FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA

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INAUGURAL LECTURE
SERIES 136

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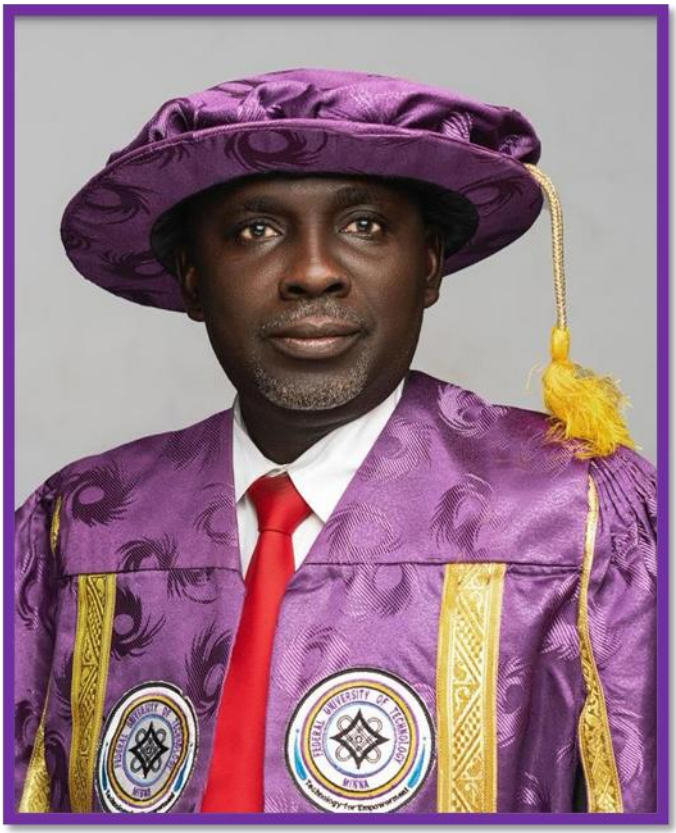
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Prof. Faruk Adamu Kuta
B.Sc. (UDUS), M.Tech. (FUTMIN), PhD (ATBU)
Vice-Chancellor



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Preamble

It is with great humility and rare privilege that I stand before you sir, my vice chancellor as well as the town and gown, to deliver the 136th inaugural lecture of this great citadel of learning , The Federal University of Technology , Minna . A University that has personally transformed me then as raw material when I was admitted as a fresh Jambite in 1994 with matriculation number 93/4104 and become a finished product in 2018 after passing through all reaction steps and all unit operations to become a full professor of Chemical Engineering in the Department of Chemical Engineering , Federal University of Technology, Minna in October , 2018.This is the 7th inaugural lecture from the department of Chemical engineering and the 3rd to be delivered by an alumnus of the department and it goes a long way to validate the popular belief that the chemical engineering department of Federal University of Technology, Minna is one of the leading department in the University .

My Vice chancellor sir, this Inaugural lecture is the academic story of young boy who lost his father at the age of 2 and got nurtured by an illiterate but hardworking mother whose only work is trading in Fish to become a professor of chemical Engineering.

My choice of Chemical Engineering as a course of study was not by accident but a deliberate and concerted desire (even at that tender age) to study the course as that was the rule for every very good student of my era in Okene to opt for either Medicine or Engineering. The alluring desire then to work in the Oil and Gas industry was also a motivating factor as will be shown in the course of this Inaugural lecture, Chemical engineering goes long beyond oil and gas industry, it is a complete way of life!

I want to at this point, My Vice Chancellor, establish what Chemical Engineering really is and what is the difference and connection between it and other engineering professions as well as other aspect of science disciplines especially chemistry . There is also the persistent misconception about chemical engineering as it is more of industrial chemistry than engineering!

Chemistry is quite a broad discipline, engaging students from gaining complete conceptual and bookish knowledge with extensive laboratory and research work. The purpose lies in the preparation of the chemists, not only for making them experts in their fields. The sensitive nature of their job as chemists also prepare them to be future scientists and chemistry explorers. That is why the bachelor's degree programs as a chemist include general subjects, such as chemistry, organic chemistry, inorganic chemistry,

biochemistry, applied chemistry, and mathematics, to name just a few. Contrary to the bachelor's coursework for a chemistry bachelor degree, students wishing to pursue a career in chemical engineering have to follow a multidisciplinary approach embedded in the field of engineering itself. As it is an amalgam of the two fields – i.e., chemistry and engineering, the students following a career in this field are trained accordingly. For instance, the core subjects in the syllabus of chemical engineering orient about engineering, mathematics, separation processes , Reaction engineering , computer sciences, fluid dynamics, and equipment design. The Chemical Engineers are experts that are typically involved in manufacturing processes. The most common is manufacturing of food, drugs, fuels, etc., on a larger scale. The initial job of a chemical engineer also requires a bachelor's degree in chemical engineering, just like chemists. Besides performing the standard manufacturing tasks, a chemical engineer also serves the active researches. Here again, the primary focus of these engineers is to improve the manufacturing processes through various techniques. These improvements are then put into the applied field of chemical engineering research, such as an improved production of drugs and chemicals that can be achieved at a larger scale. The Connection is that a chemist works in a research laboratory and produces a new formula for any new chemical under all the health and safety measures. Now, after he prepared a chemical , the chemist might make just a few bottles but, to produce it in a large quantity for the market and for large scale application , the industry needs a chemical engineer. The chemical engineer would suggest and provide unique equipment for its large-scale production, hence, promoting sales.

1.0 General introduction : Background on zeolite

One of the great words of Breck, who is one of the fathers of Zeolite Technology goes thus

'Rarely in our technological society does the discovery of a new class of inorganic materials result in such a wide scientific interest and kaleidoscope development of applications as has happen with zeolite molecular sieves' Breck, 1974

Zeolites are now hugely popular crystalline microporous aluminosilicates material which have academic, scientific and industrial interest industries (Kovo, 2012a). Zeolites are highly crystalline and are based on fundamental building blocks of tetrahedral SiO_4 and AlO_4 giving rise to a three dimensional network as shown in figure 1. The structural formula of zeolite is given as

$$\mathbf{M}_{a/n}\,[\,(AlO_2)_b(SiO_2)_c]\,\mathbf{d}H_2O$$

where **M** is the cation of valence **n** , d is the number of water molecules , **c/b** is the silica to alumina ratio, (**b+c**) is the number of tetrahedra present in the unit cell.

The framework composition is represented by the square bracket. The zeolite frameworks are generally open. Water and cations are located within the channel and cavities. The cation presence is needed in the zeolite framework to neutralise the negative charge created as a result of isomorphous substitution of Si^{4+} by Al^{3+} in the framework. The mobility of this cation among other behaviour is responsible for the unique and intriguing properties of zeolite and other zeolite-like materials. The ability of zeolites to act as multi-functional materials in many industrial applications is due to their inherent properties such as uniform pore size,/shape, catalytic activity, mobile cation and hydrophilicity/hydrophobicity (water liking or hating).

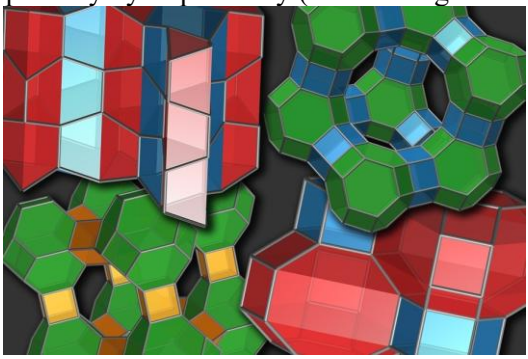


Figure 1: 3-dimensional structure of typical Zeolites

1.1. Origin and history of zeolites

Zeolite was discovered as a natural mineral by a Swedish mineralogist named Alex Fredrick Cronstedt in 1756 who observed that a certain mineral when heated rapidly, produced large amounts of steam from water that had been adsorbed by the material. Based on this, he called the material zeolite, from the Greek words meaning “boiling stones,” because of ability to froth when heated to about 200°C. Following Cronstedt’s findings, zeolites were considered as minerals found in volcanic rocks for a period of 200 years. Natural zeolites form where volcanic rocks and ash layers react with alkaline groundwater. Zeolites also crystallize in post depositional environments over periods ranging from thousands to millions of years in shallow marine basins. Naturally occurring zeolites are rarely pure and are contaminated to varying degrees by other minerals, metals, quartz, etc (Kovo & Holmes, 2010).

1.2 Type of Zeolites

There are two main group of zeolite namely Natural and Synthetic Zeolite. Natural Zeolite are natural mineral found in cavities and vugs of volcanic basalt rock and are also found in sedimentary rock much closer to the earth crust(Gottardi & Galli, 1985) . They were thought to have been formed as result of several natural activities listed below:

- Crystal formation as a result of hydrothermal activity between solution and basaltic lava flows
- Volcanic sediment deposition in closed alkaline and saline lake-system
- Formation due to activity of groundwater system on volcanic minerals
- Volcanic deposition on alkaline soil
- Deposition resulting from low temperature alteration of marine sediment
- Formation resulting from low grade burial metamorphism

Natural zeolites are of different types and structures with about 40 well known, some of which are shown in the table 1

Table 1: Some Natural Zeolites and their discovery dates

Zeolite	Date of discovery	Three-letter code used by IZA	Zeolite	Date of discovery	Three-letter code used by IZA
Stilbite	1756	STI	Mordenite	1864	MOR
Natrolite	1758	NAT	Clinoptilolite	1890	HEU
Chabazite	1772	CHA	Offretite	1890	OFF
Harmotome	1775		Erionite	1890	ERI
Analcime	1784	ANA	Kehoeite	1893	
Laumontite	1785	LAU	Gonnardite	1896	NAT
Thomsonite	1801	THO	Dachiardite	1905	DAC
Scolecite	1801		Stellerite	1909	STI
Heulandite	1801	HEU	Ferrierite	1918	FER
Gmelinite	1807	GME	Viseite	1942	
Mesolite	1813	NAT	Yugawaralite	1952	YUG
Gismondine	1816	GIS	Wairakite	1955	ANA
Brewsterite	1822	BRE	Bikitaite	1957	BIK
Epistilbite	1823	EPI	Paulingite	1960	PAU
Philipsite	1824	PHI	Garronite	1962	GIS
Levynite	1825	LEV	Mazzite	1972	MAZ
Herschelite	1825		Barrerite	1974	STI
Edingtonite	1825	EDI	Merlinoite	1974	MER
Faujasite	1842	FAU			

Natural zeolites have several applications with their best uses found in ion exchange processes mainly in radioactive treatment (clinoptilolite). They are also used in agricultural activities and as a sorbent usually performed by mordenite

However, Natural zeolites have problems of inadequate supply, impurities, non uniform pore size and low ion exchange capacities. As a result, synthetic

zeolites have to be developed to compensate for the problems/issues associated with natural zeolites.

1.3 Synthetic zeolite

These are type or group of zeolite that are prepared in the laboratory or artificially by mimicking the conditions of its natural formation but at lower temperature and much shorter time frame from a few minutes to a few days. Several synthetic zeolites without a natural counterpart and with good industrial application have been obtained. The important synthetic zeolite that now have great commercial applications are mainly those of Zeolite Y, zeolite X, ZSM-5, Zeolite A and zeolite beta. Most recent scholarly work on zeolite tend to focus on synthetic zeolite rather than natural zeolite for the following reasons as presented in table 2

Table 2: Advantages of synthetic zeolites

	Features	Synthetic zeolite	Natural zeolite
1	Purity and Consistency	High; uniform pore sizes and fixed Silica-to-Alumina ratios	Variable; often contains impurities like iron or calcium
2	Structure	Engineered for specific tasks (e.g., shape-selective catalysis)	Random, naturally occurring framework
3	Acid Resistance	Generally decomposes in highly acidic environments	Highly stable and robust in acidic environments
4	Cost	More expensive (made via energy-intensive processes)	Cheap and abundant (mined directly)

However there are still functional application of natural zeolites especially in wastewater treatment and soil amendment agents as well as in the construction industry.

1.4 Structure of Zeolites

The structure of zeolite is made up of two main layers of architecture forming the framework configuration that gives it very intriguing properties. These include the primary building unit (PBU) and the secondary building unit (SBU). In the PBU, Zeolite comprises of TO_4 tetrahedra through corner sharing giving rise to a three dimensional four-connected framework. These framework T atoms generally refer to Si, Al, and P atoms . It can even take other atoms such as Ge, Be, Ga and B etc .

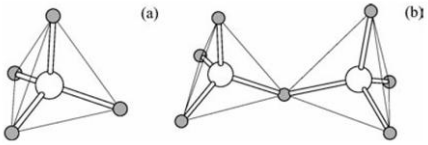


Figure 2: (a)TO4 Tetrahedron (b) TO4 tetrahedra sharing a common oxygen

The structure of zeolites is a 3D microporous aluminosilicate framework **c**omposed of corner-sharing SiO_4 /AlO_4 tetrahedra, forming regular pores, cages, and channels of molecular dimensions. The presence of exchangeable cations, high surface area, and tunable acidity makes them indispensable in petroleum refining, gas separation, and catalysis. Some examples of structure of important and industrial zeolites are shown in in figure 2

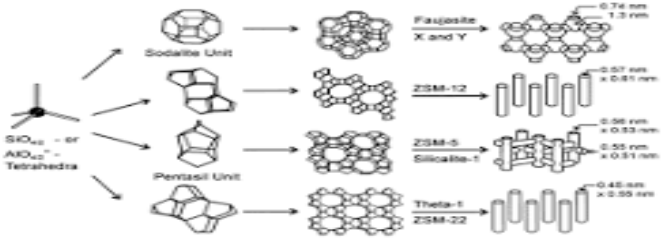


Figure 3: structure elucidation of some important zeolites

Synthesis of Zeolite

Zeolites synthesis otherwise called the man made zeolite grow of the necessity to overcome the challenges posed with the application of natural zeolite which are mainly purity and lack of controlled supply. The importance of zeolites in several human applications is in shape- selective catalysis, separations , membranes, adsorption, sensors and optics (Guo, 2016) further lay credence to the need to synthesise zeolites whose properties and behaviour can be controlled and manipulated. Since the discovery of the first natural zeolite by Axel Fredrik Cronstedt in 1756, several researchers have worked on the synthesis of zeolites as they are more useful in industries than natural zeolites due to the purity of crystalline products and uniformity of particle size. However, the early synthetic work done was not well established because they lack essential data for proper identification. Not until late 1940s, when Milton and Co- workers successfully synthesised zeolites A (LTA), X(FAU) and P(GIS) using hydrothermal synthesis, Today, many synthetic zeolites have emerged.

1.5 Methods of zeolite synthesis

There are several routes in synthesising different types of zeolites and these are but not limited to solvothermal synthetic route, ionothermal synthetic route, F^- synthetic route, microwave- assisted hydrothermal synthetic route and hydrothermal synthetic route (Kovo, 2010). The most important methods are briefly explained below:

1.5.1 Solvothermal synthetic route

This involves the use of organic solvent or mixed organic water for the synthesis of zeolite materials. The first Patent on solvothermal synthesis of zeolite was obtained by BASF in 1982 when ZSM-5 was synthesised from NaOH, silica and $Al(OH)_3$ in ether solvent or in ether- water mixtures. Generally, the non-aqueous solvent mediated synthesis produces a slow reaction due to the shortage of water available for solvating. The effect of non-aqueous solvent in the crystallization of zeolites is influenced by their viscosity. The higher viscosity of solvents reduces the mass transfer by convection which favours the formation of large crystals. For example,

1.5.2. Ionothermal synthetic route

This is the use of ionic liquids (IL) and eutectic mixtures as solvent in the synthesis of aluminophosphate zeolite analogs (Cooper *et al*., 2004). This was first reported in 2004 by Morris and co- workers, when they used 1-methyl-3-ethyl imidazolium bromide (m.p. 83 ºC) as solvent and template in the reaction system $Al(^{i}PrO)_3$-H_3PO_4-HF-IL at 150 ºC. In these studies, it was revealed that the synthesis depends predominantly on the ionic character of the solvent, since sufficient quantities of molecular water disrupt the reaction, which prevented the formation of zeolites. Nonetheless, the ionothermal approach has been further applied to the synthesis of other zeolites

1.5.3 Microwave- assisted hydrothermal synthetic route

This is an electromagnetic radiation (0.3- 300 GHz) which has been widely used recently in many chemical reactions such as organic and inorganic synthesis, selective sorption, oxidation- reduction and polymerisations among other processes (Oyinade et al., 2016). Microwave- assisted synthesis is generally faster, cleaner and more efficient than the conventional methods.

