UNIVERSITY OF ILORIN

THE ONE HUNDRED AND NINETY-EIGHTH (198TH) INAUGURAL LECTURE

“SUSTAINABLE NATIONAL DEVELOPMENT: MINERAL AND MATERIAL RESOURCES TO THE RESCUE”

BY

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THURSDAY, 20TH MAY, 2021

This 198thInaugural Lecture was delivered under the Chairmanship of:

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20th May, 2021

ISBN: 978-978-57720-8-1

Published by:

The Library and Publication Committee,
University of Ilorin, Ilorin, Nigeria

Printed by
Unilorin Press,
Ilorin, Nigeria

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My Lords, Spiritual and Temporal,
Members of my Nuclear and Extended families,
Distinguished Students of Industrial Chemistry and Chemistry Departments,
Gentlemen of the Print and Electronic Media,
Distinguished invited guests,
Greatest Unilorites!
Distinguished Ladies and Gentlemen.

Preamble

In the name of Allah, the most Beneficent, the most Merciful. Indeed, all praises and adoration are due to Allah, the Almighty and the Lord of the worlds. I sincerely thank Him for sparing my life from the day of my birth to date. I am immensely grateful to Allah for making it possible for me to stand before you all today, Thursday, 20th May, 2021 (9th Shawal, 1442 A.H.)

to deliver the 198th edition of the Inaugural Lecture Series of the University of Ilorin, *"The Better by Far"* University.

Today's inaugural lecture is unique as it is the ***first*** of its kind in the University from the Department of Industrial Chemistryof this University. I want to appreciate the great opportunity accorded me by the University of Ilorin administration under our dynamic and hardworking Vice-Chancellor, Professor Sulyman Age Abdulkareem, to present today's Inaugural Lecture.

Mr. Vice-Chancellor, sir, permit me to inform the respected audience present here today a brief history of my early life prior to joining the academics.

My Early Life History

Some over forty-five years ago, before my primary education at Alore Local School Management Board (L.S.M.B) in 1976, my late grandfather Mallam Aminu Alafara, the Magaji Alafara popularly called Baba-Agba, a farmer, whoused to assist in his farming activities saw traces of brilliancy in me and would often callme*Omot'olojuna!* This served as a strong motivation for me to brilliantly excel in my studies, which culminated in what is being celebrated today. Due to his foresight, he felt I should discontinue farming with him in the village at So'ro (Ilu iya-yọyin near Kishi, Oyo State) and Oloworu, Ipaiye District, Moro Local Government Area of Kwara State. He therefore decided to bring me back to my parents, who in-turn handed me over to my respected uncle, Late Alhaji Hanafi Lowo-ori (a renowned printer in Ilorin in the 1970s), who eventually nurtuned me. May Allah grant him Aljanat Firdaus.I must appreciate my paternal grandmother, Late HajiaUmmul-khaeri Aminu Alafara, popularly known as "IyaEleku", who also migrated with me to the family house at Alafara Compound, Alore, Ilorin inorder to guide and monitor her grandson who is standing before you today. May the Almighty Allah be pleased with them in Aljanat Firdaus (Amin).

Mr. Vice-Chancellor, sir, I began my primary education-*cum*-apprentice as a printer trainee with my uncle in 1976. It is a norm everyday to carry out house chores extensively, including recitation of the Al-qur'an (Tankara up to two Hizbu) and hawking *Ekuru* (a local delicacy made from beans) for my late grandmother daily after school, in addition to attending evening Islamiyat lesson at Ile Alhaji Alore, Ilorin. I did all of these as a routine from the primary school at Alore LSMB to my secondary school days at Mount Carmel College Ilorin, College of Education, Ilorin and as an undergraduate at the University of Ilorin. After my WASC examination at Mount Carmel College, my initial aim was to study medicine in the university, but for the delay in the release of my WAEC results in 1987, this development made me switch to Chemistry with the intention of working in the Petrochemical Industry. This probably was due to a *"Lambert"* Chemistry textbook I inherited from my cousin, Mr. Abdulganiyu Suleiman Alafara. In essence, distinguished audience, ladies and gentlemen; who could have imagined that the *boy* popularly called "Omo Iya Eleku"in those days could be standing before you today as a *Professor* to present an inaugural lecture? Indeed, immeasurable thanks are due to ALLAH for this unique opportunity, *Alhamdulillah robbil alamina*!

Introduction

Today's inaugural lecture, entitled **"Sustainable National Development: Mineral and Material Resources to the Rescue",** was actually inspired by the deep understanding of Analytical and Materials Chemistry derived from my mentors: Professors F.A. Adekola and M.A. Mesubi during my seconddegree research at the then Department of Chemistry, University of Ilorin. My first degree in Chemistry Education from the then Department of Curriculum Studies and Educational Technology, Faculty of Education, University of Ilorin, where its chemistry curriculum is laced with pedagogical skills, offered in the Bachelor of Science and Education degree programme, further strengthened me as a university teacher, and even as an Analytical and Materialchemist.

Mr. Vice-Chancellor, sir, Chemistry as a central science due to its relevance to all fields of human endeavors, draws on the ideas and techniques of Analytical Chemistry (Adekola, 2013). Thus, *Analytical Chemistry* is a branch of Chemistry that deals with qualitative analysis (finding what constituent(s) is/are in a sample) and quantitative analysis (determining how much amount of a given substance is in the sample). In the latter case, a history of the sample composition will generally have been known; or else the analyst (determiner of the unknown) would have performed a qualitative investigation. With today's instrumentation and availability of larger variety of chemical measurements, specificity or sufficient selectivity can often be achieved (Gary, 1986).

From the understanding of the above, determining the array or compositional evaluation of a substance for the design and synthesis for industrial value addition satisfying the established conditions is referred to as *Material Chemistry*. The design and synthesis or preparation of an industrial product involve the following analytical procedures: defining the problem; obtaining and pre- treating the sample; performing the required separations; making the appropriate measurements; and data presentation for necessary prediction of its purity level and product acceptability. Thus, the application of the aforementioned analytical procedures covering both the physical and chemical processes towards the transformation of raw materials into products for solving societal and human problems is termed *Industrial Chemistry*.

No doubt, the transformers of the defined raw materials to finished products of industrial value are human beings, including scientists–*cum*–analysts created by the Almighty Allah fromclay (a unique mineral): Qur'an 23 verse 12–Suratul Muhminuna: *Walaqodi 'alaqna l-insana fi zhulalatin min ti'ni* "And certainly did we create man from an extract of clay"; Qur'an 15 verse 26 –Suratul Hijr states *Walaqodialaqna l-insana* *min sol-solin min amahin masnu'nin*. "And we did certainly create man out of clay from an altered black mud". Also, in the wise words of Hindu scientists, it is believed that *"God sleeps in the minerals, awaken in plants, works in animals and thinks in man"* (Arthur, 2021). These citations lend credence to the contemporary understanding that any beneficiated product of different kinds is made up of materials, including minerals with specific properties.

Thus, *mineral* is a naturally occurring inorganic substance or material with a definite chemical composition and ordered internal structure formed as a result of geological processes (Nickel, 1995). Minerals with specific values on earth are God-created materials with distinct properties that make their uses to differ from each other. They are evenly distributed based on favourable geographic or environmental factors, which are in no way the same globally. Nigeria, for example, is naturally endowed with different mineral resources, and is one of the richest countries of the world as far as mineral resources are concerned. All the 36 States in the country, including the Federal Capital Territory (FCT), are richly endowed with diverse economic minerals of proven reserves that can adequately support the country's growth and development. Hence, minerals are resources or endowment from which wealth can be created when fully explored, exploited, processed and marketed (Rahaman, 2004).

Economic minerals of industrial value with high proven reserves in Nigeria include Sphalerite (ZnS), Galena (PbS), Chalcopyrite ($CuFeS_2$), Malachite ($Cu_2CO_3(OH)_2$), Ilmenite ($FeTiO_3$), Rutile (TiO_2), Limestone ($CaCO_3$), Talc ($Mg_3(Si_2O_5)_2(OH)_2$, Kaolin ($Al_2Si_2O_5(OH)_4$), Cassiterite (SnO_2), Gold occurring as Syvanite ($AuAg)Te_2$) and Calaverite ($AuTe_2$), Iron ore including Hematite (Fe_2O_3), Magnetite (Fe_3O_4), Siderite ($FeCO_3$), Pyrite (FeS_2) and Pyrolusite (MnO_2), among others. Proven reserves of these minerals are well documented with appropriate industrial values by the Federal Ministry of Solid

Minerals, Geological Survey Headquarters, Kaduna, Kaduna State (**Baba *et al.*, 2017a)**.

In general, there are over forty different types of minerals spread across the nation in diverse environments and the various mineral resources are categorized into strategic groups as iron and iron-alloy metals, non-ferrous industrial metals, precious metals and industrial minerals. Out of these minerals, seven strategic minerals including coal, bitumen, limestone, iron-ore, barite, gold and lead-zinc ores were identified by the Nigeria Ministry of Mines and Steel Development for aggressive reforms to encourage investment in the sector, as mining was a significant driver of Nigeria industrialization before the oil boom (**Baba *et al.*, 2017a**; Nigeria’s Mining and Metal Sector, 2016). For example, deposits of **lead and zinc ores** (used for automotive batteries, tyres, basic chemicals, galvanized sheets, pipes, etc.), which are usually found as mixtures have long been known in Nigeria but they have only been mined in the past on a very small scale. The Nigerian lead-zinc field extends for about 560km in a narrow belt from Ishiagu in Ebonyi State. An estimated 10 million tonnes of zinc-lead veins are spread over eight States with proven reserves of 5 million tonnes in three prospects in the East-Central areas of the country (**Baba** and Adekola**, 2010;** Min. and Ind. Nigeria, 2010).

The estimates of workable **iron-ore** deposits useful for steel and alloy production which stand in excess of 2.5 billion tonnes are found in Itakpe. However, Agbaja iron ore deposits (proven reserve of 1 billion metric tonnes) is the largest in Nigeria; though its high phosphorous (1.4-2.0%) and low silicon modulus ($SiO_2/Al_2O_3 = 0.89$) and fine- grained texture constitute a major problem for utilization in the blast furnace or direct reduction process. However, extensive high grade ore deposits are found in Itakpe and Ajabanoko hills between Okene and Lokoja in Kogi State (**Baba *et al.*, 2005a**; NMS Proceedings, 1999).

Copper, the 25th most abundant element in the earth crust, is found primarily in the form of **Chalcopyrite** ($CuFeS_2$) with many diverse applications in thermal and electrical conductors, ammunition, pipes, building materials and as important constituents of various metal alloys (Sahu *et al.,* 2007). Chalcopyrite deposit in the country is found in Nassarawa State; though a recent study has claimed to find a good deposit of it in Ebonyi State, precisely in Ishiagu (Edom, 2018). Plateau, Zamfara, Bauchi, Gombe, Abia and Kano States are other prominent areas where it could be found. In all, Nigeria has a copper ore deposit of over 10 million metric tons, making it one of the most coveted places in the world for international buyers to purchase the ore, considering its quantity, abundance and price (Edom, 2018).

Cassiterite (SnO_2), the principal source of tin, is used for corrosion prevention and components of some important alloys such as soft solder and bronze. In the early 1900s, Nigeria was well known in tin mining and was the second tin producing country in the world, after Russia. However, because of more attention was paid to crude oil, Nigeria is currently in the 13th position globally and ranked 3rd in Africa with an estimation of 570 metric tons after Congo DR and Rwanda (Tin Ore Mineral, 2020). Infact, by the end of World War II, the four largest tin producing countries (Bolivia, the Belgian-the Belgian Congo (Zaire), Nigeria and Malaysia) produced over 80 percent of the world’s tin. Like Nigeria, by 1986, for example, the portion of production from the four largest producers (Malaysia, Brazil, Soviet Union, Indonesia) declined to about 55 percent, while the price of tin rose from about $1,500 to $18,000 per metric ton. In response to tin shortages, during the World War II to date, the United States began stockpiling refined tin metal to ensure a strategic supply in the event of another war (Sutphin *et al.,* 1989).

Gold, an important metal found applicable in jewelry making, electronics and automotives, medicine and dentistry is widely distributed throughout the world, normally in very low concentration and generally in the native form as metal **(Baba *et al.,* 2011a).** The earth crust boasts of only 0.004 grams of gold per ton, but commercial concentrations of gold are found in some areas around the world. Gold is found native in association with other minerals like copper and silver in quartz veins, in the gravel of streams beds and with pyrites (Mesubi*et al.*, 1999). The history of gold exploration in Nigeria was not really known until 1913 when gold production was officially recorded and peaked in the period 1933-1943 when about 1-4 tons of gold were produced. Gold production declined during the Second World War period and never recovered as moves for production were abandoned by colonial companies. Generally, the gold in Nigeria is found in alluvial and elluvial placers and primary veins from several parts of supracrustal (schist) belt in the northwest and southwest axis **(Baba *et al.,* 2013a)**. These occurrences are found in Zamfara, Kaduna, Niger, Kogi and Osun States. The preliminary exploration and identification of deposits which is still ongoing has confirmed ten sites to be holding reserves of over 600,000 ounces of high-quality gold. The major deposits of primary gold have only been identified by extensive sub-surface at Iperindo (Segilola) in Osun State and also in Yauri in Kebbi State (Olade, 2019).

Among the mineral resources in Nigeria that can be found in commercial quantity and different grades with proven reserves that run into billions of tonnes is **Kaolin**. It is foundinabundance in Adamawa, Borno, Abia, Delta, Ekiti, Kaduna, Katsina, Kogi, Ogun, Ondo, Oyo and Plateau States. The kaolin mineral deposit reserve in the country is about 2 million metric tons. Kaolin is an important mineral with a wide array of applications in ceramics, paper, rubber, paint, cosmetics, blood clotting, adsorbent in waste-water treatments, among others (RMRDC, 2003).

Kwara State (surface area: 32,500sq. kilometers; Latitudes $11^0 2$ and $11^0 45$E and Longitude $2^0 45$ and $6^0 40$N with over 3 million people, created on the 27thof May 1967), is blessed with the following mineral resources: marble, granite, clay, kaolin, feldspar, gold, mica, quartzite, laterite, tantalite, rutile, ilmenite, etc. **(Baba, 2012a).** Table 1 summarises the solid minerals and their locations across the Local Government Areas of KwaraState.

Table 1: Economic Minerals of Kwara State and their Locations by Local Government Area **(Baba, 2012a; KWSEEDS, 2004)**

S/N	**Minerals**	**Location by L.G.A.**	**Deposit Potential**
1	Gold	Baruten, Patigi, Edu, Ifelodun, Kaiama, Moro	100,000 metric tons
2	Tantalite	Asa, Baruten, Edu, Ekiti, Ifelodun, Ilorin East	16,000 metric tons
3	Columbite	Isin, Edu	NA
4	Beryl	Asa, Ekiti	NA
5	Granite	Asa, Ifelodun, Moro, Ekiti, Irepodun	NA
6	Clays	Ilorin East, Asa	NA
7	Kaolin, Rutile	Patigi, Baruten, Edu, Ifelodun, Irepodun	NA
8	Marble	Ekiti, Patigi, Baruten	NA
9	Feldspar	Isin, Patigi, Baruten, Irepodun, Ifelodun	NA
10	Tin (Cassiterite)	Isin, Kaiama	NA
11	Barite	Isin	NA

NA = not available

The Nigerian economy is ranked the largest in Africa and the 30th in the World with a Gross Domestic Product (GDP) of approximately $400 billion U.S dollars in 2018 with five dominant sectors: Agriculture, Oil and Gas (petroleum), mining (solid minerals), manufacturing and services (Olade, 2019). Nigeria is a highly populated emerging market with rapid growing manufacturing and services sectors. Unfortunately, the economy is still very monolithic and dependent on the oil and gas sector which contributes about 40% of the nominal GDP, an over 90% of export earnings and 75% of gross revenues (Olade, 2019). As revenue from crude oil has declined sharply in recent years, Nigeria has struggled and is still struggling to find other revenue sources through energisingofthe other sectors of the economy. Therefore, exploration of the abundant mineral resources is a prominent source of diversifying the economic base of the country. Efforts are currently ongoing to tap the available mineral resources as the basis for industrial growth and national economic development. All hands must therefore be on deck to optimise the extraction and utilization of these abundant natural metals. Hence, there is need to develop or continuously develop simple, feasible and cost effective as well as eco-friendly routes for the extraction of metals for industrial value addition from the nation's economic mineral deposits and materials resources becomes most paramount.

Mr. Vice-Chancellor, sir, considering the vast deposit and availability of the aforementioned solid minerals resources in Kwara State and other States of the Federation, the potential of harnessing these abundant mineral deposits for exports and use in domestic industries for generation of foreign exchange and internal revenue, respectively has not been given the deserved attention. It is important to note that Nigerian minerals have high economic value and most companies in Nigeria and other parts of the world depend largely on the importation of refined metal products extracted from their metal ore bodies **(Baba, 2008; 2012a).** Consequently, the use of locally sourced minerals for our industries would enable the country to save a significant proportion of its hard-earned foreign currencies as there are increasing demands for industrial metal products. At present, the hydrometallurgical processing or improvement on the quality of Nigerian minerals has not been given serious consideration. However, the Federal Government of Nigeria is now addressing positively the solid mineral sector owing to economic recession, arising from a drop in the price of crude oil coupled with the desire to diversify Nigeria's economy. The data from today's inaugural lecture, if fully utilised, would no doubt open a new fulfilling chapter in Nigeria's economic growth and development.

Techniques of Minerals and Materials Processing: From Raw Ore to Metal Values

Mr. Vice-Chancellor, sir, till date, the extraction of metals from ores and/or concentrates is carried out either by pyrometallurgy or hydrometallurgy. Pyrometallurgy encompasses the traditional high temperature processes of roasting, smelting, converting and refining. It involves high energy consumption with emission of obnoxious gases such as SO_2 and is used to produce the bulk of non-ferrous metals from high grade ores. As historical records have shown, people have learned to construct furnaces and use fire to melt rocks and extract metals thousands of years ago. Compared to pyrometallurgy, hydrometallurgy is a relatively recent development that involves the use of water and aqueous solutions inplace of dry, high temperature methods for processing ores. Hydrometallurgy is essentially concerned with methods whereby metals, metal salts, or other metal compounds are produced by means of chemical reactions involving aqueous and organic solutions. It operates in the temperature range of $25\pm2^{o}C$ to $250^{o}C$. They can also operate at pressures of only a few kilopascals (vacuum) to as high as 5000kPa (Gupta and Mukherjee, 2003).

The minerals/ores, secondary materials and wastes, among others, are the major sources for recovery of nonferrous metals such as copper, nickel, cobalt and zinc, etc. Iron is invariably associated with most of these materials and comes into pregnant solution during *leaching,* which is an important unit operation involving the process of recovering a metal from an ore by a solvent (lixiviant) to produce a leachate (pregnant solution). In hydrometallurgical processes, the desired metals/metal values and other impurities or gangues are generally recovered from the leach liquors using leaching, precipitation, solvent extraction and electro-winning techniques.

