, a huge amount of fly ash is generated in thermal power plants, causing several disposal-related problems. As far as the disposal of fly ash is concerned, presently, the fly ash utilization for different purposes is less than 10% (of that is produced) in India, which is significantly less than that has been achieved in other countries. The major fly ash utilization area is the construction industry, which utilizes approximately 50% of the generated fly ash (due to its proven availability) for several applications as admixture in cement/concrete, lime pozzolanic mixture (bricks/blocks etc.). The other usage of fly ash are Low lying area fill (17%), Roads and Embankments (15%), Dyke Raising (4%), Brick manufacturing (2%) and zeolite etc.

Zeolites are important in view of their industrial applications, such as in ion exchange, as molecular sieves, catalysts, and adsorbents. Fly ash has the potential to be converted into zeolites. There are three important uses for

zeolites in industry, the most important being catalysis, as Zeolites are extremely useful as catalysts for several important reactions such as cracking, isomerisation and hydrocarbon synthesis. Since, the reactions can take place within the pores of the zeolite, it allows a greater degree of product control and the others include gas separation (the porous structure of zeolites can be used to "sieve" molecules having certain dimensions and allow them to enter the pores) and ion exchange (applications in water softening devices, in detergents and soaps, also it is possible to remove radioactive ions from contaminated water).

In the backdrop of above information, it is apparent that the fly ash, if managed and utilized properly can be a beneficial item for possible use in different areas. However, the current practice of utilizing the fly ash is restricted in specific domains, such as construction sector, as a filler, etc. Hence, an attempt has been made in this study to review the literature for identifying the research gaps as far as zeolite synthesis is concerned.

## Methodology

In this study, past literature has been reviewed to identify the evolution and progress of the fly ash management strategies and applications with a special emphasis on its ion-exchange property. The research gaps, which exist in this domain, have been identified on the basis of the literature review. The contents of the research articles were reviewed using the principles of content analysis and care was taken to ensure the originality of the views by using the original terminology.

Furthermore, the literature was reviewed (as a discursive prose) to synthesize and evaluate it according to the guiding concept for identifying most important future research questions. In addition to this, utmost importance was given to use the literature published in standard scientific journals.

## Results and Discussion

Currently, the applications of synthetic zeolites in different areas have noticeable presence over their counterpart i.e. natural zeolites. This is primarily due to the nature of synthetic zeolites, which are the purity of crystalline products and the uniformity of particle sizes. The customized zeolite synthesis offers many advantages over the natural zeolites, which include the ability to engineer (with wide variety of chemical properties, pore size and thermal stability) the zeolites for specific application. Besides, the natural zeolites have certain drawback like they do not show appropriate ion affinity, for example toward Cu, Cs and Co and Ur ions. Thus, the need for synthesizing more stable, efficient and predictable zeolites is omnipresent and may be ever increasing due to their possible applications. Conventional zeolite synthesis involves the hydrothermal crystallization of aluminosilicate gels, or solutions in a basic environment. The nature of zeolite affects when the crystallization takes place in a closed hydrothermal system that is undergoing increasing temperature. The autogenous pressure and varying time, composition of the reaction mixture (silica to alumina ratio; OH<sup>-</sup>; inorganic cations), reactants and their pretreatments, temperature of the process, reaction time, pH, etc. affect the nature of zeolite synthesized. In addition to this, the increasing demands of zeolite (qualitative and quantitative) warrants that the zeolite synthesis be carried out in a continuous or batch process. Thus, it is apparent that the process of synthetic zeolite synthesis is dynamic in nature and offers numerous challenges for its standardization. Hence, a periodic literature review is very essential for updating the knowledge regarding the effect of various experimental conditions, which govern the quality and quantity of synthesized zeolite.

**Zeolite Synthesis Up to 2000:** Zeolite A and faujasite (using specific conditions of temperature and chemical composition) was successfully synthesized and then compared its ion exchange properties for Cs<sup>+</sup> ions which shows 19% for zeolite A and 39% for faujasite which is applicable for waste-water treatment and radioactive waste immobilization<sup>5</sup>. During hydrothermal treatment, Si and Al contained in fly ash dissolve into basic solution which gives ring like structure and then gets converted into zeolite. Furthermore, authors have mentioned that seeding can selectively induce the formation of zeolite Y and eliminate the processes of induction and nucleation<sup>6</sup>. A conventional and microwave-assisted hydrothermal alkaline activation experiment was used to synthesize from fly ash. Authors reported that the zeolite synthesis is a function of temperature, time, and concentration of activation solution. Besides, zeolite types and its yields were also reported to be very similar when it was obtained from the microwave and conventional experiments, however, the activation time

was drastically reduced (from 24-48 h to 30 min) when a microwave was used<sup>7</sup>.

**Zeolite Synthesis After 2000:** Reactivity of fly ash towards zeolite formation is directly dependent on the SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> ratio, Fe<sub>2</sub>O<sub>3</sub> and CaO content. Authors reported that the sub-bituminous coal based fly ash with SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> ratio of 3.47 is a suitable substrate for Zeolite-A synthesis<sup>8</sup>. Three types of zeolite (NaP1 zeolite, analcime and chabazite) were hydrothermally synthesized with the fusion of fly ash and NaOH solution. The maximum conversion rate from fly ash to single zeolite was about 4075, and the total conversion rate 6080. Authors stated that the factors which influence variety and its conversion rate into zeolite were vortex, viscosity, temperature, reaction time, and NaOH concentration<sup>9</sup>.

Zeolite structures can be identified by considering a neutral SiO<sub>2</sub> framework and then substituting AlO<sub>2</sub><sup>-</sup> for SiO<sub>2</sub>. The resulting structure shows a net negative charge, which is balanced by cations (for instance, Na<sup>+</sup>, K<sup>+</sup>, or NH<sub>4</sub><sup>+</sup>) and many of these cations are mobile and free for exchange. This ion-exchange property accounts for the greatest volume use of zeolites today<sup>10</sup>. Coal fly ash was activated by hydrothermal treatment with different concentrations of NaOH solutions to synthesize the zeolites, Na-P1 and hydroxysodalite. Authors further stated that, such modification enhances fly ash significantly with respect to specific surface area and cation exchange capacity. Specific surface area increased from 1.0 m<sup>2</sup>·g<sup>-1</sup> to a maximum of 62.7 m<sup>2</sup>·g<sup>-1</sup> while cation exchange capacity rose from 25 mmol/100 g to a maximum of 300 mmol/100 g<sup>11</sup>.

Alkali fusion followed by hydrothermal treatment was used for the synthesis of X-type zeolite from coal fly ash. Beside, the cost was observed to be almost one-fifth of that of commercial 13X zeolite available in the market. It was widely reported that the crystallinity was a function of fusion temperature<sup>12</sup>. Zeolite structure development and exchange capacity is a function of variations in pretreatment steps and sodium aluminate addition. They further stated that infrared is a better option for estimating crystallinity of the zeolite during hydrothermal treatment of fly ash by using step-change of temperature in synthesis<sup>13</sup>. The zeolite synthesized was a pure form, single phase and high crystalline. Authors stated that during hydrothermal treatment step-change of synthesis temperature plays an important role in reducing the overall synthesis time while maintaining a high degree of crystallinity for the samples<sup>14</sup>.

Zeolite was prepared from coal fly ash using the fusion method and specified that a ratio of 2.25 between coal fly ash and NaOH was responsible for maximum cation exchange capacity (of 219.7 meq/100g at 2 hour fusion time)<sup>15</sup>. Furthermore adsorption and desorption properties of the ion exchange resins is dependent on many factors, however, the feed concentration is probably the strongest of them (factors) all<sup>16</sup>. Zeolite Na-P1 was synthesized from fly ash for by using optimized synthesis conditions (NaOH/SiO<sub>2</sub> molar ratio was 0.59 at an aging temperature of 47°C for 48 hours the purpose of

elimination of trace elements from brine. The reverse osmosis was reported to be effective in removing a large percentage of B, V, As, Mn, Ni, Pb, Fe, Zn, Mo, Sr, Ba, Mg, Cd and Se from a brine concentrate by using zeolite Na-P1<sup>17</sup>.

On the basis of estimated values of thermodynamic parameters such as heat of adsorption and standard Gibbs free energy that the adsorption of Cr (VI) on zeolite NaX was found to be exothermic in nature<sup>18</sup>. X-type zeolite was synthesized by alkali fusion followed by hydrothermal treatment from the coal fly ash, which as per the authors is almost one-fifth of that of commercial 13X zeolite available in the market<sup>19</sup>. Addition of sodic or potassic reagent in the starting mixture reduces the stability field for zeolite N formation. Zeolite N can also be formed using zeolite 4. Al is used as a source of Al and Si though for longer reaction times at a specific temperature when compared with kaolin as the source material<sup>20</sup>. Thus the coal quality plays an important role in the zeolification process, which directly affects the properties of zeolites, such as cation exchange capacity (CEC), specific surface area, specific gravity and particle size distribution<sup>21</sup>.

Authors clarified the mechanism of zeolite synthesis from fly ash by using various alkali solutions during hydrothermal reaction. During hydrothermal reaction, various physical and chemical properties investigated were crystal structure, surface structure and cation exchange capacity, of the obtained zeolites and the dissolved amount of Si<sup>4+</sup> and Al<sup>3+</sup> in alkali solution. The mechanism of zeolite crystallisation and the role of alkali solution play an important role on the synthesis reaction. The study showed that the OH<sup>-</sup> in alkali solution remarkably contributes to the dissolution step of Si<sup>4+</sup> and Al<sup>3+</sup> in coal fly ash, while Na<sup>+</sup> in alkali solution makes a contribution to the crystallization step of zeolite P<sup>22</sup>.

Zeolite-A (FAZ-A) was patented nationally and internationally by using fly ash. Zeolite was used for the removal of lead. Authors studied rate constants using Lagergren's model indicating the reaction to be of first order. On the basis of available data, they concluded that the zeolite showed maximum capacity of 714.28 mg/g for lead<sup>23</sup>. The fly ash conversion into zeolite was obtained by using [SiO<sub>2</sub>]/[Al<sub>2</sub>O<sub>3</sub>] ratio 1.4 to 2.5. In this the Si and Al contents of fly ash filtrates were used as starting material for alkaline hydrothermal conversion. The steps involved in zeolite synthesis were an alkaline fusion of the co-disposal filtrates, aging, and hydrothermal conversion by crystallisation at 100 °C. Different variables such as use of deionised water, different compositions of FA related starting material and different FA: NaOH ratios in fusion were investigated to increase zeolite formation<sup>24</sup>. A geopolymer material was synthesized from Class F fly ash, by studying elevated temperature curing on phase composition, microstructure and strength development. It was observed that long procuring at room temperature before application of heat was beneficial for strength development in all studied material<sup>25</sup>.

Hence a new methodology was reported for the conversion of

fly ash into zeolite. Suitable operation parameters of the process were reported using a test unit, and the optimal conditions were found to be 2.5-3.5 mol/dm<sup>3</sup> of NaOH and 0.88-1.10 dm<sup>3</sup>/kg of liquid/solid, sodium hydroxide charge from 2.2 to 3.9 mol/kg-CFA. The authors further stated that the zeolites obtained from a pilot plant had a higher cation exchangeable capacity than those from the test unit and were comparable to zeolites prepared using a conventional method<sup>26</sup>. Fly ash based zeolite-A (FAZ-A) was synthesized for the determination of its optical brightness. The improvement of optical brightness was done by using pretreatment of fly ash, acid treatment, lime treatment which in turn controls the colour development of zeolite sample & used as detergent builder<sup>27</sup>.

Fly ash was converted into single phase zeolite from fly ash by dialysis. NaOH-NaAlO<sub>2</sub> solution was used to maintain SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> molar ratio of the solutions from 0.9 to 4.3. The Na-X zeolite was produced at SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> ≥ 1.7<sup>28</sup>. Zeolites from two different fly ashes were obtained from different Lignite Power Plants and the products were tested for their potential of retaining heavy metals from a contaminated soil. It was observed that for lower FA/NaOH ratios, the excess of NaOH seemed to be prohibitive for zeolite growth, while for the higher ratios, the NaOH quantity seemed to be insufficient for the effective activation of the fly ashes<sup>29</sup>. During conversion of fly ash to zeolite fractionation of immobilized phosphorus indicated that Fe + Al-P increased most significantly and consistently among all the phosphorus fractions. Increase in dissociated Fe<sub>2</sub>O<sub>3</sub> and specific surface area probably accounted for the enhancement in phosphate immobilisation capacity of synthesized zeolites compared to the corresponding fly ash<sup>30</sup>.

Zeolite was obtained by refluxing of fly ash in NaOH solution by refluxing under microwave irradiation for 1 h. During pretreatment, the amorphous aluminosilicate of fly ash was dissolved and its dissolution rate was found to be much faster than that of conventional air oven. Author also reported that the cation-exchange capacity (CEC) of a single-phase Na-A zeolite formed at SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> = 0.8 was 508 cmol/kg which is close to the 550 cmol/kg of the commercial Na-A zeolite<sup>31</sup>. Pure form zeolite A was synthesized using four concentrations of NaOH solution to dissolve Si source from fly ash and with the addition of Al source, to prepare initial gel Author synthesized pure zeolite A by using NaOH concentrations, 1.67, 5 and 6.67 M; the synthesis temperature, 100 °C and 340, 250 and 190 min. as a crystallisation time. Furthermore they reported that the higher NaOH concentration was used, the shorter crystallisation time of zeolite A was required and the distribution of particle size zeolite A was achieved to be narrower<sup>32</sup>.

During the zeolite synthesis process the changes of mineralogical-chemical composition, cation exchange capacity (CEC), and phosphate immobilization capacity (PIC) was investigated. The zeolites were obtained by using the parameters such as temperature (40-120 °C), liquid/solid ratio (1-18 ml/g), NaOH concentration (0.5-4 mol/L) and reaction time (2-72 h). Authors reported that lower the ratio of K<sub>2</sub>O,

MgO and Fe<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub> content were related to the solubility of the oxides while the increase in Na<sub>2</sub>O and CaO was due to the increase in cation exchange capacity<sup>33</sup>. Na-A,-X and -Y zeolite was prepared by using high silicon fly ash by alkali fusion followed by hydrothermal treatment at 100 °C for 12 h. Different types of zeolite having different degrees of purity were synthesized by changing Si/Al ratio of the reaction mixture from 1.6 to 3.0. The characterization studies showed that the zeolite was crystalline, had a very high cation-exchange capability of 4.9 mequiv. g<sup>-1</sup> and possessed relatively high specific surface area of about 434 m<sup>2</sup> g<sup>-1</sup><sup>34</sup>.

An Italian coal fly ash was converted into zeolite with temperature of crystallisation ranging from 35 upto 90<sup>0</sup> C. It was reported that the zeolite X and zeolite ZK-5 were prepared by using both distilled and seawater. The formation of sodalite was competitive with zeolite X which shows a metastable behaviour at higher temperatures. Author concluded that the formation of specific zeolites required lower temperature when seawater was used<sup>35</sup>. The transformation of mechanism of a fly ash into NaX zeolite was studied. Two synthesis systems were investigated at 30-50<sup>0</sup> C in absence or presence of external soluble silica. Authors described the zeolitisation mechanism in three steps such as dissolution of fly ash, dissolution of silica from fly ash and conversion fly ash into NaX. The various effects of silica were discussed in relation with the zeolitisation mechanisms<sup>36</sup>. Later on again conversion of a French coal fly ash into NaX zeolite (faujasite) by using the optimal composition (1SiO<sub>2</sub>:0.36Al<sub>2</sub>O<sub>3</sub>:3.8NaOH:72.7H<sub>2</sub>O) for the synthesis. It was observed that the addition of soluble silica leads to a better solubilisation of the FA, about 20% more Al being mobilised. Author stated that the zeolitisation reaction was delayed when silica was added, the maximum faujasite content being reached after about 50 days instead of about 20 days<sup>37</sup>. The direct route of zeolite synthesis was preferred by using soft reaction conditions that resulted in a high yield of low cost zeolite with large crystal agglomerates. For both zeolitisation routes, the nature of alkali (KOH, NaOH, and LiOH), the alkali/MFA ratio (0.23-1.46), and crystallisation temperature and time (90-175<sup>0</sup> C; 8-24 h) were evaluated. The study demonstrated that aluminum modified W zeolite shows applicability of removal of arsenic (99%) from Na<sub>2</sub>HAsO<sub>4</sub>·7H<sub>2</sub>O solution containing 740 ppb of As<sup>38</sup>.

**Zeolite Synthesis in Recent years:** Synthetic basic sodalite, Na<sub>8</sub>[AlSiO<sub>4</sub>]<sub>6</sub>(OH)<sub>2</sub>·2H<sub>2</sub>O, cubic, P43n was synthesized by alkaline activation of amorphous aluminosilicate glass obtained from fly ash. Geopolymerisation include treatment with high concentrations of a NaOH solution at 90 °C for 24 hours. The bulk modulus was determined using a diamond anvil cell up to a pressure of 4.5 GPa<sup>39</sup>.

Chemical composition analysis of raw fly ash materials and zeolitic products from five different Brazilian fly ashes were conducted. Content of SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> was above 70 wt. % in all fly ashes. Hydroxy-sodalite zeolite was formed in all samples. NaP1 zeolite was formed in fly ashes with high content of Ca

while X zeolite was formed from the fly ashes with high content of Al. Cation exchange capacity values of the zeolitic materials were 40 times higher than fly ash samples, potential for use as ion exchangers<sup>40</sup>. High phase purity of zeolite A was synthesized from coal fly ash. The formation of zeolite was monitored by using in situ ultrasonic system and was complemented by use of ex situ technique. It was observed that the comparable ultrasonic signals were generated when both clear and unseparated fly ash based precursor solutions were used during the zeolite synthesis process<sup>41</sup>.

The crystallisation mechanism of X- and A-type zeolites from fly ash was reported by analysing the role of Mg and Ca ions during treatment with artificial sea water. The crystallisation mechanism includes pretreatment by fusion with NaOH at 550<sup>0</sup>C by using artificial sea water at room temperature (25<sup>0</sup>C). The results indicated that Mg induces the formation of zeolite domains that act as templates for the crystallisation and growth of both X-type and A-type zeolites<sup>42</sup>. Zeolite was synthesized from fly ash and rice husk ash and studied the effect of amorphous silica content on crystallization time. Fly ash was mixed with amorphous silica in the ratios of 10:0, 8:2, 7:3, 6:4 and 5:5 (wt/wt). It was observed that the mixture of fly ash and amorphous silica in ratio of 7:3 generated the highest yield and crystallinity of zeolite (faujasite type). FTIR spectra exhibited the presence of internal Si-O-Si and Si-O-Al asymmetric stretching mode and morphology studies indicated an octahedral crystal of faujasite. Author reported that the CEC and specific surface area of faujasite were 3.6 meq/g and 233 m<sup>2</sup>/g, respectively<sup>43</sup>. A raw material containing blends of circulating fluidized bed combustion (CFBC) fly and bottom ashes was used for geopolymer synthesis. Authors reported that the effective alkali fusion was achieved at 350<sup>0</sup>C for 0.5 h. The results suggested that by a moderate alkali-fusion pretreatment at temperatures slightly higher than the melting point for sodium hydroxide (318 °C), low-reactive low reactive CFBC fly ash (CFA) can be recycled together with CFBC bottom ash (CBA) for production of value added geopolymer composites<sup>44</sup>.

The rate of zeolite N synthesis was a function of temperature and type of clay minerals (such as kaolinites and montmorillonites) used. They further reported that Zeolite synthesis was more sensitive to water content and temperature when sodium was used in initial batch compositions<sup>45</sup>. Fly ash and bottom ash (with high crystalline silica content) from the coal-fired boilers within the paper industries was used for synthetic zeolite production. Authors concluded that the type of zeolite synthesis method (direct conventional i.e. one-step synthesis or two-step i.e. sodium silicate preparation and consecutive zeolite A synthesis) used resulted in different amount of product<sup>46</sup>. Na-zeolites were synthesized from Tunisian natural illite clay by alkaline fusion and conventional hydrothermal alkaline activation. In both cases, the synthetic zeolite products show better cationic exchange capacities compared with the raw material. However, the fusion method yielded a product with high crystallinity, good cation exchange properties and better surface area accompanied by shorter reaction times<sup>47</sup>.

SUZ-4 zeolite was prepared by hydrothermal technique under autogenous pressure with SiO<sub>2</sub>:Al<sub>2</sub>O<sub>3</sub> ratio of 21.22 using silica-sol and tetraethylammonium hydroxide as a silica source and a template, respectively. Authors concluded that highly crystalline SUZ-4 depended on enhanced temperature and time of crystallization conditions<sup>48</sup>. Pure-silica-zeolite AST and LTA was manufactured by using the same structure-directing agent molecule at different concentrations. Authors argued that the deviations (structure-directing agent molecules can self-assemble into dimer or trimer complexes at different concentrations) from the Liebau's rules indicate that small changes in structure-directing agent chemistry, structure, and order in solution can have a great impact on the structure selectivity of the zeolite synthesis<sup>49</sup>. Thermogravimetric method was applied for the control and determination of the quality of fly ash-derived zeolite in an industrial plant due to its short conversion factor<sup>50</sup>.

Two types of zeolites (Linde F and hydroxysodalite) were synthesized from fly ash by activation with NaOH and KOH. Blends of zeolites A and P was obtained at treatment with 3.1 m NaOH at 353 K. It was found that in both the types of zeolites, Na<sup>+</sup> had been partially replaced by Ca<sup>2+</sup>. Zeolites crystallized preferably on particles having glassy surfaces and had quite a constant composition, unrelated to that of the surface<sup>51</sup>. The technological line of approach was automated to synthesize Na-P1 zeolite from the coal fly ash synthesized zeolite contained the properties as mesoporous (61%) and approximately six times higher the specific BET surface area than fly ash which proved it to be effective as an adsorbent for heavy metal pollutants<sup>52</sup>. The beneficial use of fly ash generated from thermal power plant was highlighted in development of bricks, cement manufacturing, ceramics, fertilizer, road construction, road embankment etc<sup>53</sup>.

The applicability of fly ash as a zeolite was evaluated for the removal of lead from its aqueous solution. The adsorption was experimented by using variables metal ion concentration, contact time, pH, temperature and particle size. Adsorption isotherms, kinetics and also thermodynamic parameters have been evaluated and hence the process showed spontaneity, feasibility and endothermic in nature<sup>54</sup>. A novel zeolite has been synthesized from fly ash. The applicability of synthesized zeolite have been studied for the adsorption of transition metal ions from paper industry waste water by using variable parameters such as pH, amount of zeolite, contact time. Adsorbent showed better adsorption for Ni<sup>2+</sup> ion<sup>55</sup>.

Very recently a low cost adsorbent fly ash was studied for the removal of phenol from aqueous solution. The adsorption study was experimented by using variable parameters. Authors reported that the uptakes of phenol by fly ash decreased by increasing particle size and pH but it increases with temperature. Fly ash showed better removal ability towards phenol and hence it can be used economically<sup>56</sup>. Fly ash was modified was modified by alkali (FAN), dye (FAN-MO) and was used for the elimination of Ni<sup>2+</sup> from its aqueous solution. The batch adsorption study was evaluated by studying pH, contact time, initial metal ion concentration and amount of adsorbent. Author reported the

influence of Cu<sup>2+</sup> ions and Zn<sup>2+</sup> ions on adsorption of Ni<sup>2+</sup> ions on FAN and FAN-MO in binary and tertiary systems which showed gradual decrease of adsorption ability<sup>57</sup>.

## Conclusion

Millions of tons of waste materials are generated throughout the world, which pose serious threat to the sustainable development. The fly ash based zeolites provide an opportunity for effective as well as value added management of the fly ash. The literature review indicates that the zeolite processes developed include different methodologies, which primarily indicate modifications or alterations in pretreatment steps, alkali addition, etc. It gives formation of different structures that have potential for application in many fields (ion exchange capacity). The synthesis of zeolites from coal fly ash (which is abundant in India) with specific focus such as applications in water treatment could act as a more value-added high technology utilisation of fly ash.

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