Mobil oil Corporation was the first to use this synthetic route for synthesis of Zeolites NaA (LTA) and ZSM-5 (MFI) in 1988 (Chu and Vartuli, 1988). This was found to be significantly accelerated by the exposure of gels to microwave radiation. So, far, microwave-assisted hydrothermal synthesis has been applied for the synthesis of many zeolites such as zeolite A (LTA), faujasite (FAU), sodalite (SOD), analcime (ANA), beta (BEA), ZSM-5 (MFI), $AlPO_4$-5 (AFI),

1.5.4 Hydrothermal synthesis of zeolite

Hydrothermal synthesis of zeolite involves the hydrothermal crystallization of alumina silicates gels (formed upon mixing an aluminates and silica solution in the presence of alkali hydroxides and/or organic bases) or solutions in a basic environment. The crystallization is in a closed hydrothermal system

called autoclave at increasing temperature, autogenously pressure, varying time (few hours to several days), ageing conditions, seeding addition and sometimes application of structural directing agents (SDA) which usually is an organic molecules. This is the most useful, simple and widely used method of preparation of different types of zeolite and this author mainly used this route in making zeolite during the course of my research as a zeolite scientist(Kovo, 2010).

The preparation of synthetic zeolites through hydrothermal route is mainly through the use of precursor that provides silica , alumina , alkaline medium and other conditional material such as seeds or SDAs.

1.6 Precursor for Zeolite synthesis

The hydrothermal synthesis of Zeolites essentially utilise traditionally pure chemicals to provide the needed silica and alumina during the crystallization processes of any type of zeolites. Example of typical precursors obtained from pure chemical include Sodium metasilcate, silica sols, silical gel and metal aluminates . These pure chemicals that feed the synthesis mixture both the silica and alumina sources are expensive. Yet, cheaper raw materials such as clay minerals (kaolin, illite, smectite, interstratified illite smectite, montmorillonite and bentonite), natural zeolites, coal ashes, municipal solid waste, incineration ashes and industrial slags are available to be utilised as starting material for zeolite synthesis(Kovo et al., 2025).

Various sources of silica and alumina precursors for synthesis of different types of zeolites are illustrated in table 2

Table 3: Various Sources of Silica and Alumina used for Zeolite Synthesis

S/N	Material	Types of zeolite developed	Method of synthesis
1.	Perlite and SiO_2. sinter	Zeolite Y	Hydrothermal
2.	Rice husk ash	Na-X, Na-Y and Na-A	Hydrothermal
3.	Kaolin	Zeolite A, X and Y and ZSM-5	Hydrothermal
4.	Kaolin	Zeolite A	Hydrothermal
5.	Sodium aluminate and Silica sol	Zeolite Y	Hydrothermal
6.	Diatomite and $Al(OH)_3$	Zeolite X	Hydrothermal
7.	Fly ash and oil shale ash	Na-P1 and Na-P2	Fusion and refluxing
8.	Fly ash	Na-P1	Hydrothermal
9.	Bentonite	Hydoxysodalite	One-step
10	Aerosil 200 and Aerosil 380	Silicate-1 and ZSM-5	Dry gel conversion

1.7 Kaolin as starting material for zeolite synthesis

Kaolin is the simplest clay mineral, which is a dioctahedral mineral with its name probably derived from the Chinese word “kauling” meaning high bridge, the name of a hill near Jaucheau Fu, China, where the mineral was mined a

century ago (Kovo et al., 2025). The ideal formula of kaolinite is $Al_2Si_2O_5(OH)_4$ and its analyses commonly gives a composition close to that in the formula i.e. about 46-54 weight % SiO_2, 39-50 weight % Al_2O_3 and 13.9 weight % H_2O. Generally, the structure of the kaolinite group is composed of silicate sheets (Si_2O_5) bonded to aluminium oxide/hydroxide layer ($Al_2(OH)_4$) called gibbsite layers. The silicates and gibbsite layers are tightly bonded together with only weak bonding existing between the s-g paired layers.

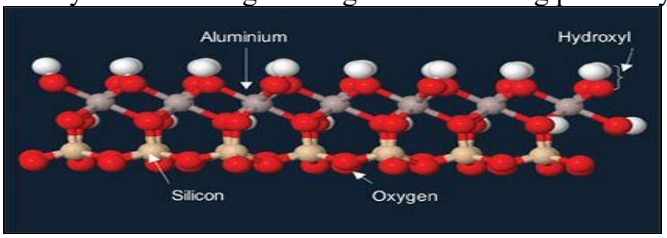


Figure 4 The crystal lattice structure of kaolinite

Kaolin is used as a starting material for synthesis of zeolites because it is a 1:1-layer mineral just like Zeolite A which makes the synthesis easier. Although, zeolites prepared from natural kaolin are always contaminated with trace amount of iron, titanium, calcium, magnesium to mention but a few . kaolin undergoes extensive refinement before it is used in zeolite synthesis. The methods of refining kaolin are typically divided into two groups; these are chemical and sedimentation methods. However, the addition of chemical can affect the properties of the kaolin, hence, sedimentation method is commonly employed at laboratory level The processes of refining kaolin have been well discussed in literature (Kovo, 2011).

After the refining, metakaolination process follows. Metakaolination is usually done at a temperature range of 550-950ºC, after which metakaolin is obtained with a loss of structural water. A small part of AlO_6 octahedral is usually maintained while the rest are transformed into more reactive tetra and penta-coordinated units. The best condition of obtaining a very reactive metakaolin as discussed by several authors is between 600 and 800ºC (Kovo & Holmes, 2010). The hydrothermal synthesis of zeolites from kaolin follows this sequence; Calcinations of kaolin to obtain metakaolin. The reaction is stated in Equation .

$$2Al_2SiO_2O_5(OH)_4 \xrightarrow{600\text{-}800^oC} 2Al_2Si_2O_7 + 4H_2O \quad (1$$

Hydrothermal reaction of metakaolin with various aqueous alkali media. Filtration and drying of zeolite sample. Nonetheless, the metakaolinization

process have been investigated by several researchers within temperature of 600 and 800^{o}C . Different temperature and exposure time employed by different researchers in metakaolinization process but in my research , a novel route to obtain lesser exposure time and temperature was developed and will be shown in my contribution .

1.8. Characterization of zeolites

The physical characterization of zeolites starts by visual inspection in principle. This inspection can be done by the use of instrument such as ordinary microscope or an electron microscope which work by enlarging small particles when visualised through them. In addition, crystalline materials may often be identified by the shape of the crystals and from this; other information such as size distribution, information about the condition of crystallization or later transformation that might take place can be drawn. Generally, there is different equipment or machines used in zeolites properties elucidation which the author utilize throughout the course of his research work in zeolites. This techniques includes; XRD, SEM, TEM, FTIR, Textural analyzer, etc . Some of this techniques are briefly describe belo:

1.8.1.X- ray diffraction

X-ray diffraction is a non-destructive analytical technique usually used in identification of phases and the orientation of crystals grown. X-ray diffraction is based on constructive interference of monochromatic x-rays and a crystalline sample. X-ray is usually produced with the use of x-ray tube or a rotating anode source. This is usually done when the core electrons in target material (usually copper, iron, molybdenum or chromium) are ejected, electrons from the higher energy bonds replace them and x- ray photons of a particular energy are released. When a rotating anode is used, the target material will be kept moving. Thus, the heat produced will be handled easily and more intense x-rays will be produced (Treacy & Higgins,)

X- ray diffraction occurs when there is interaction of x-ray with the atom's electron and mainly produce electron density distribution within the crystals. Usually, diffractions from the array of lattice points are equivalent to reflection from lattice planes (hkl). These planes are called miller indices. When a set of planes (hkl) is incident on lattice planes, it leads to maximum diffraction at a diffraction angle θ as defined by Bragg's law. In conclusion, XRD can be used to determine the type of phases present, the concentration level and amorphous content of the sample.

1.8.2 Transmission electron microscope .

TEM is used in investigating the structure, composition and properties of a specimen. TEM consists mainly of electron gum, electron beam, electromagnetic lenses, vacuum chamber, condenser, phosphorescent or fluorescent screen and a computer. TEM uses high energy up to 300 kV and produces a high resolution black and white in a vacuum chamber. The principle of TEM is based on focusing high voltage electron by the electron gun onto a thin specimen through the anode at one end of the gun to the condenser system. The condenser system has one or two electromagnetic lenses, consisting of coils of wire which create magnetic field to produce thin beam. The generated beams are focused on the fluorescent or phosphorescent screen to produce an image, diffracted pattern or nano-crystal specimen depending on the mode of operation.

1.8.3 Scanning electron microscope (SEM)

SEM evolved in the bit of continued effort of TEM improvement, It is used for the determination of sample morphology, chemical composition, crystalline structure and orientation of materials making up the sample. SEM is a machine that comprises a gum, a column, series of lenses (through which electron beam is shaped), the sample chamber at the base and series of pumps to keep the system under vacuum. When a beam of electron is generated from the field emission gum, it is accelerated through a high voltage and passed through an aperture and electromagnetic lenses to produce a thin beam of electrons. The beam scans the sample surface by CRT, electrons are emitted and collected by a detector. The detector controls the brightness of the spot on the screen, which will be watched by the operator. As more electrons are seen, the brightness of the screen is increased and as it becomes fewer, the spot becomes darker. SEM can magnify an image ranging from x15 to x200, 000 and a resolution of 1- 5 nm . When there is interaction between the samples and electrons from SEM, a variety of signals are produced. These signals can be secondary electrons, backscattered electrons, diffracted backscattered electrons, photon, visible light and heat. It is the secondary electron image that reveals the morphology and the topography on the sample

1.8.4 Fourier transforms infrared spectroscopy

FT- IR is an analytical method developed in 1970s to qualify and quantify compounds with the use of infrared absorption of molecules, hence it is mainly used to identify functional groups present in compounds or materials. Its principle is based on interference of radiation between two beams to yield a signal produced as a function of the change of path length between the two

beams. The radiation from the source passes through an interferometer to the sample before reaching the detector. Interferometer has a fixed mirror and a moving mirror which generates optical path difference and makes waves interfere in it. Thus, when a signal is amplified, the filter will eliminate the high frequency contributions and data are converted to digital form by an analog- to – digital converter before transferring to the computer for Fourier transformation.

1.8.5Textural analysis using nitrogen adsorption

The BET theory aims at explaining the physical adsorption of gas molecules on a solid surface and serves as the basis for an important analysis technique for measurement of the specific surface area of a material. In 1938, Stephen Braunauer, Paul Hugh Emmet and Edward Teller published the first article about the BET theory in the journal of the American Chemical society .The technique encompasses external area and pore area evaluations to determine the total specific surface area in m^2/g, yielding important information in studying the effects of surface porosity and particle size in many applications . Monolayer formation of gas molecules on the surface is used for the determination of specific surface area while the principle of capillary condensation can be applied to assess the presence of pores, pore volume and pore size distribution. Prior to the measurement, the sample is preheated at elevated temperature in a vacuum or flowing gas so as to remove any contaminants present in it.

1.9 Application of Zeolites

Both natural zeolites and synthetic zeolites have become an important and integral part of many process industries. The global market for zeolite production has continued to blossom to the extent that the world market for zeolite has been estimated to be around $16.6 billion while that of synthetic zeolite hold the largest market share up to 88%.

Both types of zeolites have important uses while 90% of natural zeolites are mainly applied in the construction industry with the remaining used in such processes as animal feeding, horticulture, waste water treatment, odour control and other miscellaneous applications. Synthetic zeolites are mainly applied in process industries. According to the data obtained in 2026, 81% of synthetic zeolite is used in the detergent industry while the rest are used in catalysis, adsorption and other applications (Figure 5). The increase application of zeolites in the detergent industry can be attributed to environmental concern. The use of phosphate builder has been banned in most countries because it causes eutrophication and is difficult to degrade when placed in water bodies,

Hence zeolites ie zeolite A and zeolite X offer a good replacement because of their high ion exchanging capacities.

The application of zeolites has its largest economic impact on the FCC processes . Zeolites give an increased yield over amorphous catalyst to the tune of around 40 billion US dollar a year. Zeolite Y and ZSM-5 are two of the most important zeolites used in FCC catalysis. In fact, ZSM-5 zeolite is regarded as good octane booster. Other octane booster zeolite in FCC operation include mordenite, silicalites, MCM-20 and zeolite beta.

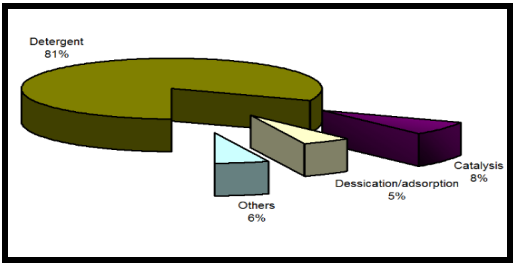


Figure 5 Usage of synthetic zeolites in 2025

Another example of the use of zeolites in catalysis in refinery operation is in hydrocracking where about 5000 to 100,000 ton of mainly zeolite Y is used in the United State alone for hydrocracking operation. Hydrocracking involves the conversion of higher paraffins over noble metallic or zeolite catalysts to yield distillate products. These and many other uses of zeolite catalyst in refinery operation are depicted in figure 6. There are other countless application of zeolite in many areas of human endeavour such as energy , health , agriculture with energy dominating especially in crude oil refining.

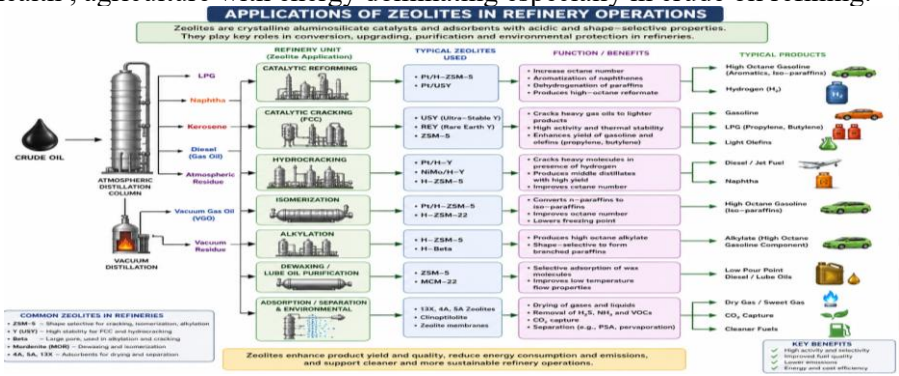


Figure 6: Application of Zeolites in refinery Operation

Some of the most recent applications of zeolites in modern processes include: Optic and electronics, Bio-catalysis, Synthesis of nanostructure catalyst and Drug release.

1.10 Zeolite membranes

Zeolite membranes have remained one of the most studied inorganic membranes because of their wide application. These are not only restricted to separation processes and catalytic membrane reactors but several other emerging processes such as applications in microreactors, sensors, electrodes and optoelectronic devices. The use of zeolites in the synthesis of membranes can be attributed to their unique properties which include highly ordered structures, uniform molecular pore sizes, high thermal stability and resistance to harsh chemical conditions. This has lead to increased research toward the synthesis of zeolite membrane using many strategies. The increased research into zeolite membranes are based on the comparative advantage over other inorganic membranes and organic membranes. These reasons include:

- Zeolite membranes when used in separation processes possess high selectivity which is significantly better than those of other inorganic membranes because of the presence of uniform and well defined pore sizes which are absent in other membranes.
- It has enhanced thermal stability better than that of organic membranes.
- Zeolite membranes possess high chemical stability and good resistance to chemical attack.

1.10.1 Zeolite membranes Preparation methods

In-situ Hydrothermal synthesis represents the most common method of preparation of zeolite membranes and films. In this method , the hydrothermal synthesis takes place whereby zeolite layers are deposited on the surface of supports through crystallization of an aluminosilicate mixture in the form of a gel or clear solution. This is formulated from deionised water, a silica source, an alumina source, a structural directing agent(SDA) and a mineralizing agent (usually NaOH). The synthesis of the zeolite membrane is performed via hydrothermal crystallization similar to the synthesis of zeolite powder. The gel or clear solution formed from mixing the synthesis precursors are placed in contact with the support in a reactor, usually an autoclave, and the preferred zeolite is grown on the supports depending on the controlled thermodynamic conditions such as time and temperature of crystallization, and the composition. Several precursors have been used as sources of silica and alumina to synthesis zeolite membrane just like powdered zeolite. Other

method making zeolite membrane include secondary seeded method The secondary growth method is considered to be an advancement over the in-situ hydrothermal method. The method involves the growth of zeolite seed crystals which is deposited well in advance onto the substrate. This is followed closely by the transformation of zeolite synthesis gel via hydrothermal treatment. This method allows the synthesis orderly and well aligned crystal in the substrate unlike the in-situ crystallization method. The major advantage of this method is the reproducibility which is almost absent in the in-situ process. Other advantages include:

1. Low crystallization temperature
2. Shorter crystallization time
3. Less stringent conditions to form coherent zeolite films
5. A preferred method for large scale production of zeolite membranes

The secondary growth method involves two basic steps:

1. Use of zeolite seeds to coat the support surface
2. Crystal growth of the seed layer into a continuous zeolite membrane using a zeolite synthesis mixture (gel or solution).

The third method, although not too common is the vapour phase transport method. This method is based on high temperature steam treatment of a dry gel converting it into a thin film of zeolite by nucleation and crystallization on the surface of the support

This method allows complete conversion of the reacting gel into a zeolite layer thereby allowing the possibility of obtaining a zeolite membrane with high Si/Al ratio. This is a major advantage over the in-situ method.

The VPT method comprises of two important steps, namely:

- Formation of a hydrogel of silica, alumina, and sodium on the support surface. Usually the support is placed in a holder inside the autoclave.
- The second step is the actual crystallization of the dry gel in the reactor with steam generated from the liquid content of the reacting species.

The steam used can be generated in two different ways. First, it can be made from water and the SDA or template fed to the dry gel by saturated vapour pressure. This method can lead to low consumption of the SDA. The second but preferred method involves placing the SDA in the support along with other solid material and allowing only the water to generate the steam . This allows the utilization of the SDA in the formation of the desired structure and also leads to the formation of a thin and oriented film.

1.10.2 Application of zeolite membranes

Traditional applications of zeolite membranes and films are mainly in the field of, microfiltration, ultrafiltration, dialysis, electrodialysis, osmosis, pervaporation, gas permeation and membrane reactors. However, zeolite membranes and films have also found important applications in fields such as sensors and dielectrics. Zeolites possess properties which can be modified to suit specific applications. An example is the tunable hydrophilic/hydrophobic properties of zeolites by modification of the aluminium content of the zeolitic material to change the interaction with water-organic mixture making zeolite membrane a very important technologies used in the production of ethanol fuel through pervaporation as shown in figure 7. Pervaporation is defined as permselective vaporization of a liquid mixture (the feed) which is subjected to permeation through a zeolite membrane and the product (permeate) is obtained as vapour at reduced pressure. It is an energy efficient and effective process and can easily replace more energy consuming processes such as distillation and adsorption.

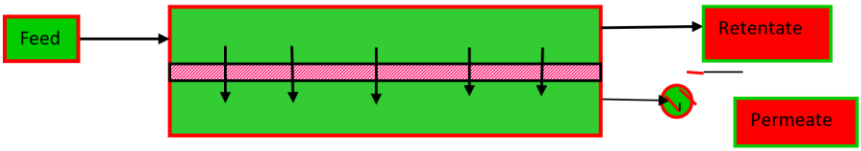


Figure 7 : Schematic illustration of principle of pervaporation

Zeolite membranes have also found important applications in the operation of reactors because of their unique properties. A membrane reactor is used to simultaneously carry out reactions and separation in one unit. Zeolite membranes in the reactor perform dual functions. The first function is to increase the conversion of equilibrium limited reactions by selective withdrawal of one of the products. The second function is to increase the selectivity of the desired product by controlled addition of a reactant through the zeolite membrane. Typical industries where zeolite membrane reactors have found huge application are shown in table 4

Table 4: Use of zeolite membrane reactors

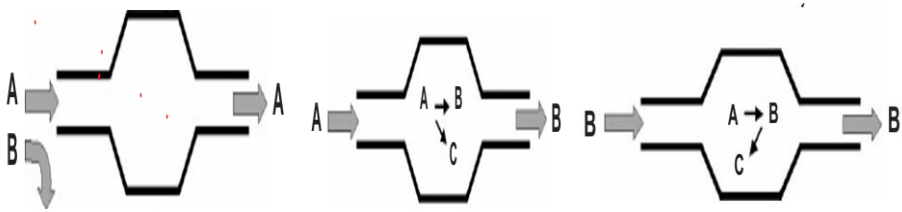
Zeolite	Type of membrane reactor	Application
Silicalite-1	Fixed bed reactor	Ethylbenzene conversion to styrene
Zeolite A	Fixed bed reactor	Methy-Tert-Butyl-ethyl (MBTE) synthesis
Zeolite A	Zeolite membrane reactor	Methanol from CO_2 and H_2
Silicalites-1	Fixed bed reactor	Hydro-isomerisation reactions
ZSM-5	Fixed bed reactor	Xylene isomerisation

Other recent applications of zeolite membrane with profound implication for emerging industries is their use as ionic conductor The presence of aluminium atoms in the zeolite framework induces a negative overall charge. This unique property enable zeolites to have the capacity to occlude the charge balancing cation within the pore spaces of the zeolite framework. In addition, the concentration of the cation in the framework can be tuned by varying the Si/Al ratio in the framework. This enables the insertion of different types of cations into the framework by ion exchange, thereby altering its properties. This property allows zeolites to behave as an ion conductor and can be used as a solid electrolyte in fuel cells, chemical sensors and batteries.

1.11 Zeolite Catalysts

Catalysts are the workhorses of chemical transformations in the industry. Approximately 85–90% of the products of chemical industry are made in catalytic processes. Catalysts are indispensable in process industries and can be well noticed in the production of transportation fuels in one of the approximately 440 oil refineries all over the world, production of bulk and fine chemicals in all branches of chemical industry , Abatement of pollution in end-of-pipe solutions (automotive and industrial exhaust) among other processes.

Zeolites possess acid sites that are catalytically active in many hydro carbon reactions, The pore system only allows molecules that are small enough to enter hence, it affects the selectivity of reactions by excluding both the participation and formation of molecules that are too large for the pores. Figure 8 illustrates how a zeolite can influence the selectivity of catalytic reactions. In the first case, one of the reactants is excluded because it cannot enter the zeolite. In the second, A reacts to give two produces, B and C, but C is too large to leave the pore. In the third case, the onward reaction of B to C is prohibited, e.g. because the transition state for this step does not fit.



a. Reactant Selectivity b. Product Selectivity c.Reaction selectivity

Figure 8: Illustration of functionality of Zeolite as a catalyst

1.12 Hierarchical Zeolites

Hierarchical zeolites are advanced zeolitic materials containing more than one level of porosity, normally combining the intrinsic micropores of conventional zeolites with additional mesopores and/or macropores. Conventional zeolites possess well-defined microporous structures, which provide high surface area, shape selectivity and strong catalytic activity. However, their small pore openings can restrict the diffusion of bulky molecules and can cause rapid catalyst deactivation by coke deposition. The introduction of secondary mesoporous or macroporous networks creates shorter diffusion pathways and improves the accessibility of active sites which are popular in several industrial applications. Such as application as catalytic cracking, Friedel-Crafts alkylation, phenol tert-butylation and esterification require hierarchical mesoporous zeolite. Others are transesterification and oxidation of benzene to phenol. It is generally accepted that the introduction of hierarchy in zeolite framework increase the yield of production of chemicals by at least 10% in addition to improve mass diffusion and elimination or reduction in coke formation for heavy molecules reactions

1.12.1.Method of making hierarchical zeolites

There are a number of methods used in the making of H-ZSM-5 and this method is broadly divided into bottom up and top down approaches. The bottom up route utilize the various synthesis precursor and supported with the right structural direction agent to act as template to obtain the preferred structure such as in dual templating and dual functional surfactant route. The top down approach entails the formation of the mesopore from an existing microporous zeolite through gradual removal of the framework halls

The bottom up approach has a number of different mechanism which include direct synthesis by dual-functional surfactant approach and Dual template mechanism with the latter being the dominant mechanism used in making hierarchical zeolite. This involves two different templates that aid the creation of the zeolite framework and formation of mesopore region(Bello et al., 2023).

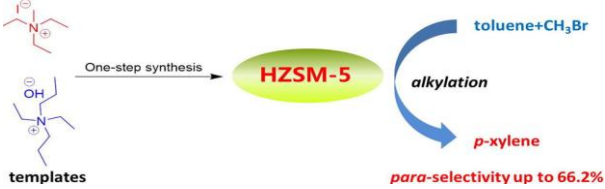


Figure 9: Dual template mechanism shape selective hierarchical zeolites synthesis

The top down methods also come up with different mechanisms or approaches with desilication approach as the dominant process with better potential towards commercialization of the production of hierarchical zeolites.
This strategy is very straight forward and has continued to gain significant attention. This method can be applied to wide varieties of zeolites. Consider an aqueous alkali solution, less reactive aluminol sites help to maintain the zeolite structure, while silica is extracted, leading to more porous structures. Hence, desilication offers increased adjustable pores through external pore-directing agent used in the process while conserving Brønsted acid sites. Generally, desilication can afford a well-tailored mesoporosity through the varying concentration of alkali, replacement of the Si/Al ratio of the main zeolite, reaction temperature and reaction time. The other top down method is basically a variation of the desilication which involves the use of realumination after the removal of silica in order to restore zeolite phase and promote the conventional Bronsted acid site present in the aluminium bonds in the zeolite framework as shown in figure 10.

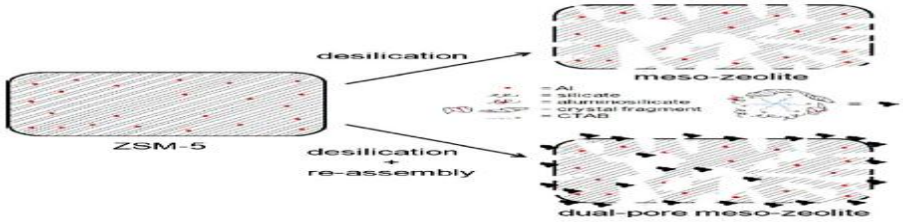


Figure 10 : A schematic diagram illustrating formation through desilication for ZSM-5 Zeolite(Gadin et al., 2023)

1.12.1 Application of Hierarchical zeolites

The combination of microporosity, mesoporosity and acidity makes hierarchical zeolites particularly attractive for catalytic processes involving large hydrocarbon molecules, oxygenated biomass-derived compounds and other molecules whose dimensions are larger than conventional zeolite pore openings. A few of the important application of Hierarchical zeolites include :

1. Application in Petroleum refining : In FCC, large hydrocarbon molecules present in vacuum gas oil and other heavy petroleum fractions must diffuse into the catalyst pores before undergoing cracking. Conventional zeolite Y, which is widely used in FCC catalysts, has predominantly microporous channels. Although these micropores provide excellent shape-selective catalytic environments,

the diffusion of large molecules into the interior of the zeolite crystals can be slow. Hierarchical zeolite Y provides additional mesoporous channels through which large hydrocarbon molecules can reach the internal microporous active sites more readily. This can improve mass transfer, conversion of heavy feedstocks, accessibility of acid sites and resistance to catalyst deactivation**.**

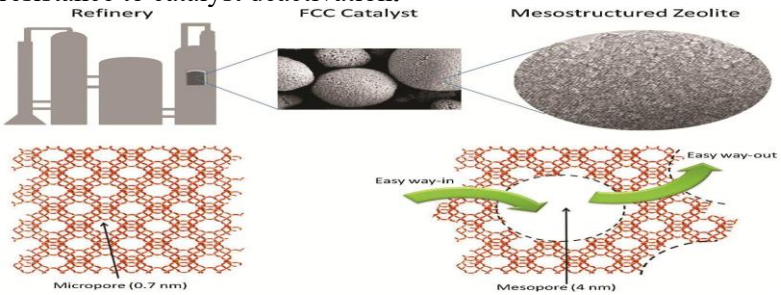


Figure 11: Illustration of use of hierarchical zeolite in FCC unit in petroleum refining

2. Biomass Conversion : Another important application is the catalytic conversion of biomass-derived molecules into fuels and valuable chemicals. Biomass contains large oxygenated molecules that can undergo dehydration, decarboxylation, decarbonylation, cracking and aromatization. Hierarchical zeolites can improve the conversion of bulky biomass-derived molecules because their secondary pores provide additional transport pathways.For example, biomass-derived compounds such as cellulose-derived oxygenates, furans, lignin-derived molecules and pyrolysis oils **c**an be converted into hydrocarbons and aromatic compounds. Hierarchical zeolites are particularly attractive for upgrading biomass pyrolysis oil because the mesoporous structure facilitates access of large oxygenated molecules to acidic catalytic sites.
3. Environmental catalysis : Hierarchical zeolites have applications in environmental protection, particularly in catalytic processes for removing pollutants from gases and liquids.Their large external surface area and interconnected pore structure can improve access of pollutant molecules to active sites. They can therefore be incorporated into catalysts for processes such as NOx reduction, treatment of industrial chemical emission , hydrocarbon emission control etc

4. Production of Biodiesel : Hierarchical zeolites can also be applied in biodiesel production, particularly as solid acid or basic catalytic components and as supports for active catalytic species. The hierarchical structure can enhance contact between relatively bulky triglyceride molecules and catalytic active sites. Two of my recent PhD students have work in this area as will be shown later

There are several other promising areas of application of hierarchical zeolite making research in this area very robust and actives. For example, work has continued to evolve to utilize hierarchical zeolite as a better alternative for carbon capture and conversions than conventional materials presently in use.

2.1 My contributions

The job of an academic staff of any university is categorised into three namely teaching , research and community service and in all of this , I have made my modest contributions.

2.1.1Teaching Contribution

I have been teaching several Chemical Engineering courses in our University and outside of the university. Some these courses which I have taught over the last twenty five years include Separation Processes , Chemical Reaction Engineering , Chemical Engineering Analysis, Transport Phenomena , Petroleum production and refining technology, advanced unit operation , Chemical Kinetics, process instrumentation and Process design/economic. I have also developed a new course in the department of material and metallurgical engineering called zeolitic material and applications and still being taught in the CCMAS , however the course is now an elective in the new CCMAS curriculum of Chemical Engineering students. I have also taught Chemical Engineering courses at the University of Calabar, Confluence University of Science and Technology, Osara, Kogi state , the University of Manchester and University of Bath both in the United Kingdom.

2.1.2 Research contribution

2.1.2.1 Synthesis Work

Suitability of Ahoko Clay for Zeolite Synthesis, **Kovo A.S.**, Edoga, M.O., and Kefas, H.M., (2003)

One of the pioneer work I did in making zeolite from Nigeria natural clay, otherwise called kaolin, is to check the suitability of Ahoko kaolin as a precursor for zeolite synthesis. This work which was done in 2003 could only utilize x-ray florescence (XRF) to determine the silica to alumina ratio of the kaolin as there is no available X-ray diffractometer (XRD) noted for giving a

definite structural analysis of crystalline material. The result of the analysis of the untreated clay material is shown in table 5

Table 5: XRF analysis of the zeolite

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	N_2O	LOI	$CaCO_3$
Crude Kaolin	44.20	39.70	0.13	1.35	0.03	0.08	0.05	0.013	12.05	2.40
Calcined clay	44.24	39.50	0.10	1.12	0.65	0.87		0.25	11.07	2.20

The result shows that the percentage elemental composition of the untreated clay gives a ratio of SiO_2/Al_2O_3 which is greater than 2 as specified by Breck, 1974 for clay that is normally used for zeolite synthesis . the conformity of the Ahoko clay with the Breck invariably implies that the Ahoko clay can be used for zeolite formulation, the treatment of the clay resulted in attrition and matrix stabilization which caused the significant reduction in SiO_2 and Al_2O_3. The Si/Al is an important factor or parameter used in the identification of zeolite type and the value obtained in this preliminary analysis is in conformity with the one cited by Breck. This work however lacks adequate characterization serving as a motivation during my PhD.

Synthesis and characterization of zeolite Y and ZSM-5 from Nigerian Ahoko Kaolin using a novel, lower temperature, metakaolinization technique, **A. S. Kovo**, O. Hernandez and S. M. Holmes (2009)

One of the significant contribution made in the area of synthesis of zeolite was the making of a very important zeolitic material with huge economic application, especially in petroleum refinery operation. This material called Zeolite Y and ZSM-5 was made from Ahoko Nigerian Kaolin using lower metakaolinization temperature that have not been previously used. This work was published in Royal Society journal called Journal of Material Chemistry A with impact factor of 9.5. The success of the work was possible due to availability of required characterization equipment during my PhD programme in Manchester which was the major weakness of my first work on zeolite synthesis from kaolin.

The work itself involved preparation of Zeolite Y and ZSM-5 using novel process of dehydrolyxation to obtain reactive phase of kaolin with an ability for transformation to zeolitic phase through hydrothermal reactions(Kovo et al., 2009).

Temperature programmed XRD was used to monitor the phase change as Ahoko Nigerian Kaolin sample was heated from room temperature to 900ºC. The in-situ XRD pattern of the ANK sample (figure 12) shows complete loss of crystallinity at 600ºC indicating formation of metakaolin due to dehydroxylation reaction.

To confirm the heating time required at 600 C to produce metakaolin, a muffle furnace was used, pre-heated to a temperature of 600° C. A set of crucibles containing 5g each of Nigerian Ahoko kaolin were loaded into the furnace, the crucibles were then removed from the furnace after 1–10 min (1 min intervals), 20 min, 40 min, 50 min, and cooled in air. The product was then characterized to determine the composition of the metakaolin. XRD studies (Fig.) indicate that, even after only 6 minutes heating, at 600°C, the metakaolinization process appears to be complete as the sample is X-ray amorphous. This is fundamentally different from other works on the metakaolinization of kaolin where higher temperatures were reported over a longer time.

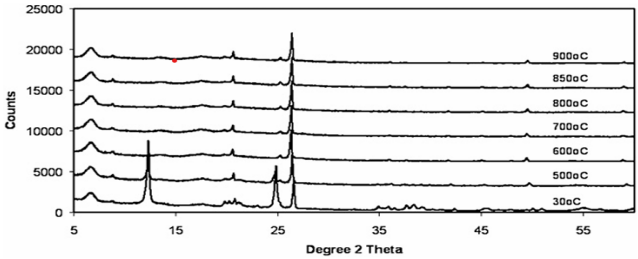


Figure 12: In-situ XRD pattern of kaolin metakaolinization process

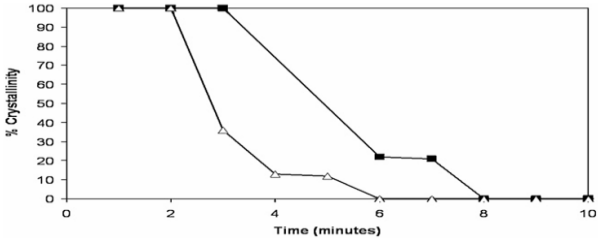


Figure 13 : Effect of time of metakaolinization on Crystallinity

The metakaolin produced by thermal treatment at 600°C for 50 minutes was utilized as a starting material for the synthesis of zeolite Y with the developed molar composition of the starting gel or precursor as 2NaOH:1Metakaolin: $7Na_2SiO_3$:$245H_2O$. The synthesis of zeolite Y was carried out at different reaction times to systematically monitor the nature of crystalline material. Figure 14. shows the XRD patterns of zeolite Y samples when the time of crystallization was varied from 3h to 9h. No zeolite formation was noticed after 3h crystallization time indicating that the conversion to zeolite had not begun. Increase in time of reaction to 6 h shows the crystallization of zeolite Y which compared well with standard zeolite Y pattern. This is in contrast with

few other works which reported the synthesis of zeolite Y after 72h. This difference between the two studies may be attributed to the degree of crystallinity in Ahoko kaolin and the quality of metakaolinization carried out. Further increases in the hydrothermal treatment to 9h leads to an increase in the intensity of the peaks corresponding to zeolite Y, indicating higher crystallinity as further collaborated by the SEM image in figure 14

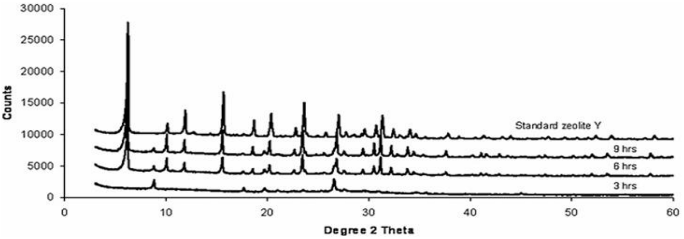


Figure 14 : XRD of Zeolite Y from kaolin at different crystallization time

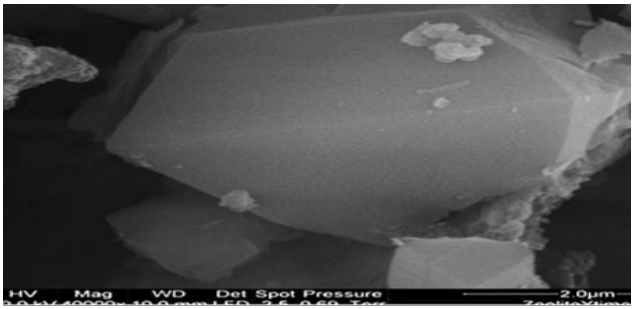
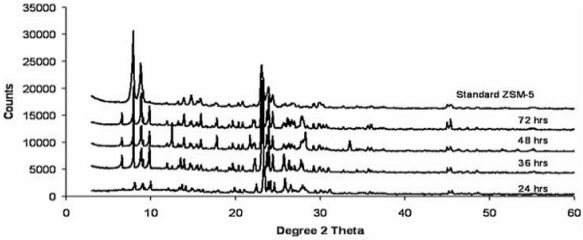


Figure 15: SEM image of Zeolite Y from kaolin at 9 h crystallization time

The metakaolin from the 50 minute thermal treatment was also used to synthesise ZSM-5. Fig. shows the XRD pattern developing with time up to 72 hours . It is clear that the metakaolin produced is effective in the synthesis of ZSM-5.



igure 16 : XRD pattern of ZSM-5 at different crystallization times (Kovo et al., 2009)

Development of ZSM-5 Zeolite from Dealuminated Nigerian Ahoko Kaolin, Kovo A. S. and Holmes S. M (2013)

Synthesis and characterisation of ZSM-5 zeolite was carried in this study using dealuminated Nigerian kaolin which serves as the source of silica and alumina. The synthesis of ZSM-5 from dealuminated kaolin was a follow up to the earlier work on the synthesis of ZSM-5 zeolite from ANK (kovo et al 2029) in which external silica was added to make up for the Si/Al ratio requirement in MFI synthesis. Since the overall objective of synthesizing zeolites from kaolin is to ultimately to reduce the cost of its production, the use of commercial external silica defeats this objective. In this work the dealumination of Ahoko metakaolin was carefully carried out to obtain a Si/Al ratio within the range of ZSM-5 starting aluminosilicate gel. Dealuminated kaolin with Si/Al of 16 as shown in table along with calculated amount of NaOH, deionised water and TPAOH was used to prepare the starting aluminosilicate gel. Hydrothermal reaction was carried out by adopting the best conditions of ZSM-5 synthesis from Ahoko kaolin using external silica.

The results show the best condition for the synthesis of ZSM-5 from the kaolin as crystallization time 148h, crystallization temperature 140^{o}C and ageing time as 36h (room temperature). The outcome of ZSM-5 preparation from dealuminated kaolin indicated a highly crystallized ZSM-5 zeolite with similar morphology from the ZSM-5 prepared from the same raw material but with additional silica as shown in figure for XRD and Figure for SEM. This results show that pure phase of ZSM-5 with BET surface area of 262m^2/g can be produced from kaolin that is dealuminated which in the long run can effectively add to lower the cost of producing ZSM-5 from abundant material like kaolin..

Table 6 : Silica and alumina composition of dealuminated ANK metakaolin measured by XRF

Time (h)	Al_2O_3	SiO_2	Al_2O_3/ SiO_2
1	21.145	75.03	6.0
2	18.19	78.84	7.4
4	11.37	85.82	12.8
8	9.33	87.79	16.0

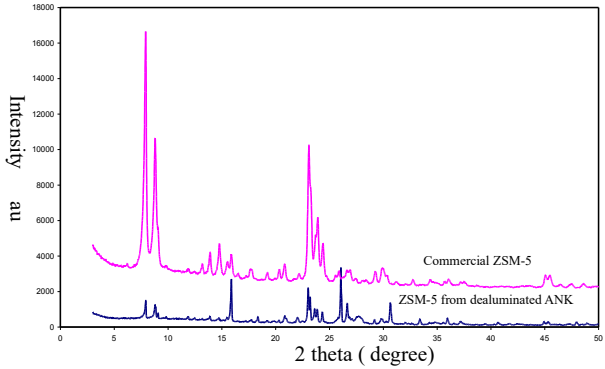


Figure 17 XRD patterns of ZSM-5 synthesised from dealuminated metakaolin at crystallisation temperature of 140°C, aging and crystallisation time of 48 and 72 hours correspondingly.

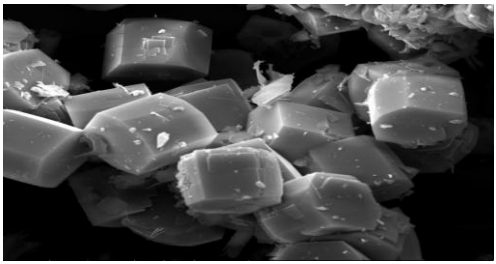


Figure 18: SEM image of ZSM-5 synthesised from dealuminated Ahoko Metakaolin. Scale bar 20µm

The direct synthesis of pure zeolite-A using 'virgin' Kaolin, Stuart M. Holmes, Abdulaziz A. Alomair and Abdul S. Kovo

Here the conversion of a Nigerian Kaolin, straight from the source without any form of pre-treatment, directly into pure zeolite-A was demonstrated(Holmes et al., 2012) . The method involves a rapid and low temperature meta-kaolinization step followed by chemical conversion directly into pure zeolite-A. The synthesis step acts as the purification step removing the 80% quartz impurity simultaneously with zeolite growth. The whole process is designed to be both economical and straightforward to facilitate commercialisation. There are numerous conventional routes to zeolite A which use pure chemical precursors such as sodium aluminate, pure aluminium powder, aluminium wire as the aluminium source and sodium meta silicate, fumed silica, colloidal silica as the silica source. The most significant barriers

to commercialisation for clay precursors have been the energy and time intensive activation of the clays to make them chemically reactive coupled with the difficulty of removal of quartz and other dense phase, unreactive, impurities from the clay which contaminate the final product. In this research we took the logical step in which we took kaolin directly from the source (the sample was collected directly from the Ahoko kaolin deposit, a 39 hectare mine, in Kogi state, Nigeria) and rapidly activate it followed by conversion into pure zeolite A without the labour intensive settling and/or centrifugation necessary to achieve the quartz levels in commercially available kaolin. Relying on gravity to prevent migration of the solid impurity to the product, the dissolved metakaolin in solution provides the nutrients for crystal growth producing pure crystals of zeolite A. All steps in the process are designed to minimise cost, the seeds are produced by ball milling commercially available zeolite rather than the time consuming and complex growth of 'nano-crystallites.' The removal of the quartz relies on a simple, gravity basis shown in figure 19, spatial separation and the metakaolinization is at a significantly lower temperature and time than the traditional route. Here, we show that using this technique, pure zeolite A with distinct XRD pattern as shown in figure20 and SEM image figure21 can be produced directly from kaolin which has had no complex processing after extraction from the ground. This work have continued to be cited being severally.

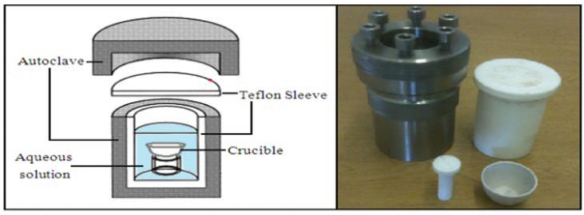


Figure 19; Illustration of the autoclave used in the hydrothermal synthesis with the Teflon holder and crucible.

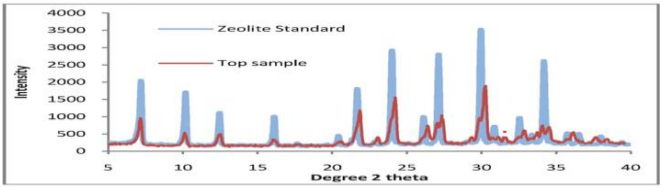


Figure 20 : XRD of the Pure Zeolite A along with the commercial Zeolite A used as standard

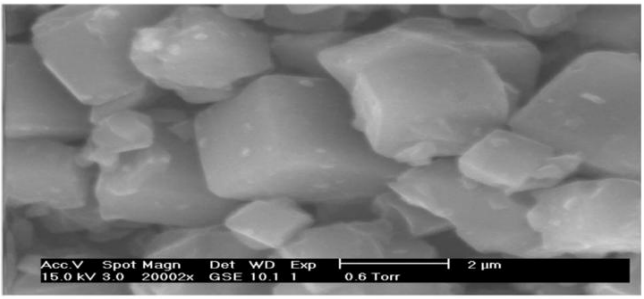


Figure 21 : SEM image of the pure Zeolite A

Synthesis and Characterization of Zeolite A from Aloji Kaolin, RekiyaAbdullahi, A.S. Kovo, ManaseAuta, A.S. Abdulkareem, and M.O. Edoga, (2017)

In this instance, Aloji kaolin obtained from eastern flank of Kogi state was used as a combined source of silica and alumina to synthesize zeolite A The raw Aloji kaolin known for its high quartz content which is detrimental during zeolitization process was purified via sedimentation process and was followed by metakaolinization at 800ºC for 3 h to obtain reactive metakaolin phase material. The metakaolin obtained was used to synthesize zeolite A through conventional hydrothermal crystallization method. The synthesized zeolite A was characterized by SEM and XRD. The optimum synthesis parameters of zeolite A synthesized through conventional hydrothermal route were 3M NaOH, crystallization temperature of 90oC and crystallization time of 72 h after aging for 24 h at room temperature with the XRD showing pure phase of the LTA crystal and the SEM depicting the typical cubical shape of Zeolite as shown in figure 22 for the sample named AC3 out of the optimization runs carried out in this research. . The crystallinity of synthesized A through conventional hydrothermal route ranged from 40 - 70%.

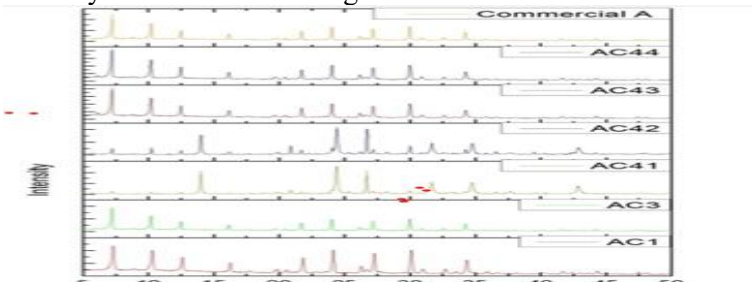


Figure 22: XRD pattern of various samples of zeolite A synthesised with sample AC3 fitting well with standard Zeolite A

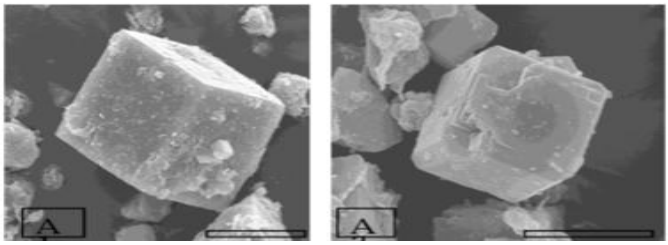


Figure 23 : SEM image of the optimum zeolite A sample with typical cubical shape noted for this type of zeolite

Effect of Temperature on the Synthesis of Zeolite X from Ahoko Nigerian Kaolin using Novel Metakaolinization Technique, A. S. Kovo (2012)

In this work, another type of Zeolite called Zeolite X was synthesized successfully from kaolin using a novel metakaolinization technique(Kovo, 2012b). The first step involved refining the raw kaolin sample, followed by metakaolinization. This was done after determining the metakaolinization temperature of Ahoko Nigerian kaolin (ANK) as 600^{o}C using in situ X-ray diffraction (XRD) and simultaneous thermal analysis (STA). A new method for the production of metakaolin was investigated in this work. Metakaolin was obtained after 50 minutes of exposure at 600^{o}C. The metakaolin produced was used to synthesize zeolite X using the hydrothermal method. Highly crystalline zeolite X was not obtained until the crystallization temperature of 80^{o}C was attained, with aging time and crystallization time fixed at 24h and 6h respectively figure 24 . Zeolite formation increases with increase in crystallization temperature as evident from the increase in the intensity of diffraction peaks. An increase in temperature beyond 100C leads to a remarkable decrease in the reflectivity of zeolite X, with formation of a completely new zeolitic phase recognized as sodalite, which was formed at 200C

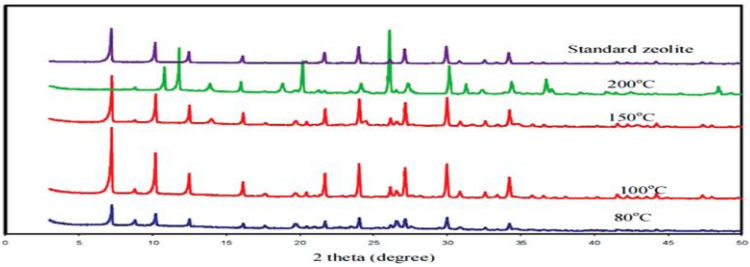


Figure 24 : XRD pattern of Zeolite X at different crystallization temperature

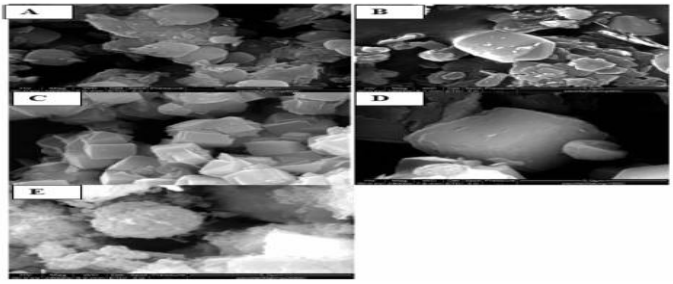


Figure 25 : SEM images of Zeolite X at different crystallization temperature

Synthesis and Characterization of Micro/Mesoporous Hβ–Zeolite Catalysts from Ahoko Kaolin, Abdulsalami Sanni Kovo, Rashida Salihu Safiyanu, Aisha Shettima Eyitayo Amos Afolabi & Abdulrazak Jinadu Otaru(unpublished)

This research introduces the utilization of Ahoko-based kaolin as a chemical alternative to silica and alumina in the synthesis of hierarchical β-Zeolite (Beta Zeolite). The work was developed through a unique process as shown in figure 26. The raw Ahoko kaolin underwent pretreatment using the sedimentation technique to eliminate impurities such as quartz. Subsequently, a dehydroxylation process was employed to convert the kaolin into metakaolin. The synthesis of β-Zeolite was conducted hydrothermally through two distinct routes. In the first route, metakaolin was utilized as the alumina source alongside an external silica source (sodium silicate nonahydrate), resulting in the synthesis of β-A. The second route involved the use of dealuminated Ahoko metakaolin as both the silica and alumina source, leading to the production of hierarchical β-B zeolite. The dealumination process of Ahoko metakaolin was conducted using a concentrated hydrogen chloride (HCl) solution at a temperature of 90 ^{o}C under reflux conditions. The zeolization of the β–crystals was carried out under optimized synthesis conditions at a temperature of 170 ^{o}C for a duration of 14 hours. The hierarchical form of the β–zeolites was achieved by desilicating the synthesized β–crystals (β–A and β–B) using a 10 wt% urea solution. The physiochemical properties of the synthesized hierarchical β–Zeolite were determined through the utilization of XRD, XRF, BET, and SEM, analysis techniques. The XRD pattern indicates the formation of BEA topology at $2\theta = 7.8^{o}$ and 2.6^{o} for both β–A and β–B. Additionally, the SEM results reveal the partial and complete formation of spheroidal morphology of β–crystals for β–A, accompanied by micro/mesoporous aggregates. On the other hand, the SEM analysis of the

hierarchical β–B zeolite material shows a hexagonal structural morphology with fewer mesopores. The surface area of the synthesized porous β–Zeolite was determined using N_2 adsorption, yielding values of 488.1 $m^2.g^{-1}$ and 452.2 $m^2.g^{-1}$ for β–A and β–B, respectively as shown in table 7 and the typical hierarchical zeolite adsorption isotherm with hysteresis shown in figure 29 .

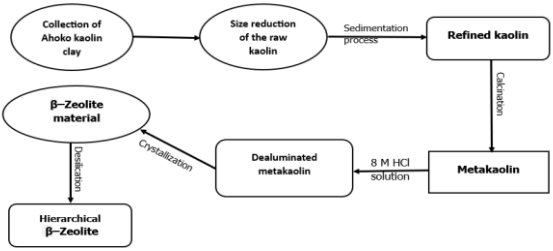


Figure 26: Process development for Beta Hierarchical zeolite synthesis

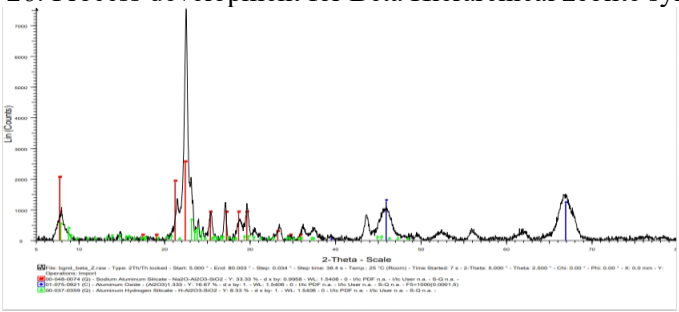


Figure 27: XRD pattern of Hierarchical Zeolite Beta

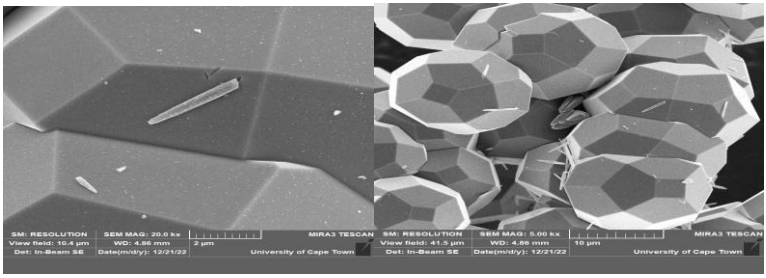


Figure 28 : SEM images of the two types of Beta zeolite synthesised

Table 7: Textural properties of the Hierarchical zeolite Beta

Sample	Si/Al	$S_{(BET)}$ (m^2/g)	Pore volume (cm^3/g)
Beta-A	76.6	488.1	0.16
Beta -B	58.56	452.2	0.17
Literature value		524	

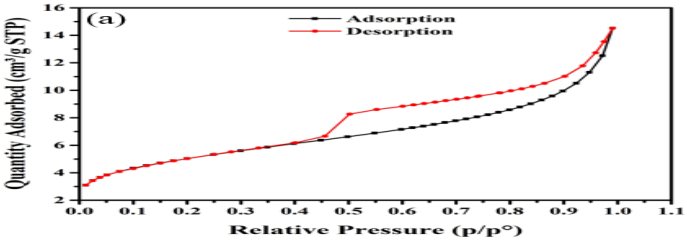


Figure 29 : N_2 adsorption isotherm of the β zeolite

2.1.2 Contribution to Zeolite Applications

Zeolites generally, whether natural or synthetic (Man-Made), are huge material with multifunctional abilities and cross fertilization of applications with advances in the area of water treatment , catalysis , renewable energy , gas separation , agriculture , heathcare, electronics and several others . My research in zeolite science in the last twenty years or more has spanned work in several of these applications field , some of which will be highlighted in this lecture.

Application in the area of Water Treatment

Synthesis of Zeolite A from Aloji Kaolin to Investigate Its Performance in Hard Water Softening (Elizabeth OKPONG, Patience Oshuare SEDEMOGUN and Abdulsalami Sanni KOVO (2020))

This is one of the works we did to show the application of Zeolite for treatment of hardwater with specific target of well water around Gidan Kwanu community outside of our University .

Aloji Kaolin in Kogi state was used as a combine sourced of silica and alumina to synthesize Zeolite A in this research . The raw Aloji kaolin was purified via sedimentation process to get rid of the underlying impurities such as quartz and this was then followed by metakaolinization at 800°C for 2h to incur reactive metakaolin phase. The purified and calcined kaolin were used to synthesize Zeolite A through conventional hydrothermal crystallization method. The synthesized zeolite A was characterised by Scanning Electron Microscopy as shown in figure 31 and X-ray diffraction method (figure 30) . The optimum synthesis parameters of zeolite A synthesized through conventional hydrothermal route was 1M NaOH, crystallization temperature of 100°C and crystallization time of 6h after aging for 6h at room temperature (Okpong et al.,). The synthesized zeolite A was used for softening of hard water containing 76ppm of calcium ions for Gidan Kwano water sample and 178ppm of calcium ions for Maitumbi water sample, the synthesized zeolite A

was able to reduce the hardness to 4ppm and 6ppm respectively for both water samples within 10 minutes of treatment (Figure 32) with the physiochemical properties as shown in table 8. . Zeolite A was therefore successfully used for water softening and timely and with a huge potential for local communities with stress water supply system.

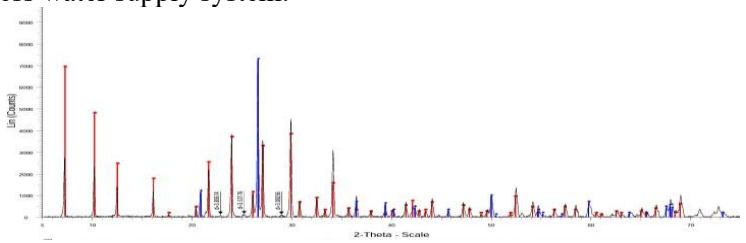


Figure 30: XRD pattern of zeolite A synthesised for water softening

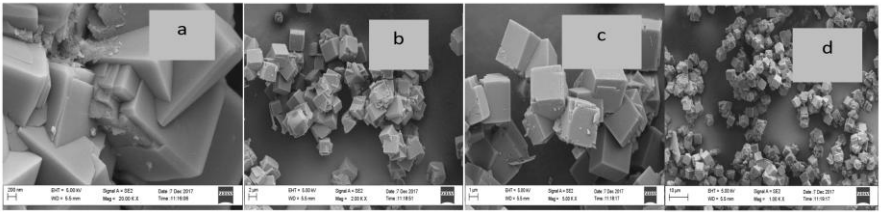


Figure 31: SEM micrographs showing the occurrence of zeolite A and associated phases obtained by hydrothermal synthesis.

Table 8 : Results of some test performed on Gidan kwano water sample.

Test Performed	Raw	Treated
pH	8.40	8.20
Turbidity (NTU)	2.22	8.20
Total Hardness (ppm)	143	24.0
Calcium Hardness(ppm)	76.0	4.00
Magnesium Hardness(ppm)	67.0	20.00
Total Dissolved Solids(ppm)	286	314

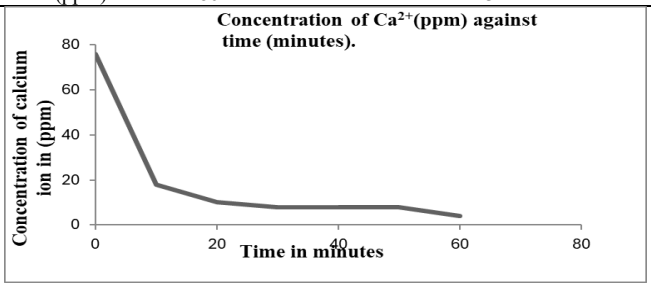


Figure32 : Graph of concentration of calcium ion (ppm) against time (min) for Gidan Kwano analysed water sample.

Column adsorption of biological oxygen demand, chemical oxygen demand and total organic carbon from waste water by magnetite nanoparticles-zeolite A composite(Abdulsalami Sanni Kovo , Sherifat Alaya-Ibrahim, Ambali Saka Abdulkareem , Olalekan David Adeniyi , Titus Chinedu Egbosiuba , Jimoh Oladejo Tijani , Mustapha Saheed , Blessing Onyinye Okafor , Yusuff Sikiru Adeyinka (2023)

In this research, (Kovo et al., 2023), we demonstrated the utilization of zeolite alongside other components to treat water with high concentration of total organic carbon , high biological oxygen demand and chemical oxygen demand which are detrimental to good water quality. Magnetite nanoparticles (NPs), zeolite A and magnetite-zeolite A (MAGZA) composite were developed by green methods. The produced nanomaterials were characterized and the effect of process parameters such as flow rate, adsorbent bed height and adsorbate inlet concentration was evaluated for the removal of biological oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC) in a column shown in Figure 33 . The characterization results demonstrated the successful synthesis of magnetite NPs, zeolite A and MAGZA composite using both FTIR and XRD (figure 34 and 35). The performance of the MAGZA composite in the fixed-bed column was superior to zeolite A and magnetite NPs. The parametric influence indicates that an increase in bed height and a decrease in the flow rate and inlet adsorbate concentration improved the performance of the adsorption column. The adsorption column demonstrated maximum performance at a flow rate (4 mL/min), bed height (5 cm) and inlet adsorbate concentration (10 mg/L). Under these conditions, the highest percent removal of BOD, COD and TOC were 99.96, 99.88 and 99.87%. Thomas and Yoon-Nelson's model suitably fitted the breakthrough curves Figure 36 . The produced MAGZA composite effectively removed BOD, COD and TOC from textile wastewater in a continuous operating mode and the characteristic of the treated textile waste water is shown in table 9

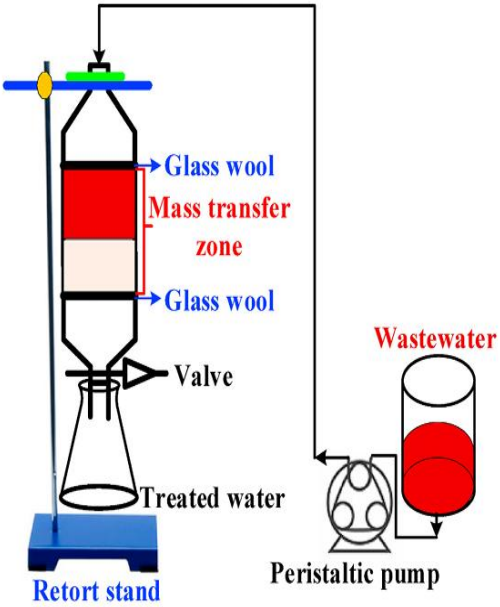


Figure 33: Set up for the work

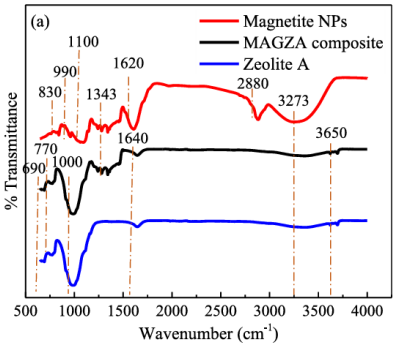


Figure 34: FT-IR spectrum of the synthesised zeolite and composites

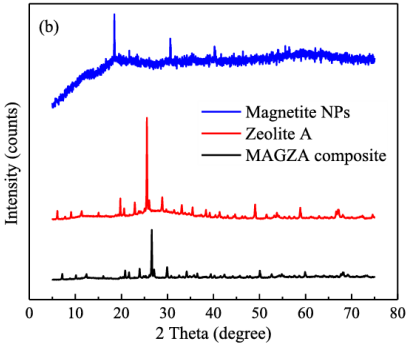


Figure 35 XRD analysis of the Synthesised Zeolite with the composite

Table 9: Characterization of raw and treated textile wastewater compared standards

Parameters	Raw Value	Treated with MAGZA composite	Removal of Pollutants (%)	WHO/EPA Standard Limit
BOD (mg/L)	6287	2.4	99.96	-/5.0–7.0
COD (mg/L)	31044	36	99.88	-/40
TOC (mg/L)	2990	4	99.87	-/<6
TDS (mg/L)	36723	500	98.64	1000/-
pH	11.40	6.5	42.98	6.0–8.5/6.0–9.5
Conductivity (μS/cm)	54810	860	98.43	-/1000
Turbidity (NTU)	7638	75	99.02	5.0
Total alkalinity (mg/L)	16443	320	98.05	-/400
Nitrate (mg/L)	1804	20	98.89	50/50
Ammonia (mg/L)	276	3.5	98.73	1.3–3.5/0.2–4.0
Chloride (mg/L)	9711	31	99.68	250/250
Phosphate (mg/L)	113	0.5	99.56	-/0.5-0.7
Fluoride (mg/L)	226	1.48	99.35	1.5/1.7
Sulphate (mg/L)	7111	25	99.65	500/250
Iron (mg/L)	3.64	0.05	98.63	-/0.3
Chromium (mg/L)	2.12	0.03	98.58	0.05/0.05
Nickel (mg/L)	1.45	0.001	99.93	0.07/0.02
Zinc (mg/L)	1.14	0.007	99.39	-/3
Lead (mg/L)	3.75	0.005	99.87	0.01/0.01
Cadmium (mg/L)	2.54	0.003	99.88	0.003
Copper (mg/L)	2.13	0.002	99.91	2/1
Manganese (mg/L)	1.12	0.002	99.82	-/0.2

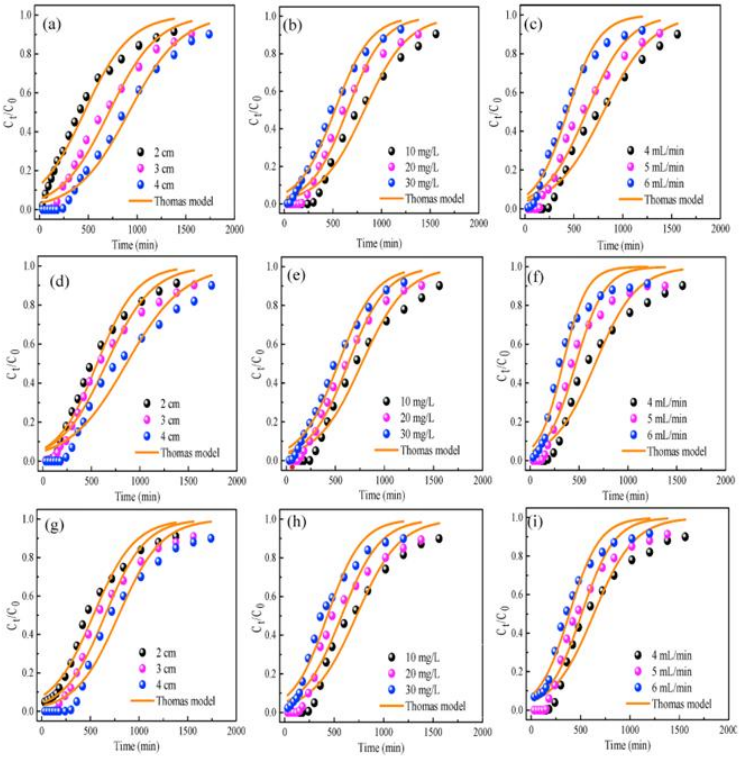


Figure 36 : Breakthrough curves showing performance

Synthesized chitosan–zeolite composite matrix for the adsorption of chromium (VI) ions(Ayokanni Adebayo Oshagbemi, ManaseAuta, Abdulsalami Sanni Kovo, Muibat DiekolaYahya, Ambali Saka Abdulkareem, Mohammed Aris Ibrahim and Kehinde Shola Obayomi (2020)

In this research which is again in the multi-area application of zeolite , we demonstrated that zeolite can cohabit with other material and preform very well in waste water treatment with specific focus on chromium removal. Chitosan–zeolite 3A composite (CS/Z) adsorbent was prepared to investigate the removal of Cr(VI) from aqueous solution(Oshagbemi et al., 2020). The chitosan (CS) was prepared from shrimp waste (shell) using chemical processes. The percentage yield and degree of deacetylation were 13.64% and 87.07%, respectively. The matrix formulation was obtained with a response surface methodology using a central com posite design. The best matrix ratio of chitosan to zeolite was 1:7. This ratio was used for adsorption studies. Batch adsorption studies were carried out to investigate the optimum condition for the removal of Cr(VI) using CS/Z and the adsorbent was characterized using X-ray diffraction and scanning electron microscopy. The influence of solution pH, adsorption dosage, initial Cr(VI) concentration, and temperature on the removal processes were investigated. Adsorbent dosage of 0.25 g using 20 mg/L as the initial solution concentration showed maximum metal uptake, at optimum pH 2. The result obtained from equilibrium isotherm adsorption studies of Cr(VI) ion was analyzed in three adsorption models namely: Langmuir, Freundlich, and Temkin. The equilibrium studies carried out followed Langmuir isotherm with the highest correlation coefficient (R2) value of 1. The kinetic parameters were evaluated utilizing the pseudo-first-order, pseudo-second-order, and Elovich-second-order. It was shown that the adsorption of Cr(VI) ions can be described by the Elovich kinetic model, with a correlation coefficient of 0.96. Thermodynamic parameters studies revealed that the adsorption process was spontaneous and endothermic in nature. In comparison between CS/Z, Z, and C, the percentage of removal was 97%, 68%, and 50%, respectively. Thus, it can be deduced that CS/Z composite adsorbent is effective and efficient for the removal of Cr(VI) ion

Development of nano-silver doped zeolite A synthesized from Nigerian Ahoko kaolin for treatment of wastewater of a typical textile company (S. Alaya-Ibrahim, A. S. Kovo, A. S. Abdulkareem, O. D. Adeniyi& M. D. Yahya (2019)

In this work, nano-silver synthesized with mango leaf extract as a reducing agent was doped onto synthesized zeolite A (SZA), produced from Nigerian kaolin via green synthesis route. The produced adsorbents were characterized using X-ray fluorescence (XRF), X-ray powder diffraction (XRD), high-resolution transmission electron microscopy (HRTEM), Fourier transform infrared spectroscopy (FTIR) and Brunauer–Emmett–Teller (BET) surface analysis, in addition, it is to be used for the treatment of local textile effluent (Alaya-Ibrahim et al., 2020). The physicochemical parameters of the effluent were analyzed using standard methods. The HRTEM micrographs revealed well dispersed AgNPs on SZA and the BET surface area revealed high surface areas of 119.98m2/g and 436.44m2/g for SZA and silver-doped zeolite A (SDZA), respectively. The array of removal of the pollutants was BOD>COD>CN->Cl->NO2->TOC for SZA and CN->BOD>COD>NO2->Cl->TOC for SDZA as shown in table10 , with the doped adsorbent removing the higher pollutants in all cases. Isothermal models, not shown in this presentation indicated that Jovanovic model (R2>0.999) was most suitable for describing the adsorption process, which conformed to pseudo-second order kinetics with intraparticle diffusion of micropore type. The thermodynamic studies showed spontaneous and endothermic reactions

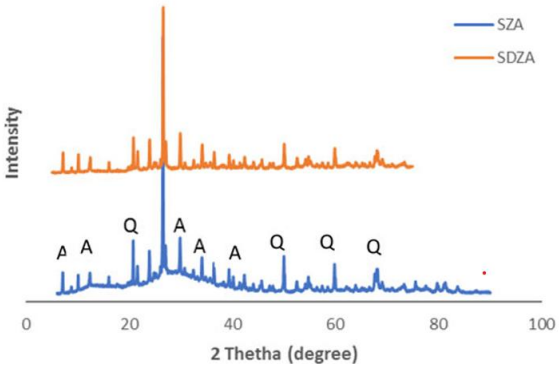


Figure 37 : XRD pattern of the two material

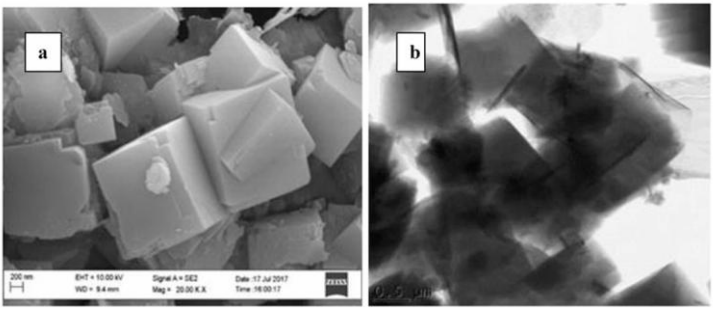


Figure 38 : TEM image of the two Zeolite samples

Table 10: Adsorption of the zeolite samples

Physicochemical parameters	Conc. Before treatment	Concentrations after treatment with SZA	Concentrations after treatment with SDZA	Standard limits (WHO/EPA)	Standard limits (NIS)
pH	11.2	9.70	9.35	6.5–8.5/6.5–9.5	6.5–8.5
TDS (mg/L)	36,582	804	637	1000/-	500
Conductivity (µS/cm)	54,600	1200	950	-/1000–2500	1000
Dissolved oxygen (mg/L)	2.80	3.10	3.50	–	–
Turbidity (NTU)	7,500	89	85	1.5/1.0	5.0
Total alkalinity (mg/L)	12,750	450	400	- /400	–
Nitrate (mg/L)	1300	25.9	23.1	50/50	50
Ammonium (mg/L)	250	5.10	4.40	1.3–35/0.2–4.0	–
Chloride (mg/L)	9,221	132	39.0	250/250	250
Phosphate (mg/L)	105	1.50	1.25	- /0.5–0.7	–
Cyanide (mg/L)	6.70	0.04	0.01	- /0.05	0.01
Fluoride (mg/L)	160	8.20	7.10	1.5/1–1.7	1.5
Sulfate (mg/L)	7,000	33	27	500/250	100
COD (mg/L)	30,083	71	60.0	- /40	–
BOD (mg/L)	6,016	4.80	2.79	- /5.0–7.0	–
TOC (mg/L)	2,110	360	440	–	5.0
Carbonate (mg/L)	300	25	23	–	–
Nitrite (mg/L)	13.7	0.42	0.09	3.0/0.5	0.2

Note: World Health Organization (WHO, 2011), Environmental Protection Agency (EPA, 2001) and Nigerian Industrial Standards (NIS, 2007).

S. ALAYA-IBRAHIM ET AL.

Application in Environmental Sustainability : odour , pollution ,

Tailoring ferro-manganese functionalized zeolite for enhanced deodorization of poultry manure, Materials Today Communications (2026) (Jimoh Oladejo Tijani, Akingbola Ezekiel Tosin , Oluwatosin Kudirat Shittu , Saheed Mustapha , Ambali Saka Abdulkareem Abdulsalami Sani Kovo, Muhammed Muhammed Ndamitso , Maymounah N. Alharthi , Kehinde Shola Obayomi, (2026)

This is another study showing a simple application of zeolite as a multifunctional material capable of being deployed to solve human problem. This study investigated the development of ferromanganese (Fe-Mn), zeolite-A and Fe-Mn-zeolite-A for the removal of some organic compounds from poultry manure. Fe-Mn was synthesized using the co-precipitation method, zeolite-A was synthesized from kaolin using a hydrothermal method, and Fe-Mn-zeolite-A nano composite was synthesized using the wet impregnation method to treat poultry manure(Tijani et al., 2026). These nanomaterials were

characterized using HRSEM-EDS, XRD, BET, HRTEM, and FTIR. HRSEM and HRTEM analysis reveals Fe-Mn consists of uniform spherical-like particles while zeolite-A has a less agglomerated cubic structure, and the Fe-Mn-zeolite-A shows a mixture of the cubic surface of zeolite-A and spherical Fe-Mn nanoparticles. EDS confirmed the presence of Al, Si, Fe, and Mn in the nanocomposite. XRD/HRSEM pattern revealed Fe-Mn spherical crystal structure (21.30 nm), spinel cubic crystal structure for zeolite-A with size (86.72 nm), while Fe-Mn-zeolite-A nanocomposite displays strong crystallinity and a mixture of spherical and cubic crystal structures (19.40 nm). FTIR spectrum of Fe-Mn indicates stretching vibration of metal-oxygen bonds in the Fe-Mn- lattice, zeolite-A peaks show bending and stretching vibration of water molecules within the zeolite, Si-O stretching vibrations, while the peaks of Fe-Mn-zeolite-A shows the combination of metal-oxygen and Si-O stretching vibrations, emphasizing synergistic behaviour between Fe-Mn and zeolite-A in the nanocomposite. The BET analysis results reveal the specific surface areas of Fe-Mn, zeolite-A, and Fe-Mn-zeolite-A nanocomposite as 58.66 m^2/g, 15.88 m^2/g, and 92.62 m^2/g, respectively. The column adsorption experiment investigation revealed that Fe-Mn-zeolite-A nanocomposite was able to remove more dimethylamine up to 97.57% within 60 min, while indole was the least adsorbed organic compound (10.05%). Other removed compounds include 2- butanone (54.34%), cyclohexane (73.7%), toluene (81.81%), butanoic acid (70.12%) and 1-methoxy-1,3-cyclo hexadiene (74.39%) at the end of 60 min contact time. The results of the isotherms and kinetics show that the order fit for the prepared nanomaterials was Fe-Mn-zeolite-A > Fe-Mn > zeolite-A for the removal of selected organic compounds and the nanocomposite showed limited recyclability. This study demonstrated that Fe-Mn- zeolite-A nanocomposite are efficient in the removal of the selected organic compounds from poultry manure.

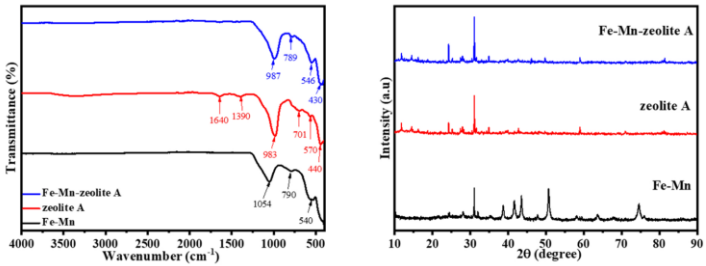


Figure 39 : FTIR (a), and XRD patterns (b) of Fe-Mn, zeolite-A, and Fe-Mn-zeolite A nanocomposite

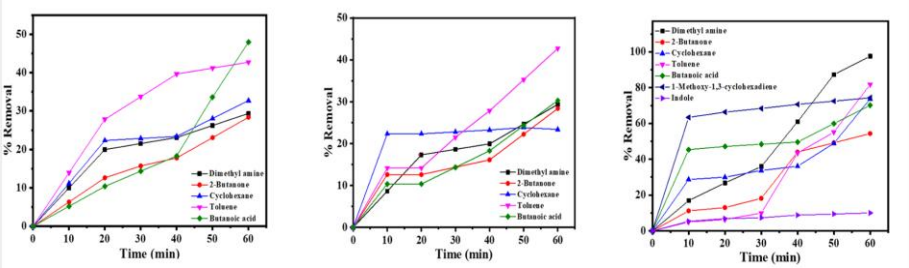


Figure 40 : Percentage removal of selected organic compounds from poultry manure using (a) Fe-Mn, (b) zeolite-A, (c) Fe-Mn-zeolite-A.

Hydrothermal synthesis of kaolin based zeolite A for use in the deodourisation of poultry litter V.C. Eluwa , A.S. Kovo , A.S. Abdulkareem, J.O. Tijani, Saheed Mustapha (2025)

This work explored the synthesis of zeolite A from Aloji Nigerian kaolin for the deodourisation of poultry litter. Refined Aloji kaolin was used as a cheap precursor for zeolite A synthesis via hydrothermal technique. The effects of alkalinity (5,6.5,8 M), metakaolinization temperature (600, 725, 850 °C), crystallization temperature (80, 115,150 °C), and stirring time during ageing (1,2,3 h), on the synthesis of zeolite A via the hydrother- mal method, were studied using Box Behnken design(Eluwa et al., 2025). The kaolin and synthesized zeolite A were characterized via X-ray diffraction, Scanning Electron Microscopy (SEM), Brunauer–Emmett–Teller (BET) and High-Resolution Transmission Electron Microscopy (HRTEM). The results show that the crystallinity and crystal size of synthesized zeolite were within 52.98–78.29 % and 13.98–33.82 nm respectively. Further findings showed that pure zeolite A crystals were formed from Aloji kaolin after 3 h at an optimum synthesis condition obtained as; alkalinity 5 M, metakaolinization temperature 850 °C, stirring time 2 h, and Crystallization temperature 115 °C. This optimum condition produced Zeolite A with a crystallinity of 78.3 % and cubic morphology, a feature that is widely associated with zeolite A. The BET result shows that this prepared zeolite has a surface area, pore size and volume of 18.8832 m2 /g, 178.461 Å and 0.070864 cm3 /g respectively. The HRTEM analysis carried out on the synthesized Zeolite A confirms the cubic morphology of the SEM result, with the selected area electron diffraction (SAED) pattern illustrating that the synthesized zeolite A is polycrystalline. The synthesized Zeolite A was applied in the removal of odour-causing agents

in poultry litter. The result of the analysis carried out using an air quality meter (gas analyzer) showed that it removed 78 % CO_2 , 70% HCHO 70 % NH and 90 % particulate matters as shown table 11 ; while the Gas Chromatograph Mass Spectrometer analysis deduced the odour causing compound in poultry litter such as 2- butanone, Toluene, dimethylamine, indole, as well volatile organic compounds and were reduced to 37 %, 30 %, 48 % and 83 % respectively. It can therefore be inferred that zeolite A synthesized from Aloji Nigerian kaolin meets the standard for commercial zeolite and thus can be used for industrial application. Thus, it is suitable for the removal of odour-causing agents in poultry litter.

Table 11 : Concentration of odour pollutants detected in raw and treated poultry litter and OSHA PEL.

S/N	COMPONENT	CONCENTRATION OF POLLUTNTS					OSHA PEL
		RAW	1 %	5 %	10 %	15 %	
1	Formaldehyde (mgm^{-3})	0.624	0.502	0.187	0.182	0.302	0.921
2	TVOC (mgm^{-3})	4.659	3.886	0.503	0.445	2.230	<1.00
3	$PM_{2.5}$ (μgm^{-3})	10	6	0	0	4	35
4	PM_{10} (μgm^{-3})	17	11	1	1	5	150
5	CO_2 (ppm)	657	528	142	178	240	1000
6	NH_3 (mg/L)	1.288	0.63	0.096	0.084	0.070	25ppm

Application in renewable energy

Production and characterization of biodiesel from Cascabela thevetia oil using synthesized hierarchically kaolin-based zeolite A catalysts R. A. Usman, A. S. Kovo, A. S. Abdulkareem & M. U. Garba (2024)

Ever-increasing energy demands and environmental issues related to the depletion of fossil fuels have motivated a search for renewable energy sources. Biodiesel has emerged as an environmentally friendly alternative to fossil fuels. The homogeneous catalyst used in the transesterification reaction for biodiesel production has the disadvantages of separating the catalyst from the products, creating environmental hazards and involving difficulties in product separation. A zeolite heterogeneous catalyst is easily separated for reuse, and by-product can be recovered. However, the micropore nature of this zeolite is constrained, causing diffusion limitation for the adsorption of tri glycerides at the catalyst's active site, thereby reducing the reaction rate and causing poisoning of the catalyst. Hierarchical zeolite has been identified as a catalyst that can overcome the limitations of microporous zeolites in the catalytic reaction. It features enlarged pores, greater stability, and improved surface area that speed up transesterification. This research developed hierarchical zeolite A (obtained as shown in figure 41)from Aloji kaolin as a catalyst for biodiesel production from Cascabela thevetia seed oil (CTO), which has not previously been reported(Usman et al., 2024). The optimized developed

hierarchical zeolite A (sample ZA6) was applied as the catalyst in biodiesel production and a biodiesel yield of 95.01% was achieved and with properties measured as presented in table 12 and conforming mostly to standard commercial biodiesel. .

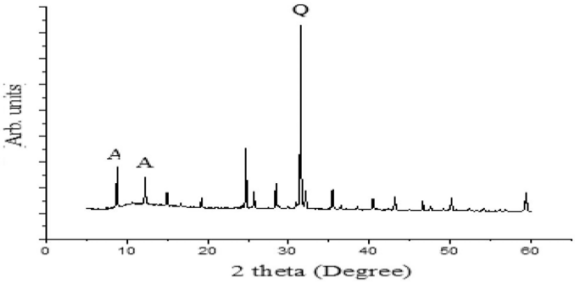


Figure 41: XRD pattern of hierarchical Zeolite A

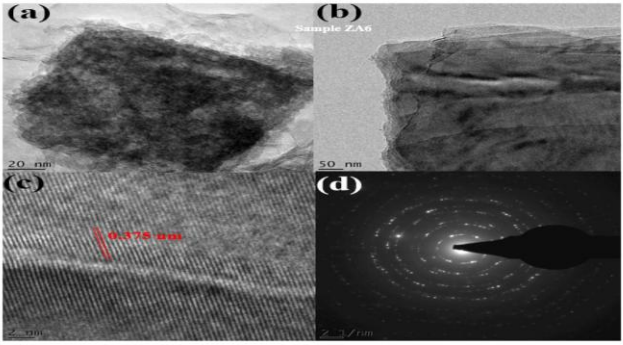


Figure 42 : TEM images of hierarchical Zeolite A catalyst

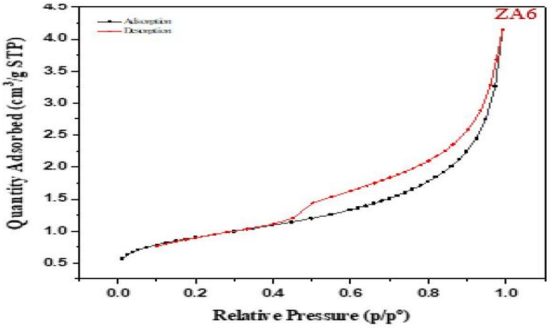


Figure 43 The nitrogen adsorption–desorption isotherm loop of hierarchical zeolite ZA6.

Table 12 : Properties of the biodiesel produced

S/N	Properties/units	ASTM limit	Produced biodiesel	ASTM method
1	Density 15 °C (g/cm^3)	0.860–0.890	0.8582	D 4052
2	Moisture content 105 °C for two h	0.03	0.11	D4442
3	Cetane number	≥47	48.96	D613
4	Viscosity (Pa. s) 40 °C	$1.9–6.0 \times 10^{-3}$	4.9×10^{-3}	D445
5	Acid number (mg KOH/g)	0.8 max	2.28	D664
6	Kinematic viscosity	1.9 – 6	1.16	D6751
7	Free fatty acid (%)	NA	1.14	D1982
8	Flash point (°C)	93 – 170	142	D93
9	Cloud point (°C)	−3 to −12	−4	D2500
10	Pour point (°C)	NA	−3	D97
11	Calorific value (kJ/kg)	37,700	40,516	E11-87

Application in Heath Care

Synthesis of Zeolite A From Kaolin Loaded With Carbon Nanotubes and the Evaluation of its Antimicrobial Activity Kovo A.S., Dyil, P., and Ali, A.F. (2018)

This study evaluated the antimicrobial activity of zeolite A loaded with Carbon Nanotubes (CNTs) against bacterial isolates usually common in water (especially wastewater). The zeolite was synthesised using the hydrothermal synthesis method while incorporation of CNTs into it was via the sol gel method. The sample was characterised using X-ray Diffraction (XRD) Fourier Transform Infrared spectroscopy (FT-IR) and Scanning Electron Microscopy (SEM) see figure 44, 45 and 46 respectively . The results showed well-defined cubic crystals of Zeolite A were formed and confirms the homogeneous distribution of CNT around them. The antimicrobial activity of Zeolite A/CNT was tested against three gram negative bacteria (Salmonella Ttyphi, Escherichia Ccoli and Pseudomonas Aaeruginosa), using the agar dilution method at concentrations of 12, 16 and 20 mg/ml. The results showed no significant activity irrespective of the concentration, only delayed growth was noticed in P. Aeruginosa figure 47.

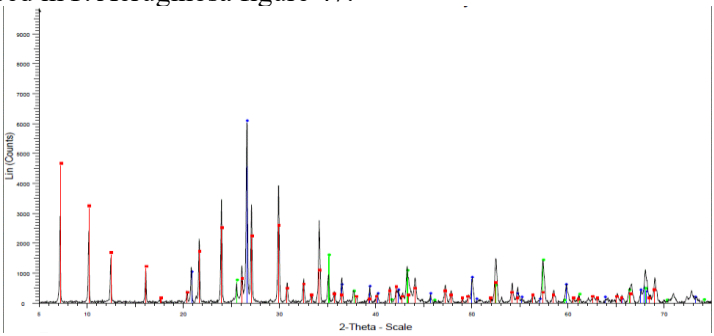


Figure 44: XRD pattern of Zeolite composite

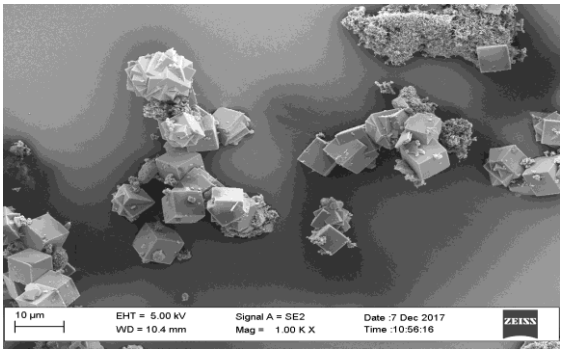


Figure 45: SEM image of the composite

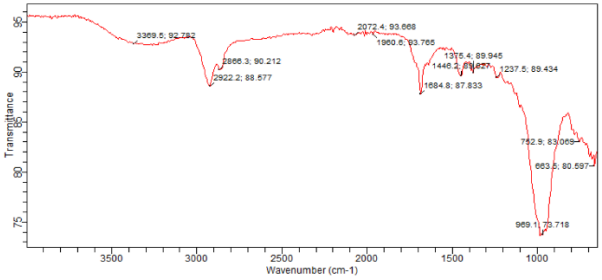


Figure 46: FT-IR spectrum of the zeolite composite

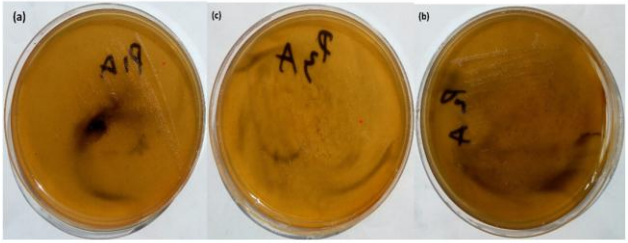


Figure 47: bacteria activity

Nanozeolites: eco-friendly materials for healthcare applications, (A review) Fatima Gogo Mayaki , Abdulsalami Sanni Kovo Oluwatosin Kudirat Shittu , Abdulrazak Jinadu Otaru and Umar Ndagi (2025)

In the form of nanomaterial, nanozeolite can exist as an essential material in the healthcare industry due to its distinctive properties. Nanozeolites are eco-friendly material with features such as high surface area, excellent ion-exchange capabilities , making them ideal for various medical devices and

pharmaceutical applications(Mayaki et al., 2025) .nanozeolites enable drug loading through physical adsorption with in pores, surface interactions and electrostatic ion exchange ,which collectively affect their sustained and controlled release profiles, enhancing drug efficacy while reducing side effects Numerous studies have demonstrated the effectiveness of nano-zeolite in treating conditions such as cancer and infections by facilitating targeted delivery and improved bioavailability. Furthermore, nanozeolites play a role in the development of sustainable Green technologies, enhancing applications in energy production, agriculture, waste management, and environmental remediation.

Challenges such as scalability, potential toxicity, and the need for advanced surface functionalization remain critical to address. Future research directions include elucidating precise drug–carrier interaction mechanisms with molecular simulations, optimizing synthesis methods for controlled morphology and functionalization, improving biocompatibility through tailored surface modifications, and expanding clinical translation. As the demand for eco- friendly and efficient health care materials increases, the importance of nanozeolites becomes more evident. This review explores their applications in healthcare, emphasizing drug delivery systems, antimicrobial uses, biosensors, and wound healing, while highlighting mechanistic pathways and developmental perspectives to accelerate their biomedical

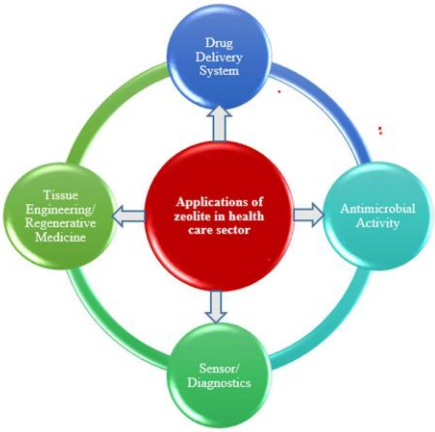


Figure 48 : illustration of application of Zeolites in Health care

Application in Agriculture

The Effect Of Synthesized Npk Loaded Surfactant Modified Zeolite A Based Fertilizer In Tomato (Lycopersycumesclentum) Cultivation Salako. O. ,Kovo, A.S., Abdulkareem, A.S. , Yusuf, S.T. , Afolabi, E.A. and Auta, M. (2020)

In this work, we showed the application of zeolite in agriculture. The surface of zeolite A synthesised from Ahoko kaolin was optimally modified by quaternary ammonium compound, HDTMA and used as fertilizer carrier. Characterization techniques such as FTIR and BET were used to characterise the zeolite A and modified zeolite A samples. Zeolite A's maximum adsorption capacity of 7.55mg/g was obtained with initial concentration of 162.6 mmol/L, contact time of 16 h, and temperature of 25 ^{o}C (Salako O et al., n.d.). The initial HDTMA concentration was the most significant term that influenced the adsorption capacity of zeolite A. The interactive effect that contributed significantly to the maximum adsorption capacity (6.27 mg/g) of the zeolite occurred with initial HDTMA concentration (243.80 mmol/L) and adsorption temperature of 25.21^{o}C as predicted by the Design Expert software version 7 used for the work. The surfactant modification of the surface of zeolite A reversed the negative charges on the framework to positive and allowed the adsorption of oxyanions such as nitrates and phosphates. The results indicated a reduction in the BET surface area of HDTMA modified zeolite A from 65 to 46.72 m2/g and 62.27 m2/g for phosphate loaded zeolite A and nitrate loaded zeolite A based fertilizers respectively. Conventional NPK 15:15:15 and the NPK loaded zeolite A based fertilizer were applied on tomato crop. The result of a higher leaf count (growth parameter) of zeolite A based fertilizer with mean (54.2) compared with NPK 15:15:15 with mean (25.7) at 11 WAT as shown in table 13 indicated the slow release property and nutrient retention of zeolite A based fertilizer. The zeolite A based fertilizer treated plants had a higher fruit yield with mean (84.69) compared with NPK 15:15:15 fertilizer with mean (69.34).

Table 13 :Effects of varieties, fertilizer sources and rates of fertilizer application on leaf count of tomato during 2018 and 2019 rainy seasons at Minna

	2018				2019			
Treatment	**6**	**8**	**10**	**11**	**6**	**8**	**10**	**11**
Variety(V)								
UC82b	124.92a	137.56a	80.35a	41.61a	62.08a	66.78b	127.65a	131.63b
Roma Vf	120.94a	133.54a	79.19a	32.23a	35.31b	107.22a	82.75b	84.86b
SE±	5.74	5.53	1.84	5.65	4.19	7.28	7.70	7.65
Fertilizer Source								
Zeolite A	99.56b	113.17b	81. 35a	54.29a	49.30a	72.21b	97.88b	102.67b

based fertilizer								
Phillipsite based fertilizer	97.43b	113.24b	77.84a	46.54a	50.60a	73.21b	89.58b	92.96b
NPK15:15;15	122.22a	133.19a	82.36a	25.76b	46.21a	105.58a	128.15a	129.10a
SE±	3.36	3.13	2.37	7.44	5.98	9.37	9.94	9.98
Rate (kg/ha)								
0	111.54b	123.67b	78.45abc	31.5a	42.67a	65.50b	82.06b	85.28b
150	129.83ab	143.17a	83.87ab	46.58a	55.07a	87.56ab	107.22ab	110.06
300	119.38ab	131.79ab	72.53c	32.21a	46.61a	84.89ab	102.22ab	105.69ab
600	130.96a	143.37a	84.25a	37.29a	50.44a	110.06a	129.31a	131.94
SE±	7.36	6.92	2.52	6.43	6.83	10.91	11.63	11.71
Interactions								
V*F	NS	NS	NS	NS	NS	NS	NS	NS
V*R	NS	NS	NS	NS	NS	NS	NS	NS
F*R	*	*	NS	NS	NS	*	*	NS
V*F*R	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	19.03	16.60	14.51	15.09	49.39	48.23	36.29	35.79

Application in construction industry

Effect of Kaolin-based Zeolite and Cement on Physical Properties of Compacted Lateritic Soil O James, S Sadiku, AA Amadi, A.S Kovo (2024)

One the most recent work we have done in the application of zeolite as a multifunctional material is in the area of construction industry where we investigated the development of cement stabilized laterite admixed with kaolin- based zeolite for civil engineering construction. Laterite soils as we know it has an inherent properties as they exhibits a number of constructional difficulties related to their workability, field compaction and strength that may be solved with zeolite stabilization. The present study developed and characterized cement stabilized laterite soil using kaolin-based zeolite as admixture for civil engineering constructions. The additives which ranged from 3 – 12% for ordinary Portland cement (OPC) and various percentages of cement replacement with zeolite (0, 15, 30, 45, 60, 75 and 90%) were added by air-dried weight of laterite soil. Atterberg limits, compaction (determined using three energy levels namely British Standard Light BSL, West African Standard WAS and British Standard Heavy BSH) and unconfined compressive strength (UCS) tests were performed on soil mixtures. The index properties tests carried out on the natural soil showed that the soil belongs to A-7-6 in the American Association of State Highway Traffic Officials (AASHTO) classification system and CL according to Unified soil classification system (USCS). Test results showed a decreasing trend in the Liquid Limit (LL) of soil-cement with higher cement and zeolite contents. The plastic limit (PL) increased as the cement and zeolite contents increased while the plastic index

(PI) decreased as both cement and zeolite contents increased. For all the mixtures and the three (3) energy levels used, it was observed that the MDD values decreases to some specific points with increase in zeolite contents before increasing as the zeolite contents increases in the mixture. Also, the results showed an increase in MDD with increase in compaction effort in the order of BSL, WAS and BSH compaction energy. Generally, it was discovered that for all compactive efforts used in the research that the OMC increases as the zeolite contents increases to some peak points before decreasing to their minimum values . The seven day unconfined compressive strength obtained for the natural soil used in the study are 82.65kN/m^2, 448.70kN/m^2 and 664.55kN/m^2 for BSL, WAS and BSH respectively as shown in figure 49 . Expectedly, it was observed that there was increase in UCS in the order of BSL, WAS and BSH compaction efforts. Also, there was significant improvement in the UCS with addition of cement and zeolite to the natural soil. Apart from increase in UCS resulting from increase in cement content, there was also increase in UCS with increase in zeolite content to some peak values before a decline was observed.

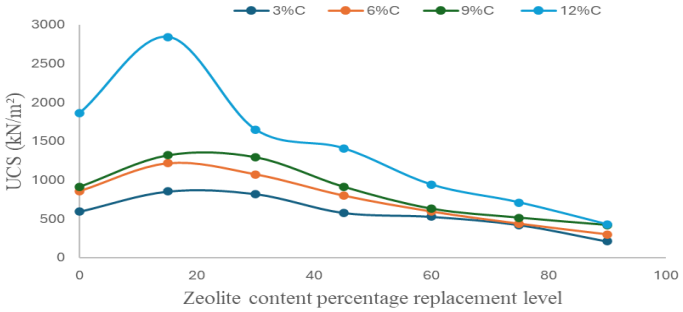


Figure 49: Variation of unconfined compressive strength of laterite soil-cement mixtures with zeolite content (WAS compaction at 7 days curing period)

2.1.3 Research Output and achievement

Mr Vice Chancellor sir, my research work in the area of zeolite technology and application have produce modest research output and achievement. In the last two and half decade of research in zeolites and associated area, I have supervised and co-supervised 22 PhD students and presently supervising and co-supervising 8 PhD students. I have also supervised 25 Master degree students and over 255 undergraduate students. I have attracted to the University in the last twelve years grants to carry out my research work. This

includes 8 different NRF TETFund grants between 2014 to 2026 both as principal investigator and co-researcher. I have won 7 Institutional based research (IBR) between 2014 and 2025. I have also won international grant by open book collectives (OBC) of the United Kingdom in 2025 and have authored and co-authored 104 research articles in different high impact journals as well as two books in different areas of zeolite science. I also have three (3) patents to my name, including United state of America patent with number US 12,138,614 B1.

2.1.4 Service to University and Community

Mr Vice chancellor sir and distinguished audience, I am very pleased to state that I have served the University in various capacities in the past twenty five years. I was a level adviser as young lecturer before going for my PhD in Manchester and was also in the sport committee as coordinator of Table Tennis from 2004 to 2007. I have since served in several other roles since coming back to the University, These roles include head of department (HOD) of Chemical Engineering from 2012 to 2016, the director of Academic Publishing Centre from 2022 to date. I have also served in several committees within the university such as doctoral award committee and book development committee where I served as the chairman. I am also a member of the committee on the University International Accreditation and serve as the facilitator of the programme. Outside the University, I was appointed and served as a member of Technical Advisory Group (TAG) of TETFund for four years from 2019 to 2022. I am presently the secretary of the editorial board of Journal of Nigeria Society of Chemical Engineers (JNSCHE). I have served as external examiner to several universities for postgraduate examination and have assessed several academics for professorial promotion. I have also served as member of panel of examiners for both local and oversea scholarship programme of Petroluem Technology Development Fund (PTDF) since 2013. I have served as vice president of Triple T Table tennis Club, Minna where we did a lot of good things to promote the game of table tennis in Minna town.

3.1 Conclusion

Zeolite has proven to be one single material of tremendous application for scientific , technological and environmental advancement . The advancement in zeolite research has continued to grow with new applications emerging for human use.

Zeolite provides the essentiality of the most important transportation fuel through gasoline production by the use of Faujasite zeolite catalyst which is numero uno for the running of fluid catalyst cracking unit in crude oil refinery operation where about 85% of gasoline is produced.
Nigeria has huge deposit of kaolin, very rich in silica and alumina which can serve as a facile and cheap material for the production of different types of commercial zeolite that can comfortably service her process industries thereby reducing dependence on important zeolites and preserving the nation's scarce foreign exchange
Zeolite structures and framework can readily by modified to engineer their properties to meet specific application need whether in catalysis, separation processes, adsorption, agriculture and heath care.
Some of the important zeolites that have been synthesised or produced from Nigerian kaolin such as Ahoko and Aloji Kaolin include zeolite A , Zeolite Y, Zeolite X ZSM-5 , zeolite beta and their hierarchical counterparts.

4.1 Recommendations

As we have seen from the lecture so far , Zeolites and zeolitic materials are crystalline or partially crystalline aluminosilicate materials characterized by interconnected pore , channels , exchangeable cations, high surface area and tunable acid -base properties . Their combination of molecular sieving , ion exchange , adsorption , catalytic and hydrothermal stability make them important in petroleum refining , petrochemicals , environmental remediation , separation processes , energy conversion , agriculture and other emerging sustainability technologies.
For research and industrial development purpose, especially making effort to internalize for Nigeria development , the recommendation will not only focus on producing zeolite with high crystallinity but also on controlling pore architecture , acidity /basicity, particle size , hierarchical porosity, stability , regeneration , cost and environmental impact . This among others were achieved in the area of zeolite research over the last two decade by myself.
The following recommendations are therefore suggested for continuous research and development in zeolite technology

1. Continuous use of locally available aluminosilicate resources : There is need to continuously investigate the use of inexpensive and locally available sources of silicon and aluminium for zeolite synthesis. Conventional synthesis often relies on relatively pure commercial reagents, which can increase production costs. In addition to kaolin

and metakaolin to make zeolites , the following local and readily materials such as rice husk ash, coal fly ash, volcanic ash, diatomaceous materials, agricultural ash, industrial aluminosilicate wastes natural zeolites, can be investigated as alternative raw materials. For countries such as Nigeria, the use of locally available kaolin and other aluminosilicate minerals is particularly promising. It can reduce dependence on imported chemicals while simultaneously converting mineral resources and industrial wastes into higher-value functional materials. However, raw materials should be properly characterized before synthesis. Important analyses include X-ray fluorescence (XRF), X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), thermogravimetric analysis (TGA), and particle-size analysis

2. Appropriate pre-treatment of starting Precursor : Raw materials should undergo appropriate pre-treatment to improve their reactivity. For kaolin, for example, calcination to form metakaolin is commonly used to disrupt the original crystalline structure and increase the availability of reactive Si and Al species.

3. The pre-treatment procedure should be optimized rather than simply adopting a temperature from literature. Excessive calcination may lead to undesirable phases or sintering, while insufficient calcination may leave poorly reactive kaolinite, Therefore, future research should establish the relationship between Pretreatment temperature, structural transformation, dissolution, nucleation, zeolite crystallization and final properties.

4. Optimize hydrothermal synthesis conditions :Hydrothermal synthesis remains one of the most important routes for producing many zeolite structures. The major variables that should be optimized include: Si/Al ratio, Na/Al or cation/Al ratio, water content, alkalinity, crystallization temperature, crystallization time, ageing time, template concentration, seed concentration and stirring conditions. Rather than changing one parameter at a time, researchers should increasingly use design of experiments (DOE), response surface methodology (RSM), factorial design, and statistical optimization. This can provide a more reliable understanding of interactions among synthesis variables.

5. Encourage template-free synthesis: Organic structure-directing agents can provide excellent control over zeolite structures, but they can also be expensive and may generate organic waste during calcination. Consequently, greater attention should be given to template-free or low-template synthesis wherever possible. The advantages include:

    1. reduced synthesis cost,
    2. reduced environmental burden,
    3. simpler processing,
    4. reduced calcination emissions, and
    5. improved prospects for large-scale production.

Where organic templates are unavoidable, researchers should investigate their recovery and reuse.

Develop seed-assisted synthesis : Zeolite seeds can accelerate nucleation and influence crystal morphology. Seed-assisted synthesis should therefore be investigated as a means of reducing crystallization time and improving phase selectivity. This approach may be particularly useful when synthesizing zeolites from low-cost natural or waste-derived materials whose impurities can otherwise make crystallization difficult.

ACKNOWLEDGMENTS

First and foremost, all praise, glory, and gratitude belong to Almighty Allah, the Lord of the Worlds, the Most Gracious, and the Most Merciful.

I am profoundly grateful to Allah for the gift of life, health, intellect, and the perseverance that have sustained me throughout my academic journey, culminating in this inaugural lecture. It is solely by His divine grace, guidance, and infinite mercy that I have been able to reach this significant milestone in my professorial career. Alhamdulillah (Praise be to God) for His countless blessings, seen and unseen, and for granting me the wisdom and strength to contribute to the advancement of knowledge.

My profound gratitude goes to the Vice Chancellor, Prof Faruk Adamu Kuta, The Deputy Vice Chancellor (academic), Engr. Prof Abdullahi Mohammed, The Deputy Vice Chancellor (administration), Prof Uno E. Uno, the Registrar, Mallam Danladi Mallam, the Bursar, The University Librarian, Prof Saka Katamba. My appreciation also goes to the following former Vice Chancellors Prof M Daniya (of blessed memory) who gave me appointment as assistant lecturer in 2001, Prof M.S Audu who appointed me as Head of Department of Chemical Engineering just when I returned from Manchester after my PhD programme, Prof Abdullahi

Bala who appointed me as pioneer director of Academic Publishing Centre of this university. Thank you all sirs .

I owe an immeasurable debt of gratitude to my beloved parents. Late Mall Sanni Usman Kovo and Hajia Hajara Sanni. I dedicate this milestone to them especially my mum who had to take the full responsibility of training me after losing my dad at age two (2). Her unconditional love, endless prayers, and early sacrifices laid the very foundation of my life and career. She taught me the value of knowledge, integrity, and perseverance. While words cannot fully capture the depth of my appreciation, I pray that this achievement brings her joy and stands as a testament to their lifelong dedication and vision for me. May Allah bless her abundantly and grant them a place in the highest echelons of Paradise.

My deepest appreciation also goes to my pillars of support at home—my wonderful wife, Mrs Aminat Abdulsalami and my beautiful children, Nabilah, Najihah, and Zarah. To my dear wife, thank you for your unwavering love, patience, and understanding, especially during the long hours and demanding phases of my research and academic duties; your companionship has been my anchor. To my beloved daughters, Nabilah, Najihah, and Zarah, you are my greatest joy and constant source of inspiration. Thank you for your smiles, your patience, and for bringing light to my life. This milestone belongs to all of us.

I must not fail to extend my gratitude to my siblings, family members and in-laws. They include my late elder brother Abdulazeez Sanni , my late elder sister Mrs Aisha Sanni, my immediate younger brother and his wife Mall and Mrs Mohammed Sanni, late Kabiru Yakubu, Imuheri Yakubu, Rahimat Yakubu, Hassan Yakubu and Hussiieni Yakubu. I must not forget my nieces and nephews, Fatimah Shehu and Ahmed Rufai and their family.

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As I conclude this Inaugural lecture, I am reminded that the ultimate purpose of scholarship is not the accumulation of knowledge for it own sake , but the application of knowledge to improve human life . The true legacy of a scholar is not measured by the number of publications produced or the title attained , but by the problems solved , the lives improved and the generation inspired . May our university, Federal University of Technology Minna continued to be centre of discovery, innovation and transformation where knowledge become a tool for national development and research become a pathway to a better future. Thank you all for your kind attention.

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A BRIEF PROFILE OF THE INAUGURAL LECTURER

Professor Kovo Abdulsalami Sanni was born on 21st November 1974 in Idoji , Okene local government area of Kogi state, Nigeria . He attended the Roman Catholic missionary (RCM South I) primary school and Etahi Community Secondary School both in Okene between 1981 and 1993 and secured admission through Jamb at first attempt to the Federal University of Technology Minna to study Chemical Engineering in 1994. He obtained his Bachelor of Engineering (B.Eng) in the year 2000 with second class upper division and Masters degree also from Federal University of Technology, Minna before securing Petroleum Technology Development Fund (PTDF) scholarship for PhD programme at the University of Manchester , United Kingdom and eventually graduating with a PhD in Chemical Engineering in April 2011. He was employed by the Federal University of Technology Minna immediately after his National Youth Service Corps (NYSC) programme in Kazaure , Jigawa as assistant lecturer in October 2001. He rose through the ranks steadily and became a full professor of Chemical Engineering in October 2018. Prof Kovo has held several administrative positions and served in different committees within the University. He was at different times a level adviser and was appointed as Head of Department of Chemical Engineering from October 2012 to November 2016 and currently the pioneer head of department of the newly created Department of Nuclear Engineering. He is presently the Director of Academic Publishing Centre of the University. He served in several committees in the University such as sport committee, library development committee, doctoral award committee where he has been the chairman for the last four years. He is presently the facilitator and member of the International Accreditation of the Federal University of Technology Minna by the Quality assurance agency of the United Kingdom.

Prof Kovo has won several academic awards both within and outside the University . He was awarded Petroleum Technology Development Fund (PTDF) scholarship to do his PhD at the University of Manchester , United Kingdom in 2007 and completed the PhD in 2011 . During his PhD programme at the University of Manchester , he was awarded the British Zeolite Association (BZA) travel grant to attend the International Zeolite Association conference in Sorrento Italy in 2010. He has also won the Pinnacle award by the Nigerian Society of Chemical Engineers (NSCHE) for the best paper presentation at her 2015 and 2024 NSCHE conference held in Warri, Delta state and Abuja respectively with cash reward of N100,000 in each case. Prof Kovo has also won several awards by the Federal University of technology Minna for publishing journal articles in Quartile 1(Q1) journal and for winning international grant and TETFUND National Research fund (NRF). In 2023 The Indian Institute of

Chemical Engineers presented the best technical paper award to him for presenting a paper on zeolite A synthesis for odour removal from poultry litters during her platinum jubilee conference in Kolkata India. In 2018 just after completing his four years tenure as head of chemical engineering department and doing his Sabbatical leave at Nigerian National Petroleum company (NNPC) in KRPC Kaduna , he was awarded the prestigious Rutherford Commonwealth Fellowship at the University of Bath , United Kingdom. He returned to Nigeria in 2019 and continued his teaching and research in the Department of Chemical Engineering and in 2022 , he was appointed to be the Director of Academic Publishing Centre where he was responsible for the publication of all TETFUND sponsored books . Till date the centre has published and produced over ten book titles totally twenty thousand (20,000) books for TETFund and several journals, including our university based journal NJTR. The Vice Chancellor also appointed him as the pioneer head of Nuclear Engineering Department in 2025 and he has lead the new department to a successful resource varication by the National University commission (NUC).

Prof Kovo has supervised and co-supervised 22 PhD students and presently supervising and co-supervising 8 PhD students. He has also supervised 31 masters students in Chemical Engineering and over 255 Undergraduates over the last two decades.

Outside the university , Prof Kovo was appointed as member of the Technical Advisory Group (TAG) of TETFUND in 2019 to 2022 and served as rapporteur of the academic publishing sub-committee. He was appointed also in 2019 to serve as the secretary to the editorial board of the Journal of Nigerian Society of Chemical Engineers (JNSCHE) and has continued in that role till date. He has served as external examiner for several universities for both Masters and PhD programme and has assessed several candidates for professorial promotion. He has also be in the panel by PTDF for both local and oversea scholarship programme as an examiner.

Prof Kovo is a member of several engineering profession associations such as Nigerian Society of Engineers (NSE) , Nigerian Society of Chemical Engineers (NSCHE), Institute of Chemical Engineers in the UK (ICHEME), Royal Society of Chemistry and fully licensed and registered with Council for the Regulation of Engineering in Nigeria (COREN).

Prof Kovo Abdulsalami is happily married with Children namely, Nabilah Abdulsalami, Najihah Abdulsalami and Zarah Abdulsalami.

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