During leaching, dissolution of metals with a suitable leachant, e.g. acids or alkalis is possible and the leach liquor thus obtained is quite acidic at times. The processing of leach solutions containing different concentrations of metal ions with high concentrations of acid/acids is very complex and separation of the metal ions using various techniques such as precipitation, adsorption, solvent extraction, ion-exchange, cementation, etc. is very cumbersome (Sarangi *et al.,* 2007). Thus, the fore-front of hydrometallurgical operation for industrial utilities is selective dissolution of valuable metal of interest from the ore or secondary sources using suitable leachant often governed by some factors such as choice of solvent (acidic/basic), leachant concentration, reaction temperature, agitation time and ore particle size **(**Alabi, 2019; **Baba*et al.,* 2019a**).

The intrinsic nature of chloride leach liquors resulting from the hydrometallurgical treatment of sulphide mineral ores is rather complex. For example, these solutions usually contain relatively high concentrations of basic metals, as well as small contents of other rare metals, frequently precious metals (Dutrizac*et al.,* 1993; Paiva and Abrantes, 2001). Therefore, for separation and/or purification of these valuable elements prior to appropriate beneficiation, the application of solvent extraction procedure is most extensively considered due to economic and safety reasons (Salgado *et al.,* 2003; **Baba** and Adekola**, 2011a; Baba *et al.,* 2009a**). Detailed characterization of the selected residues using some defined instrumentations are required at different leaching stages for assessing the dissolved and undissolved species to better understand the dissolution kinetic mechanisms and for predicting optimal metal extraction conditions. Some of the techniques that could be used in selected products analysis and characterization during leaching and solvent extraction processes include: X-ray Fluorescence (XRF) for elemental or chemical analysis; X-ray Diffraction (XRD) for material purity analysis; Atomic Absorption Spectrophotometry (AAS) or Inductively Coupled Plasma-Ordinary Emission Spectrophotometry (ICP-OES) for aqueous metal concentration analysis; Fourier Transform Infrared (FTIR) for functional group characterization, as well as Scanning Electron Microscopy (SEM) coupled with Energy Dispersive X-ray Spectroscopy (EDX) for the composition and surface morphology, among others. It is painful to note that many of our laboratories in Nigerian Universities today cannot host any serious research from beginning to completion, due to lack of aforementioned state-of-the-art equipment. For instance, many of our postgraduate student samples are normally packaged and sent to countries like UK, USA, Saudi Araba and South Africa for analysis. It is however, not strange to find lecturers contributing money from their meagre salary towards completion of student projcts for meeting defined needs.

Understanding the Reaction Kinetics in Metallurgical Operations

The bane of success in metallurgical process is inability to maximize the rate at which it occurs. Consequently, my research works have centered on metallurgical assessment for enhancing the quality and rate of production ofore dissolution process towards the establishment of extraction conditions for subsequent beneficiation activities. Habashi (1999) derived expressions for the rate of chemical reaction at the interface with the same magnitude as the rate of diffusion through the product layer, useful for some solid-gas reactions where porosity of the solid influences the rate of chemical reaction. The equation was derived for a spherical particle and neglects the change in value due to the reaction product(s), where it is expected to follow the *Shrinking Core Model* (SCM) in which the dissolution formed on the mineral surface and the dissolution continues by diffusion through this layer. The diameter of the particle remains constant but the area of the surface where the reaction takes place decreases with time proportional to the following kinetics steps: **(Fig. 1)**, the mass transfer of reagents and products through the solution; the diffusion of reagents and products through the product layer in the particle; between the surfaces of the particle and the reacting core; a chemical/and or a charge transfer reaction. Any of these steps can be rate limiting, determining the overall rate of dissolution.

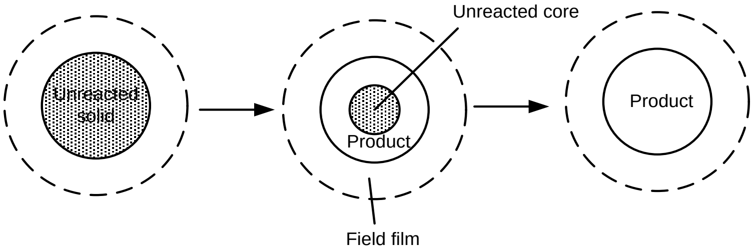


Fig. 1: The Shrinking Core Model (Habashi, 1999)

The dissolution rates of solid minerals and materials using SCM is based on the assumption that the material is a homogeneous spherical solid phase (Levenspiel, 1972; Aydogan *et al.*, 2005; **Baba *et al.*, 2020e**). It provides important information on the mechanism of dissolution of solid material in a given medium. Some of the commonly used SCMs for better understanding of the mineral dissolution route and predictionsare:

$$1-(1-\propto)^{1/3} = k_1 t$$

(1)

$$1-{}^{2}/_{3} \propto -(1-\propto)^{2/3} = k_2 t$$

(2)

$$[1-(1-\propto)^{1/3} + \frac{y}{6}](1-\propto)^{1/3} + 1 - 2(1-\propto)^{2/3} = k_3 t$$

(3)

where α is the fraction of the ore dissolved or reacted; t is reaction contact time (min.) and k_1, k_2, k_3 are the respective reaction rate constants. The Eq. (1) is applicable to a chemical reaction-controlled process at the interface; the Eq. (2) is a diffusion-controlled process through the product layer and the Eq. (3) is a mixed controlled process which is a combination of surface reaction and diffusion if $y \approx 1$. The dissolution curves will be further used to fit into any of the aforementioned equations at various contact times at different leachant concentrations, reaction temperatures or particle size to estimate the reaction order, activation energy and other constants from the appropriate Arrhenius relations for validating the reaction mechanism, followed by solvent extraction and beneficiation of the pure solution for industrial value additions.

My Contributions to Hydrometallurgical Research for Economic Development

From 14th August, 2001 to 25th July, 2008, I successfully defended my M.Sc. and Ph.D. degree dissertations entitled *"Extraction of Zinc from Sphalerite mineral deposit"* and *"Recovery of Zinc and Lead from Sphalerite, Galena and Waste Materials by Hydrometallurgical Treatments"* respectively, at the Department of Chemistry of this great citadel of learning. Besides, my other research experiences include one-year Postdoctoral research on *"Leaching of some Nigerian minerals"* at the CSIR-Institute of Minerals and Materials Technology, Bhubaneswar, India and deep knowledge gained from wide arrays of active participations at many research workshops, seminars, exhibitions and conferences in Nigeria and different parts of the globe. This background has equipped me to be prolific as an authority and a renowned scholar in hydrometallurgical research in minerals and materials processing. With *H-index* and *i10-index* of 20 and 35, respectively and more than 1100 citations and still counting on daily basis, my research outputs have been widely used by many researchers across the globe in solving various societal concerns. In June 2020, I was *ranked among thetop ten credible scientists of the 500 authors* of the scholarly research outputs of the University of Ilorin published by SciVal (https://www.scival.com/overview/authors?uri=Institution/110016); and *rated as 2nd best scientist*that made Industrial Chemistry (my department) to be at the top of Unilorin research outputs between 2016 and now (UNILORIN BULLETIN, June 8, 2020: p.1-3; THE NATION: June 11, 2020; https://thenationonlineng.net/industrial-chemistry-tops-unilorin-research-output/). These numerous recognitions from different local, national and international sources are due to undiluted, rigorous training and guidance received from my main mentor, the highly resourceful Professor Folahan Amoo Adekola, FRSC, FCSN, FIPAN, FMSN, the immediate past Dean, Faculty of Physical Sciences, University of Ilorin. Thank you very much, sir.

Mr. Vice-Chancellor, sir, for about two decades now, my research efforts have concentrated on developing feasible, low-cost, low energy and environmentally friendly techniques that have been adding value to many Nigerian sourced mineral and material resources by aqueous metallurgical methods for defined industrial applications. The applicability of my established and developed processes has also been extended to the treatment of secondary material resources for improved industrial utilizations. These are geared towards providing an alternative source of income for the country's economic growth and development; and as a possible alternative to the declining national foreign earnings from petroleum exploration, among others. Thus, my exciting and successful break-through over the years in hydrometallurgical research focusing on leaching, solvent extraction, precipitation, adsorption and beneficiation of minerals and materials has yielded the following results:

A. MINERAL RESOURCES:

(i) Zinc ores

Conventional zinc recovery process from zinc ores like Sphalerite (ZnS) involves roasting the ore or concentrate to zinc oxide or sulphate, leaching the resultant calcine with dilute sulphuric acid and followed by electrode deposition of zinc from purified solution (roasting-leaching-electrowining). This is subsequently being used as a metallic coating to improve corrosion resistance of different types of steels (Chen and Dutrizac, 2004). Thus, the need to utilize small scale and complex deposits and environmental restrictions imposed on sulphide smelters stimulated on the development of alternative methods especially hydrometallurgical routes that would avoid the production of SO_2 as a pollutant (Aydogan*et al.,* 2005). With increasing demands of zinc and purified zinc compounds in Nigeria and in urgent search for indigenous industrial zinc metal and its varieties for use in the galvanizing and basic chemical industries, **Baba** and Adekola **(2010)** successfully processed by leaching with hydrochloric acid solution, the Abakaliki (Enyigba, Ebonyi State) sphalerite orecontaining 44.71 wt.% Zn, 32.3wt.% S, 7.39wt.% Fe, 4.21wt.% Sn and 1.62wt.% Ag. The ore mineralogical purity by XRD lends support to the elemental composition by XRF where its two principal and a minor peak were observed at 3.12, 1.94 and 1.63Ǻ, respectively, with the presence of some associated minerals such as quartz (α-SiO_2), pyrite (FeS_2), ilmenite ($FeTiO_3$), cassiterite (SnO_2), hausmanite (Mn_3O_4) and baddeleyite (ZrO_2). The microscopic examination of these associated minerals showed the presence of bundles and aggregation of thin layer prismatic and spindle shaped plates. These are pale yellow in plane polarized and cross nicol. The scattered, opaque granular crystal feathery pattern **(Fig. 2)** indicates the presence of pyrite or some particles of galena within sphalerite and these appeared to be void or fracture fillings **(Baba** and Adekola, **2010).**

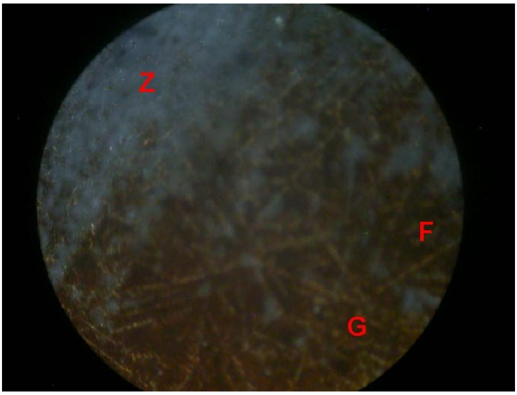


Fig. 2: Optical micrographs of Abakaliki sphalerite (×40) Z = ZnS; F = FeS_2; G = Geothite

As the kinetics of dissolution of sulphide minerals in chloride media has received considerable attention recently due to the availability of materials for construction with improved resistance to chloride attack, faster dissolution rate and the potential application of its electrolytes in the treatment of complex sulphides (Zuo-mei *et al.,* 1984) among others, the enrichment of Abakaliki sphalerite ore had been successfully experimented by **Baba** and Adekola **(2010)** in hydrochloric acid media and found to be consistent with the following stoichiometry:

$$ZnS_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_2S_{(g)}\uparrow \qquad (4)$$

At optimal leaching conditions, 91.8% dissolution efficiency was achieved within 120 minutes. The results from the dissolution suggested that the shrinking core model for spherical particles is applicable and the developed leaching process follows the surface chemical reaction consistent with the expression:

$$1-(1-\alpha)^{\frac{1}{3}} = \left[k_0[H^+]^{0.24}\left(e\tfrac{S}{L}\right)^{-0.21} r_0^{-0.63} exp.\tfrac{-39090}{RT}\right]t \qquad (5)$$

k_0 is the reaction constant, determined experimentally.

One of the economic break-throughs of this research is the conversion of the obnoxious H_2S released as a by-product from equation (4) to elemental sulphur. Sulphur is an important non-metallic product that has wide applications in pharmaceutical and other allied industries. To this end, the hydrogen sulphide gas in equation (4) was successfully converted to elemental sulphur via collection over acidic dichromate solution according to Eq. (6):

$$2CrO_4^{2-} + 3H_2S + 10H^+ \rightarrow 2Cr^{3+} + 3S^0 + 8H_2O \qquad (6)$$

The residual bright yellow product containing sulphur was air-dried and later oven-dried at a temperature of 60 °C for 12 hours. It has a melting point of 113.8 °C with a yield of 99.1% purity and the product is ready for use in defined pharmaceutical applications **(Baba** and Adekola, **2010; Baba *et al.,* 2012a).**

Mr. Vice-Chancellor, sir, during leaching, the pregnant solution obtained often contains different concentrations of metal ions (the desired and other gangues). **Baba** and Adekola **(2011a)** further treated the Abakaliki sphalerite leach liquor using combinations of solvent extraction, precipitation and cementation techniques in the purification and recovery of 95.48% zinc from loaded organic phase by bis(2,4,4-trimethylpentyl) phosphinic acid (CYANEX® 272) in kerosene extractant. The use of organophosphrous extractant such as Cyanex®272 in solvent extraction of metals has been steadily increasing because of their excellent selective nature in forming complexes under specific conditions and which has brought about a vast change in the separation technology (Kunnungo and Mohapatra, 1995; Daoud *et al.,* 2006). With Cyanex®272 extractant at optimal conditions, the stripped solution containing pure zinc was successfully precipitated as zinc oxide (ZnO: 14-7754). The zinc oxide (97.3% purity) with melting point of 1950±2 °C could be used as an important coating material for pigments, mild skin irritations, abrasions and galvanization **(Baba *et al.,* 2012a).** I have showcased this important product at the 2012 Exhibitions of the Nigerian Universities Research and Development Fair (NURESDEF, 2012) held at Federal University of Technology, Minna, Nigeria between 8th – 12th October 2012 for industrial utilization and awareness. In general, the flow chart summarizing the relevant analytical operations in the extraction-separation of zinc from other impurities in the hydrochloric acid leached sphalerite liquor is depicted in Fig. 3.

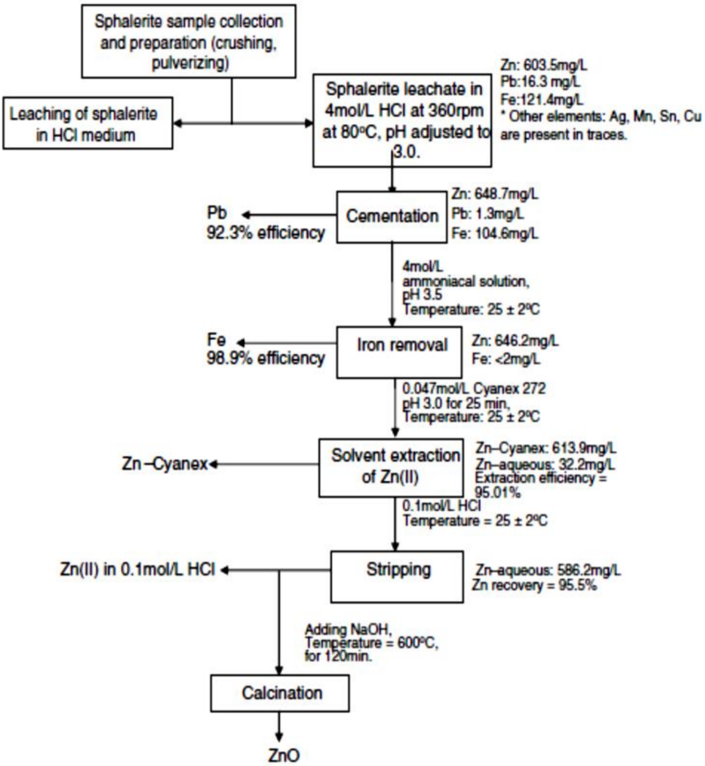


Fig. 3: Hydrometallurgical flow diagram for the recovery of Zn(II) extraction and production of pure ZnO from Abakaliki (Nigeria) Sphalerite ore **(Baba*et al.*, 2011a).**

This is ***a first in-depth study*** on hydrometallurgical recovery of zinc from a Nigerian sphalerite origin using Cyanex 272 extractant, an extract from my ***Ph.D. thesis (2008, 675 pages)*** that was ranked ***first*** among other dissertations at the Department of Chemistry and awarded the ***best***in the area of Physical Sciences, University of Ilorin in 2009 and subsequently submitted for NUC consideration.

Prior to the benevolence and kind supply of the Cyanex 272 extractant used in the aforementioned research by Dr. Oliver

Rouher and Mrs. Christine Salomon of Cytec Industries, Rungis Cedex, France, **Baba *et al.* (2004**) have initially developed a method of zinc extraction using Triphenyl phosphite (TPP) from a Nigerian sphalerite in hydrochloric acid media to obtain the following equation:

$$ZnCl_4^{2-} + (TPP)_{org} \rightleftarrows (\mathrm{ZnTPP})_{org}^{2+} + 4Cl^- \qquad (7)$$

Although, liquid-liquid extraction is not commonly used in zinc hydrometallurgy, the only metallurgical company that uses this technique for zinc processing is Bilbaro Metallurgical Company in Spain (Samara, 1968). The process known as *Espandes process* is based on extraction of zinc in chloride media from a typical leach solution to cover the following stages: Extraction of zinc chloride ($ZnCl_4^{2-}$) by a secondary amine (R_2NH_2Cl), De-extraction of zinc chloride into aqueous medium, Extraction of only zinc by di(2-ethylhexyl) phosphoric acid (D2EHPA) and De-extraction of only Zn(II) by sulphuric acid (Flett, 1978). Following these routes and with appropriate modifications, 66.07% of zinc was extracted into the organic phase within 60 minutes at ambient temperature (27±2 °C) yielding 91.2% Zn(II) successfully stripped and recovered from the organic loaded phase and the mechanism of extraction developed in Eq. (7) appeared to be chelate formation and ion exchange **(Baba *et al.*, 2004).**

Apart from the sphalerite treatment by chemical method, we have also explored the bio-hydrometallurgical approach in the enrichment of sphalerite ore using mixed culture of *acidophilic* bacteria. The use of micro-organism such as *Thiobacillus ferrooxidans* in metal solubilization process has attracted much attention in recent years. The leaching of metals using micro-organisms is very attractive because of its low cost and relatively few pollution problems compared with conventional hydrometallurgical processes (Bang *et al.,* 1995; **Baba *et al.,* 2007**, **2011**). In this context, **Baba** and Adekola in conjunction with some vibrant microbiologists from the University of Ilorin and CSIR-IMMT, Bhubaneswar, India, have successfully developed, as a substitute to conventional but scarce

Thiobacillus ferrooxidans bacteria, the mixed culture of *acidophilic* bacteria obtained from rust scrap at Motor Dumpsite in Ipata-oloje, Ilorin West L.G.A of Kwara State, Nigeria, cultured in 9K medium (Lennox and Blaha, 1991). It was observed that the highest rate of the bacterial cells growth occurs at day 2 which exhibits as high as 475 and 328 cfu/mL for sphalerite and galena respectively; then a decline was observed from day 3. This observation indicates the probability of nutrient depletion due to competition for the survival of organisms for growth factors, thereby avoiding positive oxidation. The photomicrographs of the isolated mixed culture as observed on a petri plate and under field emission scanning electron microscope (FESEM, Zeiss Supra 55) gave the following morphological characterization as summarized in Table 2:

Table 2: Morphological Characterization of isolated bacteria **(Baba *et al.*, 2011b)**

Gram staining	Cell size (μm)	pH	Temp., °C	Spore
Negative	(0.3-0.5) x (1.0-1.7)	1.5 – 2.0	28 – 35	Non-spore forming

The isolated bacteria in Table 2 was successfully employed in the bio-oxidation of Zn(II) and Pb(II) from Nigerian sphalerite and galena ores at pH 2.1 and 2.7 to achieve recovery efficiencies of 92.0% Zn(II) and 89.0% Pb(II) respectively within 5 days **(Baba *et al.*, 2011b).** Thus, the rapid consumption of primary zinc resources and ever-increasing demand for zinc metal continue to stimulate worldwide investigations on alternative routes for recovering zinc metal by bioleaching method (Xu *et al.*, 2014).

(ii) Lead ores:

Galena (PbS), the chief ore of lead and one of the most widely distributed metallic sulphides, occurs in both igneous and sedimentary rocks. It is commonly associated with other sulphide minerals such as sphalerite (ZnS), pyrite (FeS_2), chalcopyrite ($CuFeS_2$) and arsenopyrite (CuFeAsS) **(Baba *et al.*, 2012a).** In Nigeria, large deposits of proven reserves exist in Ameka, Ameri and Ishiagu near Abakaliki (Ebonyi State); at Benue and Zurak to name only a few. It is estimated that there are 30 lodes within an aggregate length of about 6000metre, as the Nigerian Mining Corporation has indicated proven reserves of up to 711,237 tonnes in Abakaliki axis for example (Ukpong and Olade, 1979; Rahaman, 2004).

Mr. Vice-Chancellor, sir, due to the increased demands for lead in automobile battery, basic chemicals and other allied industries in Nigeria and other developing countries of the world, the need to continuously develop simple and practicable routes for the recovery of the valuable metal from Nigerian galena (one of the richest in the world) becomes paramount. It is important to note that some of the pure lead end-users in Nigeria including Sunshine batteries Ikot-Ekpene (Akwa-Ibom State), Ibeto Group (Nnewi, Anambra State) and West African batteries (Ibadan, Oyo State) are no longer in operation presently due to lack of genuine raw material resources, poor funding and general maintenance challenges, among others. For sustaining some and the likes of the aforementioned industries to have reliable raw materials to be in continuous operation, the galena ore sourced from Abakaliki, Enyigba origin in Ebonyi has been quantitatively studied in hydrochloric acid solution **(Baba** and Adekola, **2012).** The insufficient kinetics studies to explain the complete dissolution of galena in HCl media in literature warrants our trial, among others. Most of the available dissolution studies did not address some basic important kinetic parameters such as reaction order, activation energy, Arrhenius factor and reaction constant and these often make the proposition of the dissolution mechanism difficult. In view of this, the galena ore whose physico-chemical analysis gave: mean bulk density = $3.88 g/cm^3 \pm 0.01$, porosity = 13.78%±0.01, pH = 8.3, point of zero charge = 7.9, moisture content = 3.96%±0.013 and loss of mass on ignition = 2.33%±0.011; assayed 58.66 wt.% Pb, 13.31wt.% S, 2.65 wt.% Sn, 0.16 wt.% Zn, 0.5 wt.% Fe and

0.087 wt.% Mn was successfully characterized with detailed provision of kinetic data in HCl medium **(Baba** and Adekola,**2012)** and other media **(Baba *et al.,* 2011c).** These were aimed at establishing the extraction parameters for the recovery of lead from the galena leachate. The results of leaching investigations showed that the galena dissolution in HCl solution increases with increasing HCl concentration, temperature, decreasing particle diameter and solid/liquid ratio at a stirring rate of 450rpm. At optimal conditions, 95% of the galena was reacted as the dissolution data fitted the shrinking core model for the diffusion-controlled mechanism with surface chemical reaction as the rate controlling step. It was also observed that at high HCl concentration, Pb^{2+} exists mainly as stable chloride complexes and when the dissolution is far from equilibrium without reversed reaction and secondary minerals, the rate equation for constant HCl concentration could be expressed as:

$$R_{diss} = dC_{Pb/dt}(S/V)k[H^+]^n \quad (8)$$

Hence from Eq. (8), the rate of dissolution of the studied Abakaliki galena ore was found to be $1.37 \pm 0.024 \times 10^{-4}$ $molL^{-1}s^{-1}$ **(Baba** and Adekola,**2012).**

In separate studies, the use of hydrochloric acid with oxidative reagents such as ferric chloride has been proven to be a possible means of extracting lead (Fuerstenau *et al.,* 1986), or with hydrogen peroxide has been found to be environmentally safe for use as a leachant (Aydogan *et al.,* 2007). Complexation takes place at the surface of hydrous galena sulphides and the adsorption of H^+ ions onto the surface of sulphur atoms in the aqueous phase is favourable with oxidizing reagents. Interestingly, with 0.3M Fe(III) in 8.06 M HCl solution, 97wt.% of the galena ore was dissolved within 120 minutes at 80 °C **(Baba** and Adekola, **2011c).** This value was slightly higher compared to when only 8.06 M HCl was used as the leachant under the same conditions for which 94.8wt.% has been previously reported **(Baba** and Adekola, **2010).** We affirmed that higher dissolution obtained in the presence of 0.3 M $FeCl_3$ oxidant could be attributed to the synergistic action of Fe(III) and HCl. The results follow a similar trend with 8.06 M H_2O_2 oxidant where we have recorded 98.1wt.% galena ore dissolution efficiency at 80 °C after exactly 120 minutes reaction. The post leaching residue analyzed by an X-ray diffractometer revealed sulphur as a major component for the two binary solutions proceeded by surface diffusion and surface chemical reaction mechanism using ferric chloride and hydrogen peroxide solutions, respectively **(Baba** and Adekola, **2011c).**

Mr. Vice-Chancellor, Sir, for more than two decades, for example, the recovery of valuable metals including lead from aqueous chloride has attracted much attention. This is due to the high efficiency of the chloride leaching process which is now recognized as a logical choice for treating complex ore concentrate (Cote and Jakubiak, 1996). In view of the intrinsic nature of chloride-leach liquors that are rather complex, **Baba** and Adekola **(2013)** have successfully used solvent extraction techniques for the purification, separation and concentration of metals from aqueous chloride media by initially considering the following organophosphorus extractants as summarized in Table 3.

Table 3: Preliminary results of the extraction yield of some extracting agents contacted with equimolar mixtures of 100 mg Pb(II) and Zn(II) in 0.1 mol/L HCl for 1 h at pH 2.5.

Extractant concentration	**%Extracted into organic phase:**	
	Pb (II)	**Zn (II)**
0.5 mol/L Cyanex®272 in kerosene	10.2	82.4
0.5 mol/L TBP in 100% MIBK	89.4	5.04
0.5 mol/L TBP in kerosene	47.9	33.5

It is evident from Table 3 that as Cyanex 272 is a good candidate for zinc extraction, Tributylphosphate (TBP) is very effective for the extraction of lead and it was used in the treatment of Abakaliki sourced galena leach liquor containing 1705.1 mg/L Pb, 98.7 mg/L Zn and 130.3 mg/L total Fe in hydrochloric acid media. In the separation of impurities, total iron was initially precipitated from the leachate by 1.0 mol/L ammoniacal solution at pH 3.5 and this process recorded 96±0.2% efficiency. The stripping of about 94.5±0.2% Pb(II) by 0.1 mol/L HCl solution was achieved from the Pb-TBP complex. In addition, separation of Zn(II) from galena leachate was done by 0.032 mol/L Cyanex®272 at pH 3.0 to achieve 94.6 ± 0.2% efficiency as 96.5 ± 0.2% of Zn(II) was stripped from Zn-Cyanex organic phase by 0.1 mol/L HCl solution. Finally, a simple hydrometallurgical scheme summarizing all analytical procedures employed with thermodynamic feasibility in the separation process for the Nigerian galena mineral was developed **(Baba** and Adekola, **2013).**

Till date, hydrometallurgical treatments have received significant attention for the treatment of lead mineral because of the difficulties encountered with conventional pyrometallurgical methods. As leaching is an important unit operation in hydrometallurgical process, the selection of an appropriate leaching reagent is beneficial to this process. For example, hydrochloric acid leachant often produces a lead chloride that is only soluble in hot water (Li *et al.,* 2016), while sulphuric acid forms a lead sulphate precipitate that could often be difficult to be separated from the resulted leaching solution. Consequently, we have recently developed a new approach to solving the aforementioned concerns using sulfamic acid (H_3NSO_3) **(Baba *et al.,* 2019a).** This acid otherwise called solid acid is an important fine chemical product that is widely applied as an acid cleaning agent, as well as the main precursor to sweet-tasting compounds. However, it is preferable to hydrochloric acid in household due to its intrinsic safety and its ease of complete deprotonation following this equation:

$$2H_3NSO_{3(aq)} \rightarrow 2H^+_{(aq)} + 2NH_2SO^-_{3(aq)} \qquad (9)$$

Thus, the potential of Gboko (Benue State) sourced galena ore assayed 72.82 wt% Pb, 19.95 wt.%S, 3.07 wt.% Au and 2.77 wt.% As as major elements were quantitatively investigated by **Baba *et al.*(2019b).** The results of our investigations showed that the ore dissolution in sulfamic acid solution increases with increasing acid concentration, reaction temperature, stirring speed and decreasing particle diameter. At optimal conditions (0.75 mol/L H_3NSO_3, -70+90 µm, 320 rpm, 70 °C), 68.2% of the initial 10 g/L ore was reacted within 120 minutes. The leach liquor, analyzed by atomic absorption spectrophotometry was found to contain 2861 mg/L Pb^{2+}, 270 mg/L Fe^{3+}, and 185 mg/L Zn^{2+} as major species. The estimated activation energy, Ea of 28.35 kJ/mol with reaction order of 0.758 supported the proposed diffusion-controlled mechanism for the dissolution process, consistent with the following stoichiometry:

$$PbS_{(s)} + 2H_3NSO_{3(aq)} \rightarrow Pb^{2+}_{(aq)} + 2NH_2SO_3^- + H_2S_{(s)} \qquad (10)$$

The unleached products analyzed by XRD consist of 31.8% anatase (TiO_2) and coesite (SiO_2) impurities. However, EDX spectrum shows the presence of molybdenum which could be processed for possible use as a catalyst in petroleum refined industries.

(iii) Gold ore

Gold, an element that occurs on the earth surface at low concentration, is one of the most important metals due to its wide applications in industry and other forms of economic activities (Bashammakh and El-Shahawi, 2011). The beauty and rarity of gold has led to its use in jewelry and in coinage and as a standard for monetary systems throughout the world (Melwamki and Mask, 2002). Over the past years, gold recovery from ore has been central in a wide range of studies as a result of its high demands and values. These circumstances have made the treatment of low-grade raw materials or refractory materials an interesting area of study. The most frequent and profitable method for the recovery of gold is the Cyanidation process, but on many occasions, the technique has many draw-backs in terms of environmentally related problems (Ojeda *et al.,* 2009). Therefore, **Baba *et al.* (2015a)** resolved the environmental challenges in the treatment of gold ore concentrate leach liquor from Borgu Local Government Area of Niger State by solvent extraction with tributylphosphate in ammoniacal thiosulphate solution. The solvent extraction technique affirmed the feasibility of total gold extraction from the gold ore concentrate. At optimal conditions (Temperature = 25±2 °C, [TBP] = 1.0 mol/L, pH = 8.2), extraction reached 77.9% within 30 minutes and 98.3% of total gold from the loaded organic phase was stripped with 0.1 mol/L thiosulphate solution and determined spectrophotometrically as its complex with 4-(2-pyridyylazo) resorcinol (PAR) at 498.0 nm. Finally, by McCabe-Thiele plot, it requires four stages of counter-current extraction for total gold extraction to take place.

We have earlier reported the results of ammoniacal thiosulphate leaching of a low-grade ore concentrate from Bargu, Niger State, as an alternative approach to conventional and toxic cyanide process. The results obtained showed that 88.4% of the gold ore was dissolved at a temperature of 80 °C within 120 minutes using 0.06 mm particle size. The dissolution data was analyzed and found to follow the diffusion control mechanism with activation energy of 37.79 kJ/mol, which support the established mechanism **(Baba *et al.*, 2013a)**.

Mr. Vice-Chancellor, sir, with the gradual depletion of rich ore deposits, it is becoming increasingly difficult in many situations to apply the conventional pyrometallurgical methods for metal extraction, since hydrometallurgical processes are only best suited for lean and complex gold ores. If there is too much gangue in an ore then its processing at high temperature causes waste of energy as well as disposal of slag coupled with evolution of toxic gaseous pollutants to the environment (Gosh and Ray, 1991). Consequently, solvent extraction used in gold recovery offers high capacity, better selectivity and faster kinetics. With the increased popularity of heap leaching of lower grade gold ores, there is hope for the development of solvents to treat these relatively clean, classified gold ore liquors (Zhao *et al.*, 1999). Therefore, **Baba *et al.* (2011a)** carried out detailed dissolution kinetics and solvent extraction of total gold from Ijero-Ekiti gold ore deposit by hydrochloric acid leaching and solvent extraction with TBP in kerosene. At optimal leaching conditions, 81.27% of the ore concentrate was dissolved within 120 minutes by 2 mol/L HCl solution at 80 °C. The analysis of the residual product (~18.73%) by XRD indicates the presence of α-quartz (SiO_2). Solvent extraction studies revealed the extraction efficiency of 85.28% by TBP. Total gold was determined by analyzing its orange-red complex with PAR spectrophotometrically at 450 nm from the ore leach liquor at optimal conditions; and the calculated enthalpy and entropy changes of 3.56 kJ/mol and -21.83 kJ/mol/K confirmed the thermodynamic feasibility of the process at 27±2 °C.

(iv) Clay Minerals

Clay minerals such as talc and kaolin are among the most important industrial minerals with diverse industrial applications depending on the physical and morphological properties of the mineral.

(a) Talc ores

Layer silicates minerals such as talc ore are of prime economic interest due to their extensive uses in industries (Nkoumbou *et al.,* 2008). Talc main industrial applications are in paper paints, cosmetics, plastics, rubbers, refractory materials, pesticides, pharmaceuticals, agro-industries and ceramics, depending on its physical properties, chemistry and mineralogy (Petit *et al.,* 2004). The major gangue minerals in talc ore include carbonates, dolomite, magnesite, serpentine, chlorite and calcite. These impurities apparently contribute to the production of undesirable characteristics, which are responsible for why talc ore do not meet some industrial uses (Castro, 1996). For example, the presence of iron impurities both in the surface of talc, and in the structure of clinochlore and accessory minerals reduces talc refractory properties and diminishes its whiteness which gives it an undesirable colour and thus limits its industrial applications (Orosco *et al.,* 2011). Interestingly, several workers have proposed various purification techniques such as floatation, wet attrition and magnetic separation in the treatment of talc ore to obtain talc suitable for industrial applications (Yehia and Al-Wakeel, 2000; Perez-Maqueda *et al.,* 2005). However, these techniques have fallen short of the aim of producing purified talc in meeting various industrial uses due to the presence of considerable amount of accessory minerals, high cost, environmental consideration and even availability of such facilities in developing countries (Castillo *et al.,* 2011; Oroscoe*t al.,* 2011; **Baba *et al.,* 2021a, Baba *et al.,* 2021c**).

Mr. Vice Chancellor, sir, we have, however, developed acid leaching technique in the selective dissolution of gangue minerals from Isanlu sourced (Kogi State) talc ore to obtain purified talc product suitable for defined industrial uses. The influences of acid concentration, temperature andparticle size on the ore leaching, as well as its surface properties were examined. The results of our investigation showed that the dissolution rates were found to be influenced by hydrogen ion concentration, temperature and particle size. At a set of experimental condition, the ore dissolution reached 62.1% by 2 mol/L HCl solution within 120 minutes at 75 °C. The extent of iron removal as evidenced by Energy Dispersive Spectra data showed a decrease in iron content from 3.75% to 0.36% and accounts for 90.4% process efficiency **(Baba *et al.,* 2015b).** This work is one of the most outstanding researches in Applied Clay Mineral Science and Applications till date.

(b) Kaolin ores

Mr. Vice-Chancellor, sir, you would recall that the report of the Vision 2020 National Technical Working Group on Minerals and Metals Development in 2016 showed that Nigerian Kaolin Annual National Demand is 250,000 tonnes while the present annual production is 5,000 tonnes. To bridge the gap, **Baba *et al.* (2017b)** successfully developed a feasible approach to prepare a high gradealumina of industrial value. This research breakthrough at the Hydrometallurgy & Mineral Processing Unit, Department of Industrial Chemistry of this great University has combined acid leaching, calcination and precipitation techniques to achieving 96.7% process efficiency. The produced alumina with melting point of 2925±2 °C as characterized is expected to find applications as filler in plastic and ceramic industries, coagulant in water treatment and for metallurgical uses in aluminium plant. I am happy to inform this audience that this product was show-cased at the Exhibition of the Science, Technology and Innovation "EXPO 2017" held at Eagle Square, Abuja, and was one of the research products that placed the University of Ilorin in the 3rd position overall.

In the search for a cheap leachant to remove iron impurities from kaolin ore body for improved industrial utilities, we have developed a low-cost purification process using oxalic acid for treating Egbeda (Osun State) kaolin deposit. Our results revealed that oxalic acid was effective in the treatment and removal of iron impurities from the ore. The developed approach indicated no iron impurities from initial iron oxide in the raw ore, put at 3.09 wt% as evidenced from EDXRF analysis. The product at optimal conditions as characterized has improved the ore whiteness properties and thus recommended for use in paper-filling, paper coating, paint and plastic filler applications **(Baba *et al.*, 2015c).**

Mr. Vice-Chancellor, sir, the increasing demands for pure aluminium and aluminium oxide of industrial grade for use in pigments, catalysis, water purification, aluminium production and metallurgical applications prompted us to develop a feasible, low-cost and eco-friendly technique for processing a Nigerian Biotite-rich kaolinite ore sourced from Nane Didan Bungudu area of Zamfara State to industrial alumina by hydrometallurgical process **(Baba *et al.*, 2019b, c).** Here, three basic units of operations: leaching, solvent extraction and precipitation methods were employed. Thus, at the optimal conditions, the chemical analysis for the prepared alumina product (Al_2O_3 : 27-4355) with a melting point and density of 2055 °C and 3.97 g/cm^3, respectively, is comparable to industrial standard with melting point and density of 2072 °C and 3.95

g/cm^3, respectively. The efficiency of the process yielded 98.3% and the product as characterized could find applications in catalytic and water purification.

The use of a Nigerian sourced kaolinite mineral by our indigenous industries would apparently assist the country in the economic diversification from the only hard-earned crude oil exploration, thereby generating employment, improving our revenue base and above all, promoting economic sustainability. This prompted us to prepare an industrial alumina from a biotite-rich kaolinite ore (BRK) by Cyanex®272. Due to the distinct advantage of chemical routes coupled with its economic viabilities, this study adopts a 'win-win' three-stage method: (i) dealumination of kaolinite to produce aluminium compound solution, (ii) precipitation of aluminium hydroxide using sodium hydroxide solution, and (iii) calcination of the aluminium hydroxide obtained to produce alumina of industrial utilities **(**Raji and **Baba *et al.,* 2020).** The thermodynamic of extraction process to produce high grade alumina (Al_2O_3 : 14-387-9021, melting point = 2056 °C) gave the apparent standard enthalpy (ΔH, entropy (ΔS) and Gibb's energy (ΔG) of 3.87 kJ/mol, 10.57 kJ/mol and -3177.6 J/mol, respectively at 27±2 °C. The pure alumina produced could serve as a valuable product in metallurgical and catalytic industries.

It is important to note that the excellent results obtained from the treatments of NaneDidanBungudu Kaolinite-rich kaolinite ore **(Baba *et al.,* 2019b, c;** Raji and **Baba *et al.,* 2020)** excited some international partners/industrialists to approach my laboratory through one of my Ph.D. students, Mr. Raji Mustapha Adekunle, for possible upgrading of Phlogopite sample (a tailing from phosphate rock) to industrial alumina by hydrometallurgical process. The upgrade project which has since commenced under my supervision is required by Foskor Company, South Africa. It is believed that the two parties will derive immeasurable benefits from the research output.

One of the conventional methods for alum production for water treatment is through bauxite ore purification. As this ore is rarely available in large quantities in Nigeria, one of the feasible approaches is to produce alumina from a typical kaolin ore. Thus, for economical consideration and energy saving purposes, kaolin with ≥35 wt.% is often used as an alternative for alum production in this regard. The conventional kaolin processing for alum production requires calcinations at high temperature and pressure, and this is not economically viable owing to the nature of unwanted by-products produced (Ford, 1992; Philips and Wills, 1982). In view of these challenges, we have developed the extraction and recovery routes for alumina (Al_2O_3) from Batagbon, Edu Local Government Area of Kwara State by sulphuric acid in the presence of flousilicic acid. The developed over-ruled process is the energy intensive calcinations process prior to the ore leaching process. The recovery of alumina at optimal conditions yielded 84.28% efficiency. The produced alum was found to compete favourably with high grade imported alum for domestic and defined industrial uses (Adekola and **Baba *et al.*, 2016**).

(v) Copper ores

Till date, approximately 700 million metric tons of copper ore deposits have been estimated around the world. Identified mineable deposits contain an estimated 2.1 billion metric tons of additional copper, which brings the total amount of discovered copper to be 2.8 billion metric tons, with undiscovered resources estimated at 3.5 billion metric tons of copper on earth (USGS, 2019). The world largest copper mine by reserve is currently located at Escondida in the Atacama Desert in Northern Chile. This mine is expected to contain more than 32 million tonnes of recoverable copper reserves by the end of 2019 (Rotuska and Chimjelmiki, 2019). Approximately, 70% of the world's copper ore reserves are contained in the mineral *chalcopyrite* ($CuFeS_2$), which are widely distributed in metallic veins in association with pyrite, bornites, chalcocite, sphalerite, etc. In Nigeria, for example, substantial deposits and proven reserves are available in the Northern part of the country with those of Bauchi and Nassarawa States being of high grade. For more than a decade, our attention has been focused on the extraction of oxidized copper ores due to depletion of high-grade copper sulphides in chloride media. Chloride systems in hydrometallurgy have been used for the treatment and recovery of precious metals including copper for a number of years, due to the fact that leaching can be carried out at ambient temperature compared to a sulphate process that requires elevated temperatures that are not suitable for ore heap leaching. Also, the stability of copper (I) oxidation state, which allows electro-deposition of copper via electron transfer that often leads to reduced energy consumption, as well as formation of stable chloro-complexes are the major considerable reasons for sulphide ore dissolution in chloride media (Dutrizac, 1992; Ucar, 2009).

Mr. Vice-Chancellor, sir, due to various interests that include environmental aspects and the possibility of increased exploitation of mixed and lower grade ores and relatively small isolated deposits inspired me to instruct one of my postgraduate students to focus on copper ore processing as there has been a worldwide upsurge of interest in hydrometallurgical processing of chalcopyrite ore for the productionof high grade copper (Ayinla, 2012).In this regard, we have successfully provided useful information on kinetic parameters for copper extraction from the chalcopyrite ore sourced from Akiri village, Awe LGA of Nassarawa State of Nigeria. The examined -90+75 µm Akiri chalcopyrite sample assayed 24.10 wt.% ± 0.10Cu, 36.53 wt.% ± 0.94 Fe and 2.20 wt.% ± 0.01 Mn with other trace elements was found to contain primarily chalcopyrite ($CuFeS_2$) and pyrite (FeS_2), which may be a mixture of pyrothite (Fe_7S_8). The XRD data also showed the presence of minor abundance (≤2%) of other associated compounds including galena (PbS), cassiterite (SnO_2), hausmanite (Mn_3O_4) and quartz (SiO_2), among others. At optimal conditions (4.0 mol/L HCl, 80 °C, with moderate stirring), 91.33% of the 10 g/L ore was dissolved within 120 minutes. The reaction mechanism of dissolution is controlled by diffusion through the ash layer around the shrinking unreacted core, supported by the calculated energy of 31.6 kJ/mol and reaction order of 0.42. The post-leaching residue as confirmed by XRD is made up of α-quartz (α-SiO_2), elemental sulphur (S°) with traces of fukuchhite ($Cu_{0.47}Fe_{0.58}S_2$) and tin oxide (SnO_2); which are important raw materials for some defined industries **(Baba *et al.*, 2013b).**

The extraction and purification of copper by dithizone in kerosene from aqueous chloride Akiri chalcopyrite leach liquor containing 934.44 mg/L Cu, 2326.73 mg/l Fe, 92.14 mg/L Mn, 0.65 mg/L Mg, 0.22 mg/L Ca, 0.076 mg/L Sn and 0.011 mg/L Pb was investigated **(Baba *et al.*, 2015c).** Although, the use of certain extracting agents such as ACORGA 5397 (El-amari*et al.*, 2013) is widely adopted in treating sulphuric acid leach copper solution commercially; LIX reagents will extract copper from chloride solution in the Cuprex process (Stevanavic *et al.*, 2009) and ammoniacal solution can be treated by some other LIX reagents such as LIX 54, 842 and 860 (Stefanova *et al.*, 2010). Despite slow extraction kinetics, dithizone as an extractant is characterized by good physical properties in terms of phase separation, low chemical stability, as compared to the LIX and ACORGA reagents. As data relating to dithizone for copper extraction has not been documented in Nigeria and coupled with the ease of interaction with metal ions to form neutral complex species, it was considered as an alternative reagent for the hydrometallurgical treatment of a Nigerian chalcopyrite ore. At optimal extraction conditions and after total iron precipitation at pH 3.5, followed by total manganese and other impurities removal at pH 4.25, the efficiency of copper extraction reached 93.6% in a single stage at 27±2 °C within 30 minutes at pH 5.0. Also, 98.3% of the copper loaded organic phase was successfully stripped with 0.1 mol/L HCl solution. Copper was later recovered from the strip liquor as pure copper oxide (Tenorite, CuO : 05-0667). Finally, the operational hydrometallurgical scheme for the extraction of pure copper and the production of high-grade copper oxide for defined industrial applications was provided **(Baba *et al.*, 2015c).**

Mr. Vice-Chancellor, sir, I am happy to inform the audience that the beneficiated CuO as characterized could find applications as *p*-type semi-conductors. The results from this investigation which I presented (through full sponsorship by Unilorin) at the 2015 Mineral Processing Technology (MPT) of the India Institute of Metals held at Andhra University, Visakhatapnam, India, was ranked the best and won the *first* position prize in the Hydro-and Bio-hydrometallurgical research category. This, till date, has earned the Hydrometallurgy & Mineral Processing Laboratory at the University of Ilorin international recognition. In the same vein, high grade industrial copper sulphate pentahydrate crystal ($CuSO_4.5H_2O$) for possible use as anti-biofueling, anti-bacterialand correction of copper deficiency in defined ecosystem was recently produced from Sabon-Gari, Zamfara State malachite ore ($CuCO_3.Cu(OH)_2$) **(Baba *et al.*, 2017c).** The process recorded 98.1% efficiency and analytical summary of the research was successfully presented at the TMS 2017 of the Minerals, Metals and Materials Society held at San Diego, California, USA, for wider audience and international acceptability.

Covellite (CuS), being a secondary copper sulphide mineral containing 66% of copper, is now considered as dimer (two molecules of CuS forming Cu_2S_2) with the copper existing as Cu(I). From a scientific perspective, covellite has drawn significant interest as a superconductor, and natural CuS show excellent metal conductivity and condense into super conducting state below 1.6 K (Tezuka*et al.*, 2007). For these reasons, the use of ammonia-ammonium sulphate solution for the treatment of Wukari (Taraba State) sourced covellite ore has been documented by **Baba *et al.* (2017d).** The advantage of this leachant relative to other leachants in copper recovery is that pH is almost constant during the leaching. Also, ammonia and ammonium sulphate generate ammonium ions required for the dissolution process. The ammonia produced by ammonium ions forms stable complex with metal ions and this leads to increased ore dissolution. With 1.75 mol/L NH_4OH +0.5 mol/L $(NH_4)_2SO_4$, -90 + 75 µm, 75 °C and moderate stirring, 86.2% of copper ore reacted within 120 minutes. The dissolution data was found to be controlled by diffusion kinetics. The EDX and phase analyses of the residues indicate that covellite is almost completely dissolved in ammonia-ammonium sulphate solution at optimal conditions. From the XRD analysis, the partially unreacted Cu and S phases were presumed to be CuO and the iron present in the CuS phase was mainly converted to hematite ($Fe_2O_3.H_2O$), as the CuS phase disintegrated and remained in the residue afterward **(Baba *et al.*, 2017d).**

Mr. Vice-Chancellor, sir, it is important to state that treatment of copper ore in sulphate media resulted in the formation of elemental sulphur, which often impede the process kinetics by forming passivating layer on the unreacted particles. Another drawback is the contamination of leaching liquor with ions due to simultaneous dissolution and stability of copper and iron ions. Thus, chalcopyrite leaching in aqueous ammonia leads to the formation of SO_4^{2-} instead of S° due to high pH of ammoniacal media. The major advantage of ammonia leaching process lies in its selectivity towards copper, since ammonia forms soluble amine complex with Cu ions and iron is completely rejected as iron oxides **(Baba *et al.*, 2014).** In view of the foregoing, the characterization and kinetic study on ammonia leaching of complex copper ore from Kokona District (Nassarawa State) was successfully experimented using PARR® 2 L capacity stainless steel autoclave available at the Department of Hydro & Electrometallurgy, CSIR-Institute of Minerals and Materials Technology, Bhubaneswar, India, under the guidance of my postdoctoral research supervisor, Dr. Malay Kumar Ghosh. The effects of parameters such as agitation, temperature, NH_3 concentration, particle size and oxygen partial pressures (ρO_2) were investigated. The results affirmed that ammoniacal leaching using O_2 gas under pressure is a feasible treatment route for Kokona ore to have selective dissolution of copper. Under standard leaching conditions of 1.29 mol/L NH_3, 120 °C, -212+125 µm particle size and 203 kPa O_2 partial pressure, it is possible to achieve 83% copper recovery in 2.5 h. However, under higher ammonia concentration and lower particle sizes, > 95% Cu extraction is feasible (Fig. 4).

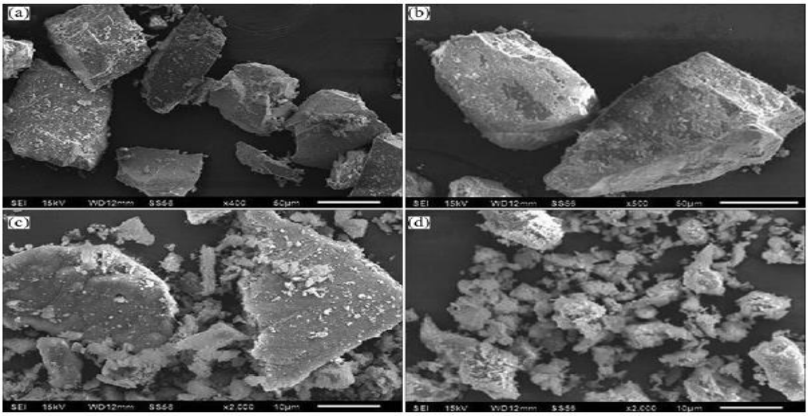


Fig. 4: SEM images of Kokona raw ore (a), 22% Cu leached residue (b), 63% Cu leached residue (c) and 95% Cu leached residue (d) **(Baba *et al.*, 2014).**

The leaching process consistent with the following stoichiometry (Eq. 11) is a reaction controlling one and precipitation of hematite does not alter the reaction mechanism as follows:

$$2CuFeS_2 + 12NH_3 + 8.5O_2 + (n+2)H_2O = 2Cu(NH_3)_4\,SO_4 + Fe_2O_3.nH_2O + 2(NH_4)_2SO_4 \quad (11)$$

The distinctive results obtained from this investigation was ranked as the best in the Institute and was one of the highly rated researches that earned me Diamond Award as the Most Valued Postdoctoral Fellow of CSIR-IMMT, Bhubaneswar, India on the 17th of January, 2012.

(vi) Manganese ores

Manganese is an essential ingredient in steel and alloys, dietary additives, fertilizers, battery cells and fine chemicals, among others. Pyrolusite (MnO_2), one of the major ores of manganese is widely distributed in the earth's crust and used extensively for the manufacturing of various ferromanganese alloys. The ore is usually mined as oxide, converted to ferromanganese or silicomanganese in a blast furnace or electric arc furnace involving high energy consumption but this releases obnoxious pollutants to the environment (Sang *et al.,* 2010). However, the unfavourable economic and environmental pressures for manganese production through blast furnace drove our interest to find alternative methods that consume low energy, less capital and with high metal selectivity, without causing air pollution. As the global annual consumption of Mn exceeds 1.3 million tonnes and is expected to increase because of strong demand in the Chinese steel industry, particularly for special steels, the continuous development of feasible and profitable processing routes becomes paramount. Consequently, we investigated and provide detailed characterization and dissolution kinetic analysis of the Kaoje (Kebbi State) pyrolusite ore in H_2SO_4 media **(Baba *et al.,* 2015d).** In a 4 M H_2SO_4 solution at 80 °C with a particle size -90+75 µm and moderate stirring, the ore dissolution rate reached 78.7%. The unleached residue produced under leaching conditions consisted of silica with admixtures of Cristobalite and Stishovite; and the dissolution data followed a SCM for surface diffusion control mechanism with derived Ea of 33.51 kJ/mol.

Mr. Vice-Chancellor, sir, the recovery of the total manganese from the sulphuric acid-leached Kaoje Pyrolusite ore was vividly examined through the combination of solvent extraction and precipitation techniques prior to the beneficiation of the purified solution as manganese oxide **(Baba *et al.,* 2016a).** Iron, which forms the major impurity in the pregnant solution, was successfully removed through goethite method at pH 3.5 and the process recorded 99.75% success. Other impurities such as Ca, Mg, Cu and Zn were co-precipitated and successfully separated from the iron free manganese at pH 5.0. An extraction efficiency of 95.1% was obtained by 0.2 mol/L Cyanex$^{®}$272 in kerosene at 25±2 °C within 40 minutes from which 98.4% Mn from loaded organic phase was recovered. The beneficiation of the recovered pure manganese solution was carried out by crystallization through alkali addition followed by calcination at 600 °C to obtain high grade manganese oxide (Pyrolusite, MnO_2 : 12-0716) proposed for use in steel production**.** I presented the results of this investigation, including the hydrometallurgical scheme for the operational extraction procedure amenable for industrial utilization and economic sustainability, at the 3rd Joint UCC-UNILORIN International Conference held at the University of Cape Coast, Accra, Ghana in August 2013**(Baba *et al.*, 2016a)**.

Mr. Vice-Chancellor, sir, with the extensive exploitation and consumption of high-grade manganese ore (total Mn>35%), considerable attention must continuously be focused on the development and utilization of low-grade manganese ore (total Mn <35%). Pyrolusite (MnO_2) and most importantly *Spessartine* ($Mn_3Al_2(SiO_4)_3$) are examples of industrial manganese ores that can be processed in meeting the demands of steel and allied industries **(Baba *et al.*, 2018a).** This, among others, have guided the focus of my research group focus on developing low cost and eco-friendly route for purifying the manganese ore to meet some defined industrial demands. One of them is our research on reductive leaching and solvent extraction techniques for the purification of Kaoje North-West Spessartine ore (11°11’00’North, 4°7°0°East), Kebbi State of Nigeria. The results at optimal conditions (1.5 mol/L H_2SO_4 + 0.2 g spent tea, 75 °C) gave 80.2% ore reaction within 120 minutes. The derived activation energy of 35.5 kJ/mol supported the proposed diffusion control mechanism. The leachate at optimal leaching was treated by alkaline precipitation and solvent extraction methods using sodium hydroxide and (di-2-ethylhexyl)phosphoric acid (D2EHPA), respectively to obtain pure manganese solution. The purified solution was further beneficiated to obtain manganese sulphate monohydrate ($MnSO_4.H_2O$: 47-304-7430, melting point = 692.4 °C). The unleached residue (19.8%) analyzed by XRD containssilicious impurities (SiO_2) which could serve as an important by-product for some defined industries **(Baba *et al.*, 2018a).**

Recently, the use of oxalic acid as a reductant, owing to its availability, high acidic strength and the ability to form metal ion selectively for further enrichment of Kaoje Spessartine ore was successfully reported **(Baba *et al.*, 2020d).** The results at optimal leaching conditions (1.5 mol/L H_2SO_4 + 1.0 mol/L $C_2H_2O_4$, 75 °C), yielded 97.2% efficiency within 120 minutes compared to 80.2% when spent tea was used as a reducing agent. In addition, the low activation energy of 16.5 kJ/mol recorded during the dissolution reaction affirmed oxalic acid to be a good candidate for the treatment of this ore for industrial value additions. The leached metal ion species at optimal conditions gave 2854.7 mg/L Mn^{2+}, 1523.3 mg/L Fe^{3+}, 205.3 mg/L Al^{3+}, 43.1 mg/L Ca^{2+} and 28.1 mg/L Sn^{2+}.

(vii) Ilmenite, rutile and iron ores

(a) Ilmenite / rutile ores

The processing ofilmenite for the production of pigment grade TiO_2 often becomes difficult due to its high iron content. This is because of the limitation in the availability of natural rutile resources. A study by Wang *et al.* (2010) focused on the beneficiation of ilmenite into synthetic rutile. As the known reserves of titanium oxides are decreasing, other titanium mineral that could be used as a substitute is ilmenite owing to its relative abundance. In order to meet the demand for high grade titanium ores, commercial practices including roasting and smelting are followed to upgrade the ilmenite resources by removing iron oxides and other impurities. Smelting produces a tatania-rich slag and a molten iron by-product (South Africa, Canada and Norway). Ilmenite roasting to synthetic rutile involves two process routes, namely *Becher process* (Australia) using ilmenite grade of 57%-63% TiO_2 and *Benelite process-roasting followed by acid leaching step* (USA, India and Malaysia) and can treat a wide range of 50%-63% TiO_2 (Lasheen, 2005).

Mr. Vice-Chancellor, sir, the aforementioned methods for upgrading ilmenite to synthetic rutile are energy intensive, coupled withexpensive process design. As alternative to minimize intensive energy disposals, we have successfully used acidic leaching-cum-mechanical activation followed by alkali roasting to treat Sagbe (Ifelodun L.G.A., Kwara State) ilmenite ore for industrial value additions **(Baba *et al.*, 2013c).**The Sagbe ilmenite ore which assayed 29.3 wt.% Ti, 27.7 wt.% Fe, 1.93 wt Zn, 0.16 wt.% Cu, 0.88 wt.% Mn, 0.12wt.% Pb and 0.05 wt.% V was one of my break-throughs and it formed part of my distinct findings at the CSIR-IMMT, Bhubaneswar, India during my Postdoctoral Research Fellowship between 2011 and 2012. During this investigation, we reported that mechanical activation significantly enhances the dissolution of the ilmenite ore. Under the leaching conditions of 90 °C, 60% (v/v) H_2SO_4 and 4 h, 72% Ti extraction was achieved from a milled ore roasted at 850 °C by 60% NaOH with valuable compounds detected as summarized in Figures 5A and5B.

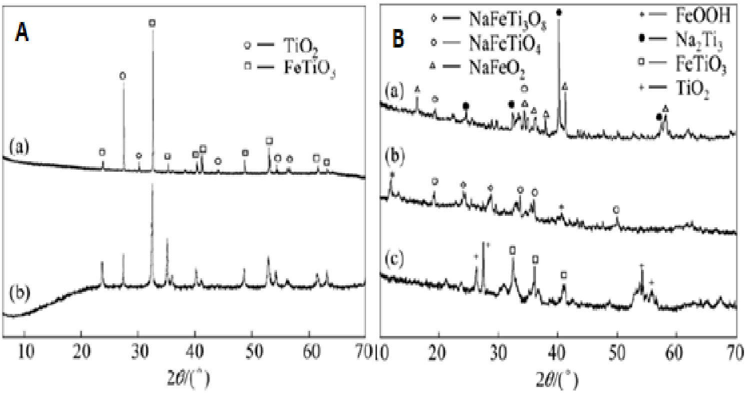
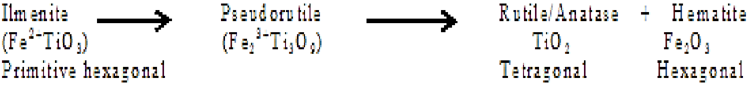


Fig. 5A: XRD patterns of unmilled (a) and milled for 60 min (b) Sagbe ilmenite; **B:** XRD patterns of roasted ilmenite (a), water treated roasted ore (b) and acid leaching residue (c).

The recovery of titanium and iron from ilmenite is, therefore, of particular interest and various extractants such as Tributylphosphate and *o*-phenanthroline have been tried over the years (Ritcey *et al.,* 1982), based on the following alteration mechanism (Suresh *et al.,* 1994):



The spectrophotometric determination of metals after extraction of metal complexes with organic solvent is widely used for trace metal ions determination. However, the method is applicable for the complex with a low partition coefficient in the aqueous : organic phase. In view of the above, we have successfully developed a hydrometallurgical route for the extraction and recovery of total iron fromthe ilmenite ore sourced from Oke-ode axis (Kwara State) for defined industrial applications **(Baba *et al.,* 2012b).**

Mr. Vice-Chancellor, sir, it is important to note that low vanadium concentration (0.0021 wt%) from Oke-ode ilmenite ore examined by ICP-MS technique make the ore to be suitably fit for industrial application in sulphate process plants. The ore mainly contains 42.06 wt.% Ti, 27.43 wt.% Fe, 11.24 wt.% Si, 3.14 w.t% S, 2.79 wt.% Cu and 0.96 wt.% Ag, among others**.** An extraction efficiency of 97% total titanium was obtained by 1.5 M TBP in kerosene from initial 10g/L ilmenite leach liquor at 27±2 °C in a single extraction stage. Iron was effectively eliminated using 3 M ammoniacal solution at pH 3.5. The stripped titanium solution was recovered from TBP-organic phase by 0.1 M HCl solution, and a practicable hydrometallurgical flow chart summarizing the operational procedures for the extraction of total titanium from ilmenite ore was provided **(Baba *et al.,* 2012b)**.

(b) Iron ores

The possibility of producing the ferric chloride crystal from the iron-ore concentrate obtained from National Iron-ore and Mining Project, Itakpe, Kogi State, for water purification was reported over a decade ago by **Baba *et al.*(2005a).** The iron concentrate with 66.7 wt% Fe contains among others 0.06 wt% P, which also make it suitable for steel production. Steel, of which iron is the key ingredient, is the world's most commonly used metal, representing almost 95% of all metal used per year. It is useful in structural engineering and for marine purposes, automobiles and general industrial (machinery) applications **(Baba *et al.*, 2017e).** The extraction and metallurgical process of iron-bearing minerals into metallic iron through blast furnace route requires two major procedures: ore preparation and reduction of oxide concentrates. However, this involves high energy during operation. We have successfully used hydrochloric acid solution in the processing of Itakpe iron-ore concentrate for industrial value addition. Under the established conditions (2 M HCl, 80 °C, optimal stirring), 92% of the total iron in the ore was dissolved within 120 minutes. The pure iron solution was beneficiated through evaporation, followed by crystallization to obtain $FeCl_3$ crystal with melting point of 304.1 °C as compared toindustrially available $FeCl_3$ (melting point of 307.6 °C). The dissolution process is consistent with the following stoichiometry **(Baba *et al.*, 2005a):**

$$Fe_2O_3 + 6H^+Cl^- \rightarrow 2FeCl_3 + 3H_2O \qquad (12)$$

(viii) Cassiterite and Wolframite ores

(a) Cassiterite ore

The fast development of science and technology coupled with some properties of tin (Sn) such as malleability, ductility and resistance to corrosion make pure tin metal useful for a wide array of utilization in tin plating, phone pads, alloying and metals coating, among others. In addition to these, the consumption of pure tin metal and its compounds are increasing tremendously as a result of its versatile end uses. With the global price equivalent to about $22,000 USD per metric ton, it is manytimes more valuable than refined zinc (**Baba *et al.*, 2020a**). In recent times, the major uses of tin are in industrial coatings on steel (27% Sn), most importantly in canning foods and drinks, electrical and electronic industries (23% Sn), in alloys such a bronze (8.5-16% Sn), as well as other pertinent engineering alloys. In placing tin metal value to address the aforementioned applications, efforts should be geared towards sourcing for high grade tin varieties such as cassiterite ore, as its deposits are widely spread in Africa and most importantly in Nigeria, where its market potentialiscurrently put at US$470 per ton **(Baba *et al.,* 2020a; 2009a)**.

Mr. Vice-Chancellor, sir, in view of the above justifications, we have recently reported the potential of cassiterite ore in Lafiagi, Edu L.G.A. (Kwara State) for industrial steel coating applications **(Baba *et al.,* 2020a).** The result of our investigations, which has attracted remarkable applause, was presented at the Minerals, Metals and Materials Society of the Pan American Materials Congress (TMS 2020: THE WORLD COMES HERE) held in San Diego, California, U.S.A in February, 2020. It was affirmed that theLafiagi sourced cassiterite ore was successfully transformed to tin chloride of industrial utilities through combinations of leaching, solvent extraction, precipitation and crystallization techniques from HCl acid pregnant solution by TBP extractant, yielding extraction efficiency of 89.31%. This novel study shows the possibility of producing high grade, domestic and industrially acceptable tin chloride ($SnCl_2$: 96-01-9553; melting point = 239.7 °C, density = 3.89 g/cm^3) suitable as steel coating material in some defined industries by hydrometallurgical process. This study is, therefore, expected to contribute to the country's economy through industrialization and poverty reduction, especially when the Ajaokuta Steel Industry resumes full operations.

The utilization of the hydrochloric acid solution for the treatment of Ijero-Ekiti (Ekiti State) cassiterite ore for industrial applications had been reported by our research group **(Baba *et al.,* 2009b).** From the study, the experimental data obtained was analyzed with SCM for diffusion control mechanism. At a set of experimental conditions, 84.9% of 10 g/L cassiterite ore at 80 °C reacted during 120 minutes leaching operations using 0.045-0.075 µm particle diameter, at a stirring speed of 360 rpm. The reaction order for the dissolution process with respect to H^+ ion concentration was found to be 0.92 with derived Ea of 50.05 kJ/mol and Arrhenius constant of $1.49\times10^{3}s^{-1}$. However, XRD data showed that about 15% of the initial solid material contained TiO_2, $FeTiO_3$, Ta_2O_5 and α-SiO_2 and are formed around the shrinking core of the unreacted material.

(b) Wolframite ore

Tungsten, found to be existing in nature as *wolframite* ($(Fe,Mn)WO_4$) and *scheelite* ($CaWO_4$), is an important metal used for several applications. It is an essential commodity whose unusual properties are explored for various industrial uses such as its use as cemented carbide and high-speed steel tools, wood working construction, mining and wear protections on which the world's economic wellbeing depends. Other important applications of pure tungsten metal include chemicals, catalysts, X-ray tubes, super alloys and radiation shielding (Zhang *et al.*, 2016). At present, the world's tungsten reserves are estimated to be 3×10^{6} tonnes and most ore contain less than 1% WO_3. Hence, natural and synthetic scheelites are the most important raw materials used in tungsten production for defined industrial uses. For instance, many Nigerian wolframite ore deposits contain admixtures of *scheelite* and *stolzite* which could be easily processed to obtain the desired products. Ammonium paratungstate (APT), the main intermediate product forindustrial tungsten metal and tungsten carbide is the fundamental raw materialsthat is used for hard metal production, illumination and coating applications (Guiqing *et al.*, 2016; **Baba *et al.*, 2018b).**

Mr. Vice-Chancellor, sir, due to the increasing demands for pure wolframite ore in the form of ammonium paratungstate, the treatment of wolframite ore sourced from NaneDidanSoroinBungudu L.G.A. of Zamfara State for improved industrial applications was successfully examined and the impressive finding was presented at the TMS 2018 Annual Meeting held in Phoenix, Arizona, U.S.A **(Baba *et al.*, 2018b).** The wolframite ore containing admixtures of *scheelite* ($CaWO_4$: 96-900-9631) and *stolzite* ($PbWO_4$: 96-900-9813) was investigated in hydrochloric acid chelated with phosphoric acid to extract tungsten via solvent extraction. The result at optimal conditions (1.5 mol/L HCl + 2.0 mol/L H_3PO_4, 75 °C) yielded 95.0% ore dissolution efficiency. Tungsten recovery from the leachate at optimal conditions containing 6.3 g/L W, 0.231 g/L Fe and 0.08 g/L Mn was carried out by solvent with 0.15 mol/L Aliquat 336 in kerosene. Pure tungsten was successfully recovered as APT and beneficiated to produce high grade tungsten oxide of industrial value. Sir, permit me at this moment to pay a glowing tribute to one of the contributing authors, *a hardworking, hydrometallurgist specie,* ***Mr. Muhammed O. Muhammed*** (a reliable and highly resourceful M.Sc. graduate) who passed away on Wednesday 26th February, 2020. May Allah forgivehis shortcomings and grant him Aljanat firdaus, (Aamin). As part of our efforts in this field, we have recently reported the possibility of obtaining ammonium metatungstate (AMT), $(NH_4)_6[H_2W_{12}O_{40}].4H_2O$: 96-901-3322) from Anka (Zamfara State) sourced wolframite ore by hydrometallurgical process. The AMT produced is another form of tungsten coumpound widely used in the preparation of industrial tungsten alloys and ammonium phosphotungstate for catalyticapplications (Girigisu and **Baba, 2021; Baba *et al.,* 2021b**).

(ix) Beryl, calcite and barite ores

(a) **Beryl ores**

Beryl ore ($Be_3Al_2Si_8O_{18}$), a tectosilicate mineral of hexagonal structure with pegmatitic origin is the most abundant mineral of beryllium metal. Its unique properties such as high melting point (1285±5 °C), low neutron absorption, good thermal conductivity and dimensional stability make beryllium and its compounds useful in many high technological applications such as X-ray, automotive, electronics, ceramics, computer/electronics and nuclear science. Conventional methods of beryllium ore processing for defined industrial applications involve high temperature treatment requiring high energy usage to obtain high grade products. However, as there exists limited literature on the beryllium ore processing in Nigerian through hydrometallurgical method, we have made attempts to develop environmentally friendly approach for the recovery of industrial beryllium and aluminium compounds from beryl ore sourced from Ologoma, Ifelodun LGA, Kwara State with the following compositions: 20.53 wt.% Al_2O_3, 63.10 wt.% SiO_2, 11.20 wt.% BeO, 2.84 wt.% Fe_2O_3, 1.68 wt.% Ag_2O and 0.14 wt.% ZnO. At optimal leaching conditions, 89.3% of the ore was reacted by 1.25 mol/L H_2SO_4 solution at 75 °C within 120 minutes. The SEM images of the leached beryl ore as characterized showed dissolute-etches, pits and marks on the crystal surface indicating that the beryllium content in the raw ore has been successfully leached. However, the 10.7% of the unleached products contain admixtures of silicate containing compounds such as *xenotlite* ($Ca_6Si_6O_{17}(OH)_2$: 023-0125), *antigorite* ($Mg_3Si_2O_5(OH)_4$: 021-0963), *chrysolite* ($Mg_3(Si_2\text{-}xO_3)(OH)_{4\text{-}4x}$: 025-0615) and *kaolinite* ($Al_2Si_2O_3(OH)_4$: 029-1488), which can be further treated to serve as a by-product for defined industrial uses **(Baba *et al.*, 2018c).**

The species in the leached liquor containing 1612.0 mg/L Be^{2+}, 786.7 mg/L Al^{3+}, 98.1 mg/L Fe^{3+} and 63.4 mg/L Ag^+ at established leaching conditions was further treated and purified to obtain industrial beryllium compound. Under the following conditions (0.15 mol/L Cyanex®272, 27±2 °C), extraction yield of beryllium and aluminium reached 91.68% and 97.89% at equilibrium pH of 3 and 4, respectively. A 0.05 mol/L H_2SO_4 solution was found to be adequate for the stripping of about 99.0% Be and 95.0% Al from the loaded organic phase. The pure solutions containing metal ions were accordingly beneficiated to obtain industrial beryllium and aluminium compounds: *Bromellite* (BeO : 04-0843) and *Alumina* (Al_2O_3 : 18-9043) respectively. These compounds can find applications in high-performance semi-conductor parts, especially as additives in radio equipment, structural ceramic materials; paints and as catalytic materials, among others (**Baba *et al.*, 2019d**; Olaoluwa and **Baba *et al.*, 2020**).

Mr. Vice-Chancellor, sir, the purification and optimization of the beryl leach liquors were also carried out to obtain high grade beryllium oxide (BeO), beryllium sulphate ($BeSO_4$), beryllium chloride ($BeCl_2$) and aluminium oxide (Al_2O_3) for specific industrial utilities at the Hydrometallurgy &Mineral Processing Laboratory, Department of Industrial Chemistry, University of Ilorin. Each of these products is available for Exhibition in our laboratory. For example, "Preparation of highgrade Beryllium oxide for industrial applications by hydrometallurgical process" was presented at the 4th Association of West African Universities Conference, held at Universite Felix Heuphouet-Boigny, Abidjan, Cote D'Ivoire in October, 2016 **(Baba** and Olaoluwa, **2016).**

(b) **Calcite ore**

In Nigeria, there is a vast deposit of calcite ore or limestone in the Benue trough, Sokoto and Chad basins. However, the ore at Mfamosing near Calabar (Cross River State) with estimated reserves of 30 million tonnes is the purest deposit in Nigeria. It is about 50 meters thick at the quarry site. Till date, calcite ore is widely used as crushed stone or aggregate for general building purposes, road beds and railway lines, production of asbestos, glass and ceramics materials in Nigeria (Fatoye and Gideon, 2013). It will be a worthwhile venture to upgrade calcite ore uses for producing high grade hydroxyapatite (HAp) for defined industrial applications. HAp is an important inorganic biomaterial with a wide array of uses in biomedical and dental applications due to its similarity to main mineral components of hard tissue of human bone.

In the above context, we have carried out enrichment of Ewekoro Calcite ore for hydroxyapatite production. Although, Ewekoro (Ogun State) ore with estimated reserves of 35 million tons is not the most abundant as compared to Nkalagu (Ebonyi State) with estimated reserves of 174 million tonnes, however, its ease of accessibility and mineral protocols in obtaining the ore guided our choice. To the best of our knowledge, there is practically limited data in this area of research in Nigeria. No doubt, the utilization of this abundant ore deposit in producing high grade HAp would add value to the country's economic viability, growth and development, most especially considering its biomedical applications.

Mr. Vice-Chancellor, sir, we have successfully carried out a study on the enrichment of Ewekoro (Ogun State) calcite ore deposit via diammonium hydrogen phosphate medium by hydrothermal method **(Baba *et al.,* 2016b).** The HAp powder formed was used to determine chemical structure and nature of HAp crystals at different reaction temperatures and times of operation. Under a set of experimental conditions, different morphology, crystallinity and stoichiometric ratios were obtained. At optimal conditions (1 M $(NH_4)_2HPO_4$, 85 °C, 6 h reaction time), a rectangular, rod-like and layered HAp crystal formed yielded Ca/P molar ratio of 1.66, which is close to the stoichiometric HAp ratio of 1.67 required for biomedical applications **(Baba *et al.,* 2016b).**

In the same vein, our efforts at producing high grade barium sulphate ($BaSO_4$) compound from Azara (Nassarawa State) barite ore deposit for use as drilling mud for oil and gas applications have started yielding positive result. For example, we have developed various leaching routes to remove appropriate impurities from the barite ore bodies to obtain >90% pure $BaSO_4$ for use as drilling agents for defined oil and gas industries. The properties of the well characterized $BaSO_4$ obtained at optimal conditions were in accordance with the API standards (Olasinde and **Baba, 2020).**

Mr. Vice-Chancellor, sir, due to time and space constraints, please permit me to summarize some of our other works on mineral processing from different sources in Nigeria and across the globe, aimed at engendering economic sustainability and development (Table 3).

Table 3: Summary of my other research findings in mineral processing in Nigeria and across the globe.

S/N	**Minerals & Sources**	**Title**	**Workdone/ Achievements**	**References**
1	Tantalite (Oke-Onigbin, Kwara State)	A study of the kinetics of the dissolution of a Nigerian Tantalite ore in hydrochloric acid.	The results of the study indicated that the dissolution reaction is topochemical and is greatly influenced by hydrogen ion concentration with 67.2% recorded.	**Baba *et al.*,(2005b)**
2	Iron-ore concentrate (Itakpe, Kogi State)	Investigation of chemical and microbial leaching of iron ore in sulphuric acid	The dissolution kinetics follows a SCM with the surface chemical reaction as the rate controlling step. The ore is non-sulphidic as there was no growth of *thiobacillusferroxidans*on the iron sample. The concentrate may be a mixture of hematite (Fe_2O_3) or magnetite (Fe_3O_4).	**Baba *et al.*, (2007a)**
3	Rutile (Oke-ode, Kwara State)	Dissolution kinetics and leaching of rutile ore in hydrochloric acid	The study showed that with 4 M HCl solution, 83.3% of 10 g/L of leachant at 80 °C was dissolved within 120 minutes, as dissolution mechanism followed diffusion control reaction.	**Baba *et al.*, (2009c)**
4	Pegmatite	Lixiviation of	The results	Adekola and **Baba**

	rock (Courseof Oyun river near Fufu,Kwara State)	manganiferrous aluminosilicate mineral (MASM) in hydrochloric acid.	derived from 2008 Senate Research Grant (VCO/PO/96) on the Source of Manganese from Unilorin Dam showed that MASM mineral could constitute a major geogenic or natural source of Mn and Fe in the river system. The research is of great assistance to the policy makers in the pro-active management of river Oyun water system.	*etal.,* **(2009)**
5	Sphalerite (Abakaliki, Ebonyi State)	Thermodynamic study of lead and cadmium by sphalerite ore in hydrochloric acid.	Feasibility of the sphalerite ore as a potential adsorbent for Pb^{2+} and Cd^{2+} in aqueous solution was developed.	**Baba *et al.*, (2011d)**
6	Anglesite (Ikpeshi zone, Edo State)	Dissolution kinetics and solvent extraction of lead from Anglesite ore.	Extraction yield of 89.11% of the total Pb(II) by 0.5 M TBP in kerosene was obtained at 25±2 °C and its thermodynamic properties evaluated.	**Baba *et al.*, (2011e)**
7	Pyrite (Akiri zone, Nassarawa State)	Dissolution kinetics of pyrite ore by hydrochloric acid	The dissolution of pyrite ore was H^+ ion dependent as 76.4% of the ore reacted within 120 minutes at optimal conditions.	**Baba *et al.*, (2011f)**
8	Chalcopyrite (Akiri	Ferric chloride leaching of a	The reaction products of the	**Baba *et al.*, (2012c)**

	village, Awe LGA, Nassarawa State)	Nigerian chalcopyrite ore	leaching system are characterized to contain sulphur and jarosite and are responsible for the passivation of chalcopyrite.	
9	Pyrolusite (Kaoje, Kebbi State)	Optimization of pyrolusite ore dissolution in hydrochloric acid	The results of leaching showed that 4 M HCl solution at 80 °C produced 67.3% dissolution, reaction occur by diffusion control mechanism.	**Baba *et al.*, (2013d)**
10	Chalcopyrite (Akiri village, Awe LGA, Nassarawa State)	Quantitative leaching of a Nigerian chalcopyrite ore by nitric acid	The extent of ore dissolution reached 81.46% at optimal conditions with 19% undissolved species were found to contain α-SiO_2 and SnO_2.	**Baba *et al.*, (2014b)**
11	Malachite (Sabon-Gari, Zamfara State)	Dissolution assessment of a Nigerian malachite mineral b Ammonia-ammonium sulphate solution	At optimal conditions, 96.6% of the ore reacted. The calculated Eas of 44.51 kJ/mol at the beginning and 29.01 kJ/mol at the optimum leaching with mixed control kinetics proposed.	**Baba *et al.*, (2016c)**
12	Kaolin (Share, Irepodun LGA, Kwara State)	Treatment of a Nigerian kaolin ore for improved industrial applications	Under the established conditions, 78.5% of kaolin ore reacted with 97.1% iron removal efficiency was reported.	**Baba *et al.*, (2016d)**
13	Ixiolite (Aba-Paanu,	Upgrading of a Nigerian Ixiolite	The thermodynamic	**Baba *et al.*, (2016e)**

	Oluyole LGA, Oyo State)	ore columbite by sulphuric acid treatment	feasibility of the conversion of raw Ixiolite to columbite of industrial value established from the 71.14% of the reacted ore.	
14	Fayalite (Igbo-ora, Oyo State)	Enrichment of a Nigerian Fayalite ore by a hydrochloric solution	Dissolution efficiency of 84.2% was achieved from the raw ore body made up of Fayalite (Fe_2SiO_4) and spinel $(Mg_{0.23}Mn_{0.77})Al_2O_4$. The unleached product, kaolinite can be processed for use in paper and paint industries.	**Baba *et al.*, (2017e)**
15	Covellite (Wukari, Taraba State)	Treatment of a Nigerian covellite ore Part I: Dissolution kinetics study by Ammonia solution	Under established conditions, 75.1% of covellite ore dissolved with 120 minutes with consumption of leachant minimal and the leach liquor is entirely free of iron	**Baba *et al.*, (2017f)**
16	Covellite (Mines around Wukari, Taraba State)	Dissolution potential of a Nigerian complex covellite ore by Ammonia-ammonium chloride solution	82.9% dissolution achieved; the dissolution kinetic evaluation with SCM for diffusion control and derived Ea of 31.16 kJ/mol supported the dissolution reaction.	Balogun and **Baba *et al.*,(2017)**
17	Copper ore	Leaching	Leaching kinetics	Ambo and **Baba *et***

	(Los Pozos Mining District, Chile, South America)	kinetics of Near Infrared Sensor-Based Pre-concentrated copper ores by sulphuric acid	of efficiencies of 95.5% and 83.7% were obtained after 2 h for the product and middling ore categories, respectively.	***al.*, (2017)**
18	Biotite-rich kaolin	Preparation of industrial alumina from a biotite-rich kaolinite (BRK) ore byCyanex 272	The purification conditions and thermodynamic feasibility of extraction process to obtain high grade alumina (Al_2O_3 : 14-387-9021, m.p. = 2056 °C) was established.	Raji and **Baba *et al.*, (2020)**

B. MATERIALS RESOURCES:

Mr. Vice-Chancellor, sir, please recall that earlierin the course of today's inaugural lecture, I informed this august audience that there is concurrent increase in demands for many metals such as zinc, lead, gold, tin, etc for defined industrial applications, which has led to gradual depletion of these non-renewable resources. This gradual depletion calls for measures aimed at recovering of these resources from spent materials for sustained industrial utilizations. This, among others, has led to our research direction towards the recovery of the industrial metal values and useful compounds from the secondary material resources using the optimization of the developed mineral processing routes which are not limited to the following:

(i) Spent Batteries

(a) Zinc-carbon batteries

A battery is an electrochemical device that basically converts chemical energy into electrical energy. It consists of an anode, a cathode, an electrolyte, separators and external case. The two basic types of batteries are *primary batteries* such as zinc-carbon, alkaline manganese, silver oxide and mercuric oxide; and *secondary batteries* such as lead-acid, nickel cadmium, nickel metal hydride and lithium ion. A drawback of this type of batteries is their limited lifespan; typically, between six months to four years. The short life is due to internal deterioration of the lead plates which constitute the electrodes for the battery (**Baba *et al.*,2010;** Bernades *et al.*, 2004). In recent times, the consumption of zinc-carbon (Zn-C) batteries have tremendously increased as the global population and economic explosion increases with resultant larger spent-battery wastes (Belradi *et al.*, 2012). Thus, spent batteries contribute to the environmental menace due to its high component of heavy metals.

In most Sub-Saharan Africa, zinc batteries constitute, by far, the dominant portion and could therefore be considered as one of the valuable secondary raw materials for the recovery of zinc and other precious metals for defined industrial uses (Bermavdes *et al.*, 2003). For example, treatment of Zn-C batteries requiring low energy during processing could find a wide array of applications in calculators, remote control and several other uses where small amounts of energy are required. The annual world production of small-portable batteries characterized with distinct shapes and sizes is more than 100 billion (Bermavdes *et al.*, 2003). Out of this mass production, Zn-C batteries cover approximately 31%. The spent Zn-C batteries powder is generally made up of $ZnMn_2O_4$, ZnO, Mn_2O_5, MnO_4, $Zn(NH_3)Cl_2$ with other valuable compounds such as NH_4Cl, carbon and plastics. Thus, the precious metals associated with spent Zn-C batteries often discharged on farm land may find its way into the ground water, thereby causing environmental havoc (Buzatu*et al.*, 2013; **Baba *et al.*, 2020b; 2009a**).

Mr. Vice-Chancellor, sir, the potential of solvent extraction using Cyanex$^{®}$272 for the recovery of zinc from spent zinc-carbon batteries after a prior leaching in hydrochloric acid was successfully investigated by **Baba *et al.* (2009a).** The spent Zn-C batteries, the cheapest and the most popular brand (Tiger Head type-manufactured in China), in the Nigerian market were collected, processed, examined by ICP-MS and they were found to contain 41.30 wt.% ZnO, 4.38 wt.% Fe_2O_3, 2.69 wt.% MnO_2, 1.01 wt.% Al_2O_3, 0.36 wt.% CaO and 0.11 wt.% PbO. During leaching with 4M HCl solution at a temperature of 80 °C using 0.050 – 0.063 mm particle size, 90.3% of the 10 g/L spent Zn-C battery was dissolved within 120 minutes. The dissolution results indicated that the shrinking core model for spherical particles is applicable and the surface chemical reaction has been established to be the rate controlling step for the dissolution process whose derived activation energy was found to be 22.78 kJ/mol. The XRD analysis also showed that post-leaching residue contained mainly the α-Quartz. As the post-leaching residue is non-hazardous, it can therefore be sent to the factory for re-use. An extraction yield of 94.23% zinc by 0.032 M Cyanex®272 in kerosene was obtained from the spent Zn-C battery leach liquor at 25±2 °C and stirring time of 25 minutes. Iron, constituting major impurity, was effectively separated by precipitation prior to Zn extraction using ammoniacal solution at pH 3.5, while lead and other trace elements were first separated from Zn and Fe by cementation process. An efficiency of 95% was achieved for the stripping of zinc from the loaded organic phase by 0.1 M HCl solution for appropriate beneficiation to defined industrial products.

Recently, my group successfully extracted zinc from Zn-C batteries leach liquor and subsequently beneficiated the solution to obtain 98.1% pure zinc oxide suitable as coating and industrial raw materials for some indigenous industries. The hydrometallurgical flow-sheet for economic metal rescue from Zn-C batteries for defined industrial applications was provided (Fig. 6). This work was among the highly rated research in the Energy Technology and Carbon-dioxide Management Symposium at the recently held TMS 2020 Annual Meeting and Exhibition in San Diego, California, USA **(Baba *et al.*, 2020b).**

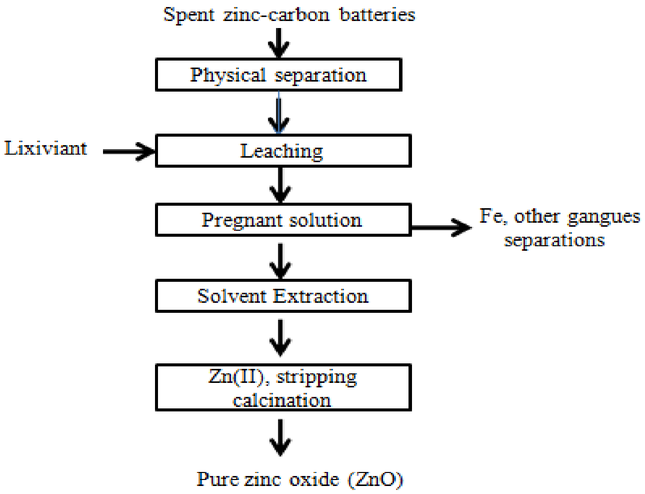


Fig. 6: Hydrometallurgical flow-sheet for economic metal rescue for zinc-carbon batteries for defined industrial application **(Baba *etal.*, 2020b).**

(c) Automobile batteries

Over 60% of the world's output of lead is consumed in the manufacture of lead-acid storage batteries, most of which are used in the transportation industry. Growth in electric vehicle demand coupled with restrictions on lead usage elsewhere will likely result in a greater friction of the world's lead output being used. However, the high level of poverty in some developing countries, especially in Sub-Saharan Africa has steadily increased motorcycle utilization due to its commercial value, which if not put under control could become nuisance to the society **(Baba *et al.*, 2010)**. Most of these materials contain precious metal values, which can be technically recovered by means of mechanical and chemical treatments. The materials recovered show some advantages as they could be returned to the batteries production as raw materials or can be used for other purposes (Tenorio and Martha-de-Souza, 2004). Therefore, there is a justification for the increasing battery consumption per capital. Metal recovery from spent batteries is convenient for economic reasons, as large amounts of solid waste can be re-used as secondary raw materials (Salgado *et al.,* 2003). In this regard, **Baba *et al.*(2013d)** have successfully used liquid-liquid extraction technique to affirm that dithizone in chloroform is a good candidate for extracting lead (II) from motorcycle battery ash leachate. At established conditions, 98.4% of the total Pb(II) was extracted into the organic phase by 0.01 mol/L dithizone in chloroform with stripping efficiency of 95.1% of total Pb(II) achieved.Also, the thermodynamic investigation on total Pb(II) extraction at optimal conditions showed that the extraction is thermodynamically favourable with 19.06 kJ/mol, -37.9 kJ/mol and -63.1 J/K recorded for the free energy enthalpy and entropy changes respectively at 300 K.

(ii) Electronic wastes (*E*-wastes)

(a) Printed circuit boards (PCB)

The productions of electrical and electronic devices are the fastest-growing sector in the manufacturing industries. Every year, 20 to 50 million tonnes of electrical and electronic equipment are produced worldwide, which could pose great risks to human health and the environment when not properly managed (Osuagwu and Ikerionwu, 2010). To date, *E*-waste, including PCB is one of the major pollutants to the environment. As there is no standard or generally accepted definition of *E*-waste in the world; however, once electronic devices reach the end of their useful life, they become electronic wastes (E-wastes) or waste from electrical and electronic equipment (WEEE) (Tippaywong *et al.,* 2009). Thus, dumping of these E-wastes have negative health consequences such as leaching toxins into the soil, air and ground water, which later enter into crops, animal and human body systems causing harm to their health and well being. In Nigeria, the *E*-waste is becoming an important waste stream in terms of both quantity and toxicity. For instance, the importation of end of life (EOL) EEE and updated ones is a major source of *E*-waste in the country; and the actual quantity of *E*-waste that is imported (second hand goods) is unavailable due to high rate of illegal importation. Therefore, due to the rising global demand for EOL electrical and electronic equipment, especially in the third world countries like Nigeria; it is imperative to develop effective, low cost and eco-friendly technique to manage the resultant E-waste, that may even improve value addition, in contravention to conventional reductive-roasting technique that requires high energy.

Mr. Vice-Chancellor, sir, we have successfully developed Energy-saving approach of metals extraction from *E*-waste printed circuit boards by Cyanex$^{(R)}$272 in chloride medium. This was reported at the 2nd U6 Consortium (2014) International Conference, CPUT, Cape Town, South Africa **(Baba** and Ahmed, **2014).** The *E*-wastes used in the study were discarded Dell desktop Computer PCBs. They were obtained from a waste collection point situated at Moris Junction, Minna, Niger State of Nigeria. This is the main area in Minna where used electronic gadgets are dumped. After physical separations, the metallic component of the raw *E*-wastes examined by XRD contain *Sasaite* ($Al(Fe)_{14}(PO_4)(SO_4)_3(OH)_7.0.84H_2O$: 031-0020); *Propylene* ($(C_3H_6)n$: 54-1936); Rutile (TiO_2 : 24-1043); *Impure copper oxide* (CuO : 10-1329); *Iron oxide* (Fe_2O_3 : 24-1463) and *Silicon-oxide* (SiO_2 : 82-1558) and were subsequently subjected to acid leaching to obtain 79.7% dissolution efficiency at optimal conditions. The residual products containing 20.3% made up of Quartz (SiO_2 : 65-0466) containing admixtures of aluminium silicate (Al_2SiO_3) and other compounds such as Polypropylene ($(C_3H_6)n$: 54-1936) and Graphite (C : 74-2328) could be further re-processed for use as by-products for some defined local industries. Also, quantitative extraction conditions on the produced leach liquor by Cyanex®272 extractant for aluminium, iron and copper were favoured at pHs of 1.2, 3.6 and 4.5 to achieve 91.4%, 98.9% and 99.1% respectively, as the number of counter-current extraction stages were predicted by Mc-Cabe Thiele diagrams; ditto for the data obtained for the discarded *Hp* and *Xenox* desktop computer PCBs examined (Ahmed, 2014).

(b) Discarded Cell Phones

In today’s world, improved technology has led to an over-reliance on mobile phones as essential daily gadgets across the world. In Nigeria, truckloads of electronic wastes including spent cell phones, detrimental to human health and the environment are illegally imported from developed countries. A cell phone consists of different components – a circuit board, a liquid crystal display (LCD), rechargeable battery, metals, plastics, ceramics and trace materials (Sahu and Srimivasan, 2008). For example, circuit boards of a mobile or cell phone consist of copper (II), gold, nickel, zinc, beryllium, tantalum and other metals. Cu(II) and its compounds represent 15% of the weight of a typical circuit board. The world uses more than 15 million tonnes of Cu(II) in building, construction and electrical applications including all aspects of infrastructure and technology (Mahmoud and Barakat, 2001). Therefore, resulting from the concurrent increase in demand for metal and gradual depletion of non-renewable mineral resources, our attention has since been directed to the recovery of metals from secondary sources to contribute to the *“waste-to-wealth”* initiatives of the Federal Government of Nigeria. Recycling of metal wastes is fast growing rapidly in the country since the cost of safe disposal of hazardous materials is quite high when compared with the amount of waste produced coupled with the limited storage capacity **(Baba *et al.*, 2014c).**

In the above context, Mr. Vice-Chancellor, sir, we have successfully processed for industrial value addition, the discarded cell phones collected from a cell phone repairer shop at Computer Village, Ikeja, Nigeria **(Baba *et al.*, 2016f)**. After dismantling with hammer mill followed by separation of the plastic-like types from the metal containing parts, the metal-like portions were treated hydrometallurgically. This investigation opened up a technique to recover and recycle Cu(II) from the metallic components of the discarded cell phone. At established optimal conditions, 95% of total Cu(II) was extracted from which 97% of the Cu-loaded organic phase was quantitatively stripped into aqueous phase by 0.1 mol/L HCl solution. Thus, the purified stripped Cu(II) could further be recovered as salts by evaporation-cum-crystallization or metal cathode powder through electrowinning for defined industrial uses.

(c) Spent Deposited Sludge of Transformer Oil (DSTO)

For many decades, the transformer oil has been a major threat to the environment due to its high content in polychlorinated biphenyls (PCBs) (Hotzinger *et al.,* 1974). Globally, 30-40 billion litres of mineral oil are presently utilized in transformers and the demand will tremendously increase with time (Choi and Huh, 2013). The transformer oil often serves as an insulator and coolant within the transformer. Consequently, the government can promulgate and enforce strict environmental regulations in line with the global environmental laws to drastically reduce both accidental and non-accidental hazards associated with mineral transformer oil utilization (USEPA, 1976). As a practical measure towards reducing the negative impact of transformer to the environment, my studies attempted a recovery procedure from sludge formation in spent transformer oil utilizations **(Baba *et al.,* 2018d).** The sludge contents were made up of precious heavy metals such as Ni, Zn, Au, Hg, Cu and Co which may be toxic, but could serve as a valuable industrial product if thoroughly purified and recovered successfully. Depending on the type and capacity, a typical transformer oil contains 90-1485 kg of oil with varying degree of recoverable sludge containing precious metals after degradation **(Baba *et al.,* 2019e).**

Mr. Vice-Chancellor, sir, due to fluctuating crude oil prices and the Covid-19 pandemic that apparently knocked down the global economy and the desire to diversify Nigeria’s economy, recycling initiatives are other preferred options to address economic melt down. To this end, **Baba *et al.* (2019e)** have successfully employed leaching and solvent extraction techniques to treat spent DSTO obtained from Aiyetoro III 300 kVA Distribution Transformer having 245 kg oil weight capacity with 25 kg of recoverable combined sludge oil mixture. As the oil purification is required for keeping the transformer power voltage operating at optimal capacity, successful regeneration of pure oxidized transformer oils has led us to ascertain its potency with respect to the American Standard Testing and Measurement (ASTM D1819) regulations indicating its suitability for refining to meet some defined industrial utilities. At a set of experimental conditions, the leach liquor containing 1243.4 mg/L Cu^{2+}, 789.2 mg/L Fe^{2+}/Fe^{3+}, 110.7 mg/L Ca^{2+} and 23.5 mg/L Al^{3+} treated and beneficiated to achieve 96.8% copper recovery efficiency. Further purification of the copper solution at optimal extraction conditions was examined through combinations of precipitation and crystallization techniques to obtain a high grade copper oxide (CuO : 96-900-9471; melting point = 1309 °C/1326 °C industrial standard) amenable for use as *p*-type semi-conductor for doping and absorbing agent in photovoltaic device.

(iii) Waste Poultry Egg-shell utilities for HAp powder

Till date, the synthesized calcium phosphate compounds such as hydroxyapatite (HAp), $Ca_{10}(PO_4)_6(OH)_2$ have generated a great deal of interest because of the wide variety of their medical applications, especially in orthopedics, plastic and dental surgeries. These bio-ceramics are biocompatible and bioactive because they display link with bone. As HAp is widely used to repair, fill, extend and re-construct damaged bone tissues, our considerable research efforts were recently geared towards the development of artificial bone-like material that do not cause damage to healthy tissue and are readily available.

Mr. Vice-Chancellor, sir, with everyday records of several million tons of egg-shells as bio-waste across the world and in line with the*waste-to-wealth* initiative of the Federal Government of Nigeria, **Baba *et al.* (2020c)** have recently examined the prospect of HAp powder successfully prepared using Tanke sourced calcined waste poultry egg-shells (as a calcium precursor) via chemical precipitation method with phosphoric acid (H_3PO_4) as a phosphorus source. At a set of experimental conditions, the pure crystal of HAp powder produced withCa/P ratio of 1.66 (against conventional Ca/P ratio of 1.67) was well characterized for its possible use in biomedical applications. This high-grade product is relatively cheaper as compared to the industrially available HAp powder produced through energy intensive thermal process, which is sold between \$638/kg to \$795/kg.

To ascertain its safety to human and environment before being adopted for value addition, **Baba *et al.* (2020c)** successfully conducted *Acute* and *Sub-chronic* toxicity evaluation of HApin albino rats. Toxicity results showed no signs of toxicity in relation to clinical, haematological and biochemical alterations, except a dose dependent increase in the bilirubin concentration. Therefore, at optimal conditions, biomedical indices examined showed that the HAp powder yielded 98.1% purity (Fig. 7), and is relatively safe, making it suitable for oral and orthopaedic applications**.**

Fig. 7: Images of the pure HAp produced from waste poultry egg-shells for biomedical applications **(Baba *et al.*, 2020c)**

This HAp powder produced in our laboratory has attracted enormous commendations with keen interest developed by the Minister of Science and Technology, Dr. Christopher OgbonnayaOnuas the University's Director of Laboratory to Product Centre, Prof. A. A. Adedeji show-cased the HAp product to the Honourable Minister at theExhibitions of the Science & Technology Innovation EXPO 2020 between 15th – 20th March, 2020 in Abuja **(Fig. 8).**

Fig. 8: 2nd from **Left**: Dr. Christopher OgbonnayaOnu (Hon. Minister of Science & Technology); 4th: Prof. A.A. Adedeji and 5th: Prof. Baba Alafara at the EXPO 2020 Exhibitions in Abuja in March, 2020.

In a separate study, we have carried out laboratory synthesis of HAp via precipitation technique using incubated hen waste egg-shells sourced from an apartment in Tanke area, Ilorin South LGA of Kwara State, Nigeria, which was mechanically cleaned with distilled water prior to crushing and other processing to obtain fine agglomerates, oral and spherical-pellet-like HAp crystal (76-0565) with Ca/P ratio of 1.67 for biomedical applications **(Baba *et al.*, 2013d).**

Mr. Vice-Chancellor, sir, due to the want of time and space, please permit me to summarize some of my other research achievements on material resources carried out successfully in Nigeria and other parts of the world (Table 4):

Table 4: Some of my other material research endeavours successfully carried out in Nigeria and other parts of the world

S/N	Minerals treated & Sources	Title	Workdone/Achievements	References
1	Spent FORGO 3FM45, 6V motorcycle battery, supplied by Farouq Battery Charger, Ipata-Oloje, Ilorin, Kwara State	Leaching of lead from spent motorcycle car battery in hydrochloric acid. Part I: Dissolution kinetics	The dissolution process analyzed to be diffusion control mechanism with surface chemical reaction as the rate controlling step gave 82.2% efficiency. The 17.8% undissolved species contained mainly silica (α-SiO_2), useful a by-product for some defined industrial applications.	**Baba *et al.*, (2010a)**
2	A brand of used mobile phone from a repairer workshop in Ilorin	Study of metals dissolution from a brand mobile phone waste	The beneficiation of valuable metals from a brand of spent mobile phone by leaching process in laboratory scale with dissolution efficiency of 87.4% was achieved at optimal conditions.	**Baba *et al.*, (2010b)**
3	Spent WANLI S-1010 185/80 R14 automobile tyre, supplied by a vulcanizer in Ilorin	Dissolution kinetics and zinc(II) recovery from spent automobile tyres by solvent extraction with Cyanex®272	The results showed a significant possibility of selective recovery of Zn(II) from tyre ash by hydrometallurgical treatments. An extraction yield of 93% Zn^{2+} by 0.032 M Cyanex®272 was obtained from a 10 g/L tyre ash leach liquor was achieved at 25±2 °C within 25 minutes at optimal conditions.	**Baba** and Adekola **(2011)**
4	Spent dry cell DELPHI car battery, supplied by Farouq Battery Charger, Ipata-Oloje, Ilorin	Kinetic analysis of total lead from spent car battery by hydrochloric acid leaching	The spent dry cell car battery assayed 84.63 wt% PbO, 4.07 wt% CaO, 2.18 wt% MnO, 0.93 wt% Fe_2O_3, 1.67 wt% ZnO and 0.15 wt% TiO_2 with dominance presence of $Pb_3O_2(NO_3)_2$ was treated by HCl solution to obtain 83.8% dissolution efficiency at optimal	**Baba *et al.*, (2011g)**

			conditions.	
5	Manganese nodule, Bhubaneswar, Orissa (India)	Separation of iron and zinc from manganese nodule leach liquor using TBP as extractant	The efficiency of extraction processes was 100 and 99.7% for Fe and Zn respectively,while about 99.5% stripping efficiency was obtained for both Fe and Zn from the initial leach liquor containing 0.29 mol/L Mn, 0.12 mol/L Fe and 0.087 mol/L Zn, as process flow chart for the recovery of pure Mn solution was provided.	Patnaik and **Baba *et al.*, (2013)**
6	Spent catalyst from a fertilizer industry in India	Aqueous processing of nickel spent catalyst for a value-added product	Nickel was recovered from a fertilizer industry spent catalyst by leaching with HNO_3 followed by nickel hhydroxide precipitation. A regression equation was developed and employed to predit conditions for 100% extraction which were experimentally tested. Nickel hhydroxide leach liquor and its maximum discharge capacity was found to be 155 mAh/g. a 3-stage counter current leaching circuit was designed to obtain a leach liquor of suitable pH.	Sheik and **Baba *et al.*, (2013)**

Conclusion

Mr. Vice-Chancellor, sir, this lecture has vividly demonstrated that Nigeria is abundantly and richly blessed with immeasurable mineral and material resources with high potentials to solve the country’s needs if adequately and effectively harnessed. This gesture would contribute to the country’s economic and technological growth and development; and thereby invigorate the desire of the country to diversify its economy from the current sole dependence on petroleum as a source of foreign exchange. In view of my research endeavours and contributions spanning about two decades, this lecture concludes that:

1. The findings of the reported studies underlie the importance of adoption of hydrometallurgical techniques in the minerals and materials processing for socio-economic development and sustainability in Nigeria, by ensuring significant full-scale utilization of the abundant, untapped mineral and material resources.
2. The hydrometallurgical method can be successfully explored to replace other mineral and material processing methods that are generally expensive with high energy consumption and environmentally hazardous.
3. The beneficiation of spent materials to high grade industrial products in compliance with the *waste-to-wealth* initiatives of the Federal Government of Nigeria as another viable source of revenue generation can be strengthened through hydrometallurgical process; and
4. Further development and genuine collaborative research can be successfully undertaken at the Hydrometallurgy and Mineral Processing Research Unit, Department of Industrial Chemistry, University of Ilorin, Nigeria to re-define and promote technological advancement for sustainable economic growth.

Recommendations

Mr. Vice-Chancellor, sir, following the highlights of my research activities described in this lecture, you will agree with me that the hydrometallurgical processing as a means of optimizing the quality of Nigerian mineral and secondary materials for industrial value additions has not been given the deserved attention. However, it is evident that Nigeria-sourced mineral resources have high economic values, but unfortunately have not been effectively harnessed. This is because of the apathy and preference of many local industries for imported raw materials. However, when local and secondary raw materials are fully tapped, it will stem the importation of refined products, thereby preserving our hard-earned foreign exchange, improving the economy, reducing unemployment and poverty, and sustaining the industrial growth and development. Therefore, I recommend as follows:

1. The use of locally sourced refined mineral and material resources for the country's industries that would enable the country to save a significant proportion of her hard-earned foreign exchange should be rigorously pursued. This becomes pertinent with the downturn in the world's economy following Covid-19 pandemic. By this measure, income earned from this can be used to complement those derived from petroleum exploration, which could be used to cushion the effect of the economic meltdown occasioned by the Covid-19 pandemic.
2. Government and other relevant stakeholders should as a matter of urgency put necessary machinery in motion to revive the many indigenous steel plants and allied industries to boost the country's economy and create employment for the country's teaming unemployed youths.
3. The Ministry of Mines and Solid Mineral Development and other critical stakeholders should form alliance with Hydrometallurgy and Mineral Processing Research Unit of our Department and similar laboratories across the country to promote and fund researches in science and technology, especially onthebeneficiation of Nigeria mineral resources for industrial value additions. This will propel economic prosperity by reducing direct export of these minerals, which are often sold at lower prices, to the detriment of our economic well being.
4. The establishment of a Hydrometallurgy and Mineral Processing Research Centre in the university, equipped with the state-of-the-art facilities, is urgently required to improve the quality of research that will effectively contribute to nation building and development. This can be facilitated in conjunction with the Federal Ministries of Solid Minerals Development and Mines & Steel Development.

5. The development of a roadmap that will promote a linkage between research and industry should be put in place for the optimized translational and transformational value chain transmission.
6. The government should put in more efforts in the implementation of its *waste-to-wealth* initiatives to facilitate industrial growth, reduce poverty and promote environmental sustainability.
7. As no nation can develop without research and genuine innovations, government should as a matter of national emergency, address the poor infrastructures in various tertiary institutions, provide substantial funds for cutting edge researches, support indigenous researchers and adequately promote the utilization of local raw materials and manufactured goods. These, if faithfully implemented, will launch the country into committee of industrial nations, where Nigeria truly deserves to be.

Acknowledgements

No words can be enough to sufficiently capture my limitless thanks, profound appreciation and adoration to the Almighty ALLAH, the Lord of the worlds, the All Kind and Ever Merciful, Who has absolute knowledge but inspires whom He pleaseswith a bit of it. May the peace and blessings of Allah continue to be on the soul of the noblest of mankind, Muhammad Rasulullah (SAW), his household and companions. *Alhamdullillah robbil Alamina* for the privilege He granted me to contribute my own quota towards solving societal problems. The presentation of today's inaugural lecture is another glowing testimony of His magnanimity towards me, making it possible to show-case the extent of my scientific research endeavours in seeking practicable solutions to human, societal and national challenges thus far, *Shukrahlillahi!*.

Definitely, in doing this, the Almighty Allah has used a lot of people, some of whom are physically present to witness today's lecture. To all of you, I say a big thank you on behalf of myself and the entire ALAFARA family. However, I have to specifically acknowledge some people that Allah has used to oil my journey so far.

First of all, I sincerely thank the dynamic and hardworking Vice Chancellor, University of Ilorin, Professor Sulyman Age Abdulkareem, for giving me the opportunity to deliver this inaugural lecture. I owe him yet immense gratitude that during his leadership, I attained the Professorial Chair with effect from 1stOctober, 2017 and for appointing me the Head of Industrial Chemistry Department.

However, I have done nothing to ordinarily deserve what Allah has blessed me with, I will be nothing if not for Allah's mercy and the beneficence and honour of my parents, Alhaji Baba Bukhari Alafara and my late mother, Alhaja Shifau Anike Baba Alafara, who as obedient servants of Allah gave birth to me, nurtured me, and gave me all the support to succeed. I pray Allah take good care of them as indeed they took care of me when I was young. To my guardians, the Late Alhaji Hanafi Lowo-ori Alafara (whose very corrective and inspiring guidance kept me on track at the most fundamental temptuous beginning) and Alhaji BusariAlade (retired Principal Assistant Registrar, Unilorin), may Allah reward them abundantly and be pleased with the dead. I equally pray to Allah to repose the soul of my late grand parents, Mallam and Mrs. Aminu Baba-Agba Alafara, and grant them Al-janat firdaos. I value the support of my *siblings:* (Baba) Afusat, Salihu, Ibrahim and Rahmat Alafara. May Allah continue to be our guide and bless the souls ofFatimah and Abdulwaheed Alafara and grant them Al-janat firdaos. The untiring efforts of (Aminu) Batuli, Salamat, Belau (RIP), Aunty Nagode, Ajarat Agunko, Kusumu Olowo (RIP), Suebat Abayawo and Mrs Adijat Ahmad Baba-edu Alafara on my professional development is well acknowledged.

The unique, ever memorable, most appreciable guidance of my Ph.D., M.Sc. supervisor and immediate past Dean, Faculty of Physical Sciences, Prof. F.A. Adekola, is highly appreciated. His uncommon erudition, rare humility and exemplary zeal to lift others up are my assurance that he is destined for greatness. May the Almighty Allah bless him and his progeny. I am highly indebted to my other teachers, Prof. M.A. Mesubi (my M.Sc. co-supervisor, Prof. I.O. Abimbola (my undergraduate supervisor), Prof. A.S. Olorundare (who taught me ingredients of teaching as a profession and qualities of a good teacher) and Dr. Malay Kumar Ghosh (my Postdoctoral Research Fellow Supervisor at the Hydro & Electrometallurgy Department, CSIR-IMMT, Bhubaneswar, Orissa State, India). I sincerely appreciate the Library and Publications Committee of the University, particularly, the immediate past Chairman, Prof. S.F. Ambali, for adding value to this lecture, the current Chairman, Prof. A.K. Salami for his support and to Dr. Iliyas Rasaq Ayodeji (Federal University Dutsinma) and Prof. Mahfouz Adedimeji (Pioneer VC, Ahman Pategi University) for the editorial assistance.

I am thankful to my teachers and senior colleagues at the *Department of Chemistry, University of Ilorin*: Professors G.A. Olatunji (former DVC, RTI), E.O. Odebunmi, J.A. Obaleye, G.O. Adediran, U.B. Eke, S.A. Adediran, Olaofe, S.A. Lawani, S,A.Ibiyemi and Late A.A. Owoyale. I also thank my teachers at other levels: *College of Education, Ilorin:* Mrs E. Balogun, Mr. Rotimi, B.O. Salihu (RIP) and S.S. Sangoyomi; at *Mount Carmel College, Ilorin:* Mr. SalihuAlubarika (English Language), AlhajaSilifatIshola (Mathematics), Mr. S.K. Oni (RIP) and C.I. Ozonuwe (Chemistry), Alhaji IsiakaAjetunmobi (IRK) and Late Mr. Alao (Principal); and at *Alore LSMB School, Ilorin:* Alhaji Ibrahim, late Alhaja Abike Oloru (appointed me Class 4B monitor, 1979/80), Alhaji Moyosore, Alhaji Shehu A. Aliyu and late Alhaji Ayinla (Headmaster, who appointed me School Time-keeper in 1981/82). I thank you all for the guidance, training and mentorship provided. I have also learned a lot under Profs. D.S. Ogunniyi and Adenike T. Oladiji when I served under them as Deputy Director, Central Research Laboratories of this university.

I owe Prof. Shuaib Oba Abdulraheem, OFR, NPOM, Talba of Ilorin, former Vice-Chancellor, University of Ilorin, a profound gratitude. He graciously facilitated my appointment into the University of Ilorin on the 4th June, 2002. Jazzakllahu khair, sir. In the same vein, I acknowledge Prof. I.O. Oloyede for appointing me to serve in the University's Town and Gown Committee (being my first ever University committee assignment in 2009); and Prof. AbdulGaniyu Ambali, OON, FMSN, for kick-starting the process of my promotion to the rank of Professor and for finding me worthy of appointment as the Deputy Director, Central Research Laboratories of this great citadel of learning between 2014 and 2017. He also nominated me to represent the University at the International Workshop on Research & Development and Innovation – Paradigm Shift for Nigeria Tertiary Education at University of Dayton, Ohio, USA in August, 2015. This unique opportunity has very positive significance in my research and innovation integrity to date.

I appreciate the interest and tremendous support constantly demonstrated by Prof. A.G.F. Alabi, FNSE and Prof (Mrs.) Medinat F. Salman, FMAN. I sincerely acknowledge Professors M.O. Ibrahim, A.Y. Abdulkareem, A.S. Abdussalam, S.A. Kuranga, B.F. Sule, B.O. Yusuf, Y.A. Quadri, O.A. Omotesho, M.M. Akanbi, SAN (VC, KWASU), A.B. Olayemi and I. Arowosaiye Yusuf. My profound thanks to Professors S.O. Akande, M.A. Akanji, O.B. Oloyede, A.A. Adeoye, H. Salihu, A.O. Oniye, A. Gobir, R.A. Lawal, A.G.A.S. Oladosu, I.O. Katibi, A.O. Issa, B.S. Alabi, M.T. Bakare-Odunola, A. Yusuf, A. Muhammad-Lawal, B.L.Adeleke, A.A. Adegoke, A.D. Yusuf (CMD, UITH), A.A. Alanamu, O.T. Mustapha, M.K. Mustapha, S.O. Malomo, I.A Adimula, R.G. Jimoh, M.T. Yakubu, S.O. Bolu, R.A. Bello, O. Ogunsanwo, M.A. Belewu, A.A. Annougu; R.B. Adeniyi, A.O. Taiwo, K.J. Oyewumi, C.O. Akoshile, A. Olokoba (IPCMD, GHI), A. Alaro, N.M. Abdulraheem, A.A. Oba, O.M. Bamigbola, J.A. Gbadeyan, K. Rauf, O.M. Kolawole, Y.O. Imam, S.A. Adaramaja, A. Mahmud, L.A. Yahaya, K.R. Ajao, J.K. Joseph, S.T. Babatunde, A. Gunu, J.O. Atteh, U.S. Ugbomoiko, A.A. Jimoh, Y.A. Jimoh, A.T.Ande, P.O. Fatoba, B.A. Oyejola, E.T. Jolayemi, P.A.

Osanaiye, R.A. Ipinyomi, W.B. Yahya, A.O. Adejumo, A.A. Adewara,O.Y. Abdul, K.I. Adam,A.A. Toye; G.C. Nzeh, F.A.O. Olasehinde-William, A.T. Alabi and E. Balogun (Mrs). I am also grateful to Drs. S.O. Shuaib, S. Ismael, F.F. Abdulrazaq, A.O. Amoloye-Adebayo, R.A. Odunola (Director, UIHS), A.G. Adeniyi, A.B. Alabi, H.M-B. Musa (Arikewusola), K.M.U. Gbodofu, T.T. Ibrahim, O.A. Oladipo, T.O. Lawal, S.A. Bello, O.A. Falae, L. Yusuf-Babata, E.O. Titiloye, A.S. Idowu, M.S. Dada, K.O. Babalola, O.A. Fadipe-Joseph, G.N. Bakare, K.A. Bello, J.U. Abubakar, B.M. Ahmed, J.K. Odusote, I.A. Jawondo, S.B. Isiaka, S.O. Oniyangi, G. Bello, O.A. Akanbi, O.A. Adekanye, O.O. Ige, B.U. Olayinka, O. Job, M.K. Garba, D.O. Owolabi, O.A. Iyiola, K.O. Ibrahim; H.T. Ambali, A.A. Ahmed, S.S. AbdulBaki, K.S. Ameen, S.I. Abdulkareem (Mrs) and other respected academics of Unilorin too numerous to mention. I value all your interests in me.

To my senior and junior colleagues in the Departments of Industrial Chemistry and Chemistry of this University, including Professors O.O. Dosumu, N. AbdusSalam, O.O. Oluwaniyi, A.C. Tella, L.A. Usman, F.O. Nwosu, G.B. Adebayo (RIP), O.S. Oguntoye, O.A.A. Eletta; Drs. M.F. Zubair, A Lawal, A.M.O. AbdulRaheem, G.V. Awolola, H.K. Okoro, F.O. Okeola, O.M. Ameen, S.O. Owalude, H.I. Adegoke, O. Atolani, A.A. Hamid, M.O. Bamigboye, O.K. Yusuf, A. Rajee; Mr./Mrs. S.A. Adebayo, A. Abu, H.F. Babamale, A.A. Mohammed, O.D. Saliu, B.O. Orimolade, V.O. Adimula, M.T. Baker-Arowona, R.O. Ismaeel, S. Elelu, M.O. Bello, A.A.Mukadam, F.T. Samoh, M.F. Audu, I acknowledge your contributions to my research endeavours. The efforts of all Laboratory and Technical Staff, especially the contributions of Mr. S. A. Asala, S.A. Ajala, O.K. Balogun, S. Adesuyi, Lates S.A. Durojola, M.A.B. Adebayo and A.C. Tomilayo; J.F. Odedina, A.A. Ahmed, S.O. Bello, D.O. Jemirin, J. Adamu, F.K. Olowe, A.A. Abdulqadir, M.K. Subair, S.T. Fakunle, T, Theman and Mrs. Olowoniwa are gratefully acknowledged. The various assistance of administrative staff of the Department and the Faculty including the inputs of Mrs. J.T.

Arungbemi (*aka* HOD Admin. & Pioneer Secretary-ICH), H.T. Olowoseye (Current Secretary, ICH), F.M. Adeniyi, F.J. Saka, F. Babalola; O.A. Dopamu, B.B. Ahmed, M.B. Usman, S. Yakubu, A.A. Ayoku, J. Kamaldeen, M. Bankole, O.A. Ogunsanya, S.A. Onaolapo; M.E. Ajakaye (Mrs), I.F. Hassan, R.O. Ibrahim, and A. Balogun are applauded. I appreciate your immeasurable contributions that have sustained my Headship of the Department of Industrial Chemistry of this University.

To my distinct hydrometallurgy and material co-researchers in and outside Nigeria: Professors A.G.F. Alabi, R.B. Bale, B. K. Mishra, R.F. Atata, T. Subbaiah, K.I. Omoniyi, Drs. D.S. Rao, K. Sanjay, B.C. Tripathy, M. Mohaptara, R.N. Ahmed, K. Sarangi, P.C. Rout, P. Sandeep, S. Swaroopa, S.S. Sahu, A.I. Ambo, A.R. Sheik, A. Baral, Engr. A.S. Aremu (MD, LNRBDA, Ilorin), S.R. Pradhan, A.A. Njan, P. Patnaik, O. Job; S.A. Yahaya; Engr. & Mrs. A. Jimoh; Mrs. F.A. Abubakar and S.R. Tripathy, I thank you all for accepting to collaborate and share ideas with me. The working relationship of the *Material family in Nigeria* under the amiable MSN National President, Prof. (Mrs.) Esther U. Ikhuoria and MSN Immediate Past President, Prof. A.S. Ahmed; *The Nigeria Chemists* under the leadership of immediate past and current CSN National President, Profs. S.O. Okeniyi and M.N. Chendo; *The Minerals, Metals & Materials Society (TMS) of Pan-American Materials Congress, USA* under the Executive Directorship of Prof. J. Robinson; EPD Chair, Prof. Cindy Belt and Chair, Hydro- & Electrometallurgy Committee, Assoc. Prof. Gisele Azimi (where I'm currently serving as the Secretary), I greatly appreciate your contributions in boosting my research endeavours globally.

I sincerely appreciate our epochal silent achiever; the hardworking Executive Governor of Kwara State, His Excellency, Mallam AbdulRahman AbdulRazaq, for giving me today's honour by his physical presence at this inaugural lecture. I pray Allah to continue to protect and guide him in the conscientious, painstaking process of uplifting Kwara State to greater heights, Aamin.

To our highly respected royal father, the custodian of the revered stool of Alimi dynasty, His Royal Highness, the Emir of Ilorin and Chairman Kwara State Traditional Council of Chiefs, *Mai-Martaba,* Alhaji (Dr.) Ibrahim Sulu-Gambari, CFR, I am indeed grateful for the honour and prayer organized for me to receive Sheikh Alimi'sblessings in your palace following my appointment as a Professor in 2017. May Allah continue to strengthen, bless you with long life, sound health and prosperity. By extension, I appreciate the support of Balogun Ajikobi and Balogun Fulani of Ilorin; Alhaji Imam Bashir, OON - Chief Imam of Ilorin; Grand Mukadam of Ilorin, Sheikh Sulyman Abubakar Dan-Bornu; Alhaji AdioSalihu Alafara – the Chief Imam & Magaji Oloworu, Ipaiye District, Moro LGA; Mallam Salahudeen Ajagbe Abdulkareem Alafara – the turbaned 10thMagaji of Ile Alafara, Alore, Ilorin and other Magajis; Alhaji Abdulwaheed Aliyu Al-Imam - the Chief Imam of Alore Central Mosque; Alhaji Musa Abubakar Babaita- the Chief Imam, Babaita Central Mosque and other Imams; late Alhaji Yusuf Amuda Al-Imam Alore (*aka*Baami Ile Kewu, my Quranic teacher); Sheikh Alhaji Muibullah Alli (MukadamTijjaniyah); Sheikh Abdulmumeen Hanafi Ayara (National Missioner, Ansarul Islam), Sheikh Abubakar Mubasir Imam Anabi-lonigba Mosque, Kuntu (who turbaned me as *Odo-adini* in the year 2000) and other Ulamau in Ilorin Emirate and Kwara State in general.

My special and immeasurable thanks go to the Tertiary Education Trust Funds (TETFund, Nigeria); Governing Board of Association of African Universities (AAU) and Carnegie Corporation of New York; The Minerals, Metals & Materials Society (TMS, USA),Dr. Oliver Rouher and Mrs Christine Salomon of Cytec Industries, Rungis Cedex, France; the Academy of Sciences for the Developing World (TWAS), Trieste, Italy; CSIR-Institute of Minerals and Materials Technology, Bhubaneswar-751013, India; Pan African Materials Institute (PAMI); MTN, Nigeria; African Leadership Institute (ALI), USA; Adisa Bakare Education Endowment Funds; Moro

L.G.A. Kwara State; Director, Mines &Cadestral Office, Abuja; and above all, the University of Ilorin for the various honours and benevolence I enjoyed in support of my research endeavours.

By extension, I sincerely appreciate the late Mr. OluFalaja; Engr. Suleiman Yahaya Alapansanpa (Dan-Masani of Ilorin); Alhaji (Prince) Abdulkadir Mahe (former Clerk of the House) & family; Alhaji (Barr.) F.A.B. Ibrahim; Engr. AbdulrasaqJimoh – FNSE & family; Alhaji R.A. Lawal; Alhaji Abubakar Korotapa; Alhaji Hanafi Abdulkareem; Alhaji SikiruSaidu, AlhajaMuslimat Ayo Umar, Alhaji Abdulmumeen Deji Imam (MD Ayoka Petroleum &Munirat Enterprises), Mr. Abdulganiyu Babatunde (PM Baglad Ltd., Toronto, Canada), Mustapha Yahaya (SIA, UK); Alhaji Moruf Oladimeji Adeshina, Alhaji Ahmed Raheem Babatunde Kobiowu; Alhaja Rahmat O. Gobir, Mr. Damon Mastandrea (*Materials Today*, Elsevier, Philadelphia, USA); Alhaji Tijani Bashiru Akanfe, Alhaji AbdulraheemAdisa, Chief Acho V. Nwaokorie, Deacon Ogugua Hilary E., Dr.&Dr. (Mrs) Olagunju – Dallas, USA, Dr.Abdulraheem S. Oba (Arewa Clinics), Alhaji Faruq Yusuf and Mrs. Olasumbo F. Oyeyemi (Former Com. for Finance & Planning, KW/S) for their supports. I will not forget the academic efforts and support of the late Barr. Imam Kayode Eleshin-nla, Alhaji & Mrs. A.O. Raji, Alhaji Sakiru Mohammed, late Alhaji J.S. Mohammed and Dr. Saliu Wahab Alafara (Ag. Provost, COE Oro). I am sincerely very grateful to you all.

To my students-*cum*-research associates: Drs. I.K. Ayinla, O.S. Ayanda, O.A. Arodola & J.O. Majasan; Awaiting Doctors F.T. Olasinde, A.S. Ibrahim, D.T. Olaoluwa, S. Girigisu, M.A. Raji, C.O. Adeyemi, F.A. Balogun & A.Y. Abdulkareem; A.A. Womiloju, Late M.O. Muhammed, Y.A. Salubi, D.O. Ojutemeiden, A. E. Nnamani, A.S. Ogedengbe, E.E. Toye, L. Ibrahim, F.A. Abubakar, A.O. Tijani, D.G. Sosanya, R.O. Sanni, A.J. Lawal, S.S. Ahmed, Lawal B. Kikelomo, J.T. Samson, O.O. Opaleye, S.E. Adeboye, F.T. Oluwaleke, J.S. Ayodele, F.T. Olajide-Aremu, D.P. Fapojuwo, R.A. Gbadamosi, A.O. Yusuf, A.Y. Abdulrasheed, Y.A. Hamzat, H.L. Muhammad, T.D. Afolabi, J.J. Fasiku,Oluwagbemiga M. Adebola, Hikmah A. Afolabi, Komolafe Zaynab, R.K. Babatunde and M.O. Ganiyu, the success of today's lecture is a collective success engendered by your collaborative efforts, ideas and inputs. I thank you very much.

I acknowledge the University's wonderful administrative and supportstaff who have indeed contributed and enriched my working experience till date: Drs. F. Olowoleni and S.A. Adisa; Messrs M. Alfa-nla, A. Abdulsalam, K.K. Babamale, T. Bamigboye, A.B. Sayuti, A.G. Dauda, late G.A. Yahaya, B.S. Baba, K.I. Akogun, A. Ahonusi, F.F. Folusho; Mrs. O. Oyeyemi, A.H. Adi, T. Oladosu, B.O. Ishola, M.B. Zakariyyah, F.M.E. Osiki (*aka* my Registrar), R.Y. Ogedengbe, R.A. Selekere, B. Momodu, A.A. Ojibara, K.W. Garba and all other Registry Staff too numerous to mention. At the Bursary wing, I thank Messrs Abiodun Saka Yusuf, A.A. Ahmed, O. Abdul-Baki, M.A. Dere, M.J. Akanbi, A. Olaniyan, O.A. Gobir, A. Lawal, B.B. Lawal; Mrs A.J. Ogbede and S.B. Durowade.

To my brothers, sisters and all my youth friends across Alafara family and extensions: Bros. Raufu Ajagbe, Alhaji Suleiman Okanla, Garba Adio, Musa Adio, Shafi Amao, Salihu Alade, Suleiman Salahudeen, Usman Ayinde, Taiye Hassan Lowo-ori, Bolanle Lowo-ori, Fasilat Abdulraheem, Abdulganiyu Lowo-ori, Kazeem Lowo-ori, SalimanYinusa Alagbede, Gafar Adio, Sule Onibata, Rasaq Raheem, Suleiman Dagi, Wahab Akata, Abdulazeez Saka and Tunde Saka Arubiewe, Raufu Salman Dagi, Raufu Atu, SalihuAdara, Raufu Busari (NYSC), Mallam Abdulazeez Arowona and Hon. Tunde Gbogiri, I value your constant advice, guidance and supports at all times. To my wonderful friends and colleagues: Drs.Sidiq Mashood, Ahmed Musa, Hanafi A. Hammed, Abdulkareem Usman, Ajadi Jimoh, HafsatAbolore Ameen, Halimat A. Abdulrahim, Lawal A. Zubair, Khadijat Abdulkareem, Sherifat Abubakar; Engr. M.J. Abdul (Rector, KwaraPoly), M.D. Ibrahim (Provost, COET Lafiagi); Hon. Justice Kamaldeen Abdul Lateef, Abdurraheem

Ahmad Sayi; Barr. Mallam Bushra Imam Aiyegbami; Messrs Ibrahim Abdulrasaq, Issa Zubair, AlikinlaMuideen Yinka, AtandaSaadu, Adeyanju Waheed, Tunde Bashorun (RIP), Nasir Ameen, Yekeen A. Salman, Wahab Garba, Ganiyu Amari, Issa Olanrewaju Bolude, SaliuRasaq Humble, Ektepo Pius, CSP Abdullahi Olatunji Bello, Hon. Issa Adara, Alhaji Taiye Ahmed Al-Imam Alore, Alhaji Ibrahim Buba& Yinka Ambali (NOSDRA, Abuja),Wale Ajetunmobi (SA to Lagos State Governor on Media); Dr. Joi Nuneieh, Ben Olofu & Engr. FiitoNwidum (HYPREP); Alhaja M.F. Fulani, F.D. Gidado, Fatimah Abolore Jimoh, Afusat Okekere, Sidikat Gidado Kankatu, Afusat Sallah; Mr. Baba Zubair, Nathaniel Pamdaya, Prince Soladoye, T.R. Muhammed, Mrs. A.F. Babalola; thank you for being part of my success story. The courageous efforts of the late Mallam Ahmad Baba-edu Alafara, Late Alhaji Isiaka Laaro Agbaji; Late Mallam Sakariyyah Amasa Arubiewe, Abdulraheem Oloja Alafara are well appreciated. My immediate neighbours at Aderoju Community, Tanke – Ilorin: Alhaji & Alhaja Umar Nda, Nasirudeen Abdulsalami, Navy Ojulari, Mustapha Apalando, Yakub Imam, Balogun, Salami, Abdulganiyu Ahmad Al-Imam; Prince & Mrs Uche Udu, