International Journal of Advance and Applied Research
www.ijaar.co.in
ISSN – 2347-7075 Impact Factor – 8.141
Peer Reviewed Bi-Monthly
Vol.12 No.3 January – February 2025

Zeolites Synthesized from Coal Fly Ash: Structural Features, Properties, and Applications

Dr. Kapure G. P.
Dept. of Physics, S.G.B. Mahavidyalaya Purna, Dist. Parbhani, MS.
Corresponding Author - Dr. Kapure G. P.

DOI - 10.5281/zenodo.21532675

Abstract:

Coal Fly Ash (CFA), a low-cost and silicon-rich industrial byproduct, has emerged as a promising raw material for zeolite synthesis. Zeolites, crystalline aluminosilicates with tunable frameworks, exhibit unique physicochemical properties such as ion-exchange capacity, molecular sieving, and catalytic activity. This paper provides a comprehensive review of zeolite synthesis from CFA, structural features, classification, acidity/basicity, exchange properties, and industrial applications. Special emphasis is placed on ZSM-5 and Faujasite Y, two widely studied synthetic zeolites, along with characterization techniques such as XRD, FTIR, SEM, and BET analysis.

Keywords: CFA, synthesis, XRD, FTIR, EDAX, Applications, Exchange Properties.

Objective:

The primary objective of this research is to **synthesis, characterization, and evaluate zeolites derived from coal fly ash** for their potential applications in catalysis, adsorption, and environmental remediation. Specifically, the study aims to:

1. **Utilize coal fly ash** as a cost-effective and sustainable source of silica and alumina for zeolite synthesis.
2. **Develop synthetic zeolite structures** (such as ZSM-5 and Faujasite Y) through hydrothermal methods and optimize their physicochemical properties.
3. **Characterize the synthesized zeolites** using advanced analytical techniques (XRD, FTIR, SEM, BET, EDAX) to determine crystallinity, morphology, and surface area.
4. **Investigate ion-exchange and adsorption capacities** to assess their efficiency in removing pollutants and catalyzing chemical reactions.
5. **Compare structural and functional performance** of CFA-derived zeolites with conventional synthetic zeolites.
6. **Demonstrate environmental and industrial feasibility** of converting solid waste into high-value functional materials.

Introduction:

Coal Fly Ash (CFA) is a silica-rich waste material generated from thermal power plants. Its major constituents, **SiO_2 and Al_2O_3**, make it suitable for zeolite synthesis. Synthetic zeolites derived from CFA offer ecological benefits by reducing raw material mining and solid waste disposal. They are widely applied as **heterogeneous catalysts, adsorbents, and molecular sieves** in gas separation and purification.

"The primary aim of this research was to use zeolite adsorbents prepared from solid waste residues of coal fly ash, and to demonstrate the feasibility of using this material as catalyst and adsorbent in synthesis of fine chemicals and in purification of contaminated waste water."

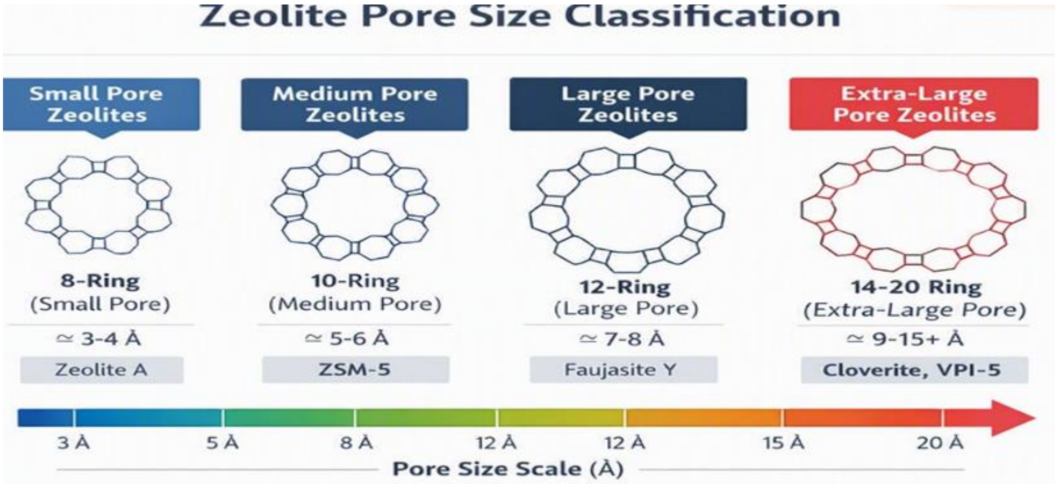
Historical Developments:

- **1756**: Cronstedt discovered stilbite, naming it "zeolite" (Greek: *boiling stone*).
- **1930s**: Richard Barrer pioneered systematic zeolite synthesis under high pressure and temperature.
- **1960s–70s**: Mobil introduced organic cations, leading to MFI-type zeolites (ZSM-5).
- **1980s–90s**: Discovery of aluminophosphate and titanosilicate molecular sieves expanded applications.
- Presently, zeolite research exceeds **3600 publications annually**, with applications in detergents, catalysis, adsorption, and energy storage.

Structural Features of Zeolites:

Zeolites consist of **$[SiO_4]^{4-}$ and $[AlO_4]^{5-}$ tetrahedra** linked via oxygen atoms, forming a 3D framework.

- **Primary Building Units (PBU):** Tetrahedral Si/Al sites.
- **Secondary Building Units (SBU):** Rings and cages (S4R, D6R, etc.) that define pore topology.
- **Framework Properties:**
  - Channels: 2.2–8 Å
  - Cavities: 6.6–11.8 Å
  - Surface area: up to 900 m^2/g
  - Ion-exchange capacity: up to 700 meq/100 g



Classification of Zeolites:

Zeolites are classified based on:

- **Framework topology (Meier & Breck classification):** 7 groups (Analcime, Faujasite, Mordenite, etc.).
- **Si/Al ratio:**
  - Low silica (1–1.5) → Zeolite A, Faujasite Y
  - Intermediate silica (2–5) → Mordenite, Clinoptilolite
  - High silica (>5) → Faujasite X, BEA
- **Pore size:**
  - Small (8-ring) → Zeolite A
  - Medium (10-ring) → ZSM-5
  - Large (12-ring) → Faujasite Y
  - Extra-large (14–20 ring) → Cloverite, VPI-5

Acidity and Basicity:

- **Brønsted Acidity:** Proton exchange sites due to Al substitution.
- **Lewis Acidity:** Electron pair acceptor sites from framework oxygen.
- **Basicity:** Arises from framework oxygen ions and hydroxyl groups. Applications: Hydrocarbon cracking, isomerization, and aromatization.

Exchange Properties:

Cation Exchange Capacity (CEC) is a critical property:

- Higher Al substitution → Higher CEC.
- Selectivity depends on pore size, ion hydration, and framework accessibility. Applications: Removal of toxic ions from wastewater, heavy metal adsorption.

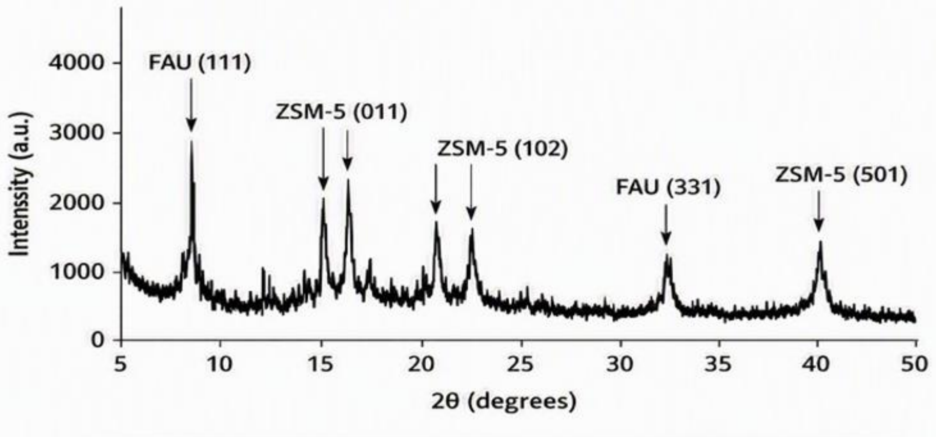


Figure : XRD Pattern of Synthesized Zeolite from Coal Fly Ash.

Case Studies of Synthetic Zeolites:

ZSM-5 (MFI Framework):

- Developed by Mobil (1972).
- Medium pore zeolite with **10-ring channels** (5.1 × 5.5 Å).
- Properties:
  - High thermal stability
  - Shape-selective catalysis
  - Aromatization, oligomerization, cracking reactions
  - Ion-conducting and dielectric properties

Faujasite Y (FAU Framework):

- Cubic structure with **supercages (12 Å)** linked by 12-ring windows.
- Formula: $(Na_2, Ca, Mg)_{29} [Al_{58}Si_{134}O_{384}]\cdot 240H_2O$
- Applications:
  - Fluid catalytic cracking (FCC)
  - Gasoline production
  - Ammonia removal from wastewater

Physico-Chemical Characterization Techniques:

- **XRD:** Determines crystallinity, lattice constants, and phase purity.
- **FTIR:** Identifies vibrational modes of Si–O and Al–O bonds.
- **SEM:** Reveals morphology and particle size.
- **BET Analysis:** Measures surface area and porosity.
- **EDAX:** Provides elemental composition.
- **Conductivity (DC/AC):** Studies ion transport and dielectric properties.
- **GC & GC-MS:** Analyzes catalytic products.

Industrial and Environmental Applications:

- **Catalysis:** Hydrocarbon conversion, fine chemical synthesis.
- **Adsorption:** Removal of toxic gases (SO_2, NH_3), water purification.
- **Ion Exchange:** Heavy metal removal from effluents.

- **Energy:** Dielectric materials for batteries and fuel cells.
- **Environmental Protection:** Waste valorization, pollution control.

Conclusion:

Zeolites synthesized from CFA represent a sustainable pathway for advanced material development. Their tunable framework, high surface area, and ion-exchange properties make them indispensable in catalysis, adsorption, and environmental remediation. Future research should focus on **novel framework designs, hybrid composites, and scale-up processes** to enhance industrial adoption.

References:

1. Barrer, R. M. (1930s). *The sorption of polar gases by zeolites*. Proc. Royal Society.
2. Meier, W. M., & Breck, D. W. (1974). *Zeolite structure classification*.
3. Argauer, R. J., & Landolt, G. R. (1972). *ZSM-5 synthesis and properties*.
4. International Zeolite Association (IZA). *Framework codes and nomenclature*.
5. Davis, M. E. (1990s). *Large pore molecular sieves: VPI-5 and Cloverite*.
6. Harris, D.; Heidrich, C.; Feuerborn, J.; Global Aspects on Coal Combustion Products. Coaltrans. 2019
7. European Coal Combustion Products Association e.V. ECOBA Statistics 2016. Essen: ECOBA e.V.
8. Ryu, G.U.; Khalid, H.R.; Lee, N.; Wang, Z.; Lee, H.K. The Effects of NaOH Concentration on the Hydrothermal Synthesis of a Hydroxyapatite–Zeolite Composite Using Blast Furnace Slag. *Minerals* **2021**
9. Kang, Y.; Swain, B.; Im, B.; Yoon, J.-H.; Park, K.H.; Lee, C.G.; Kim, D.G. Synthesis of Zeolite Using Aluminum Dross and Waste LCD Glass Powder: A Waste to Waste Integration Valorization Process. *Metals* **2019**
10. ach, M.; Grela, A.; Komar, N.; Mikuła, J.; Hebda, M. Calcined Post-Production Waste as Materials Suitable for the Hydrothermal Synthesis of Zeolites. *Materials* **2019**
11. Jha, B.; Singh, D.N. *Fly Ash Zeolites*, 1st ed.; Advanced Structured Materials Series; Springer: Singapore, 2016; Volume 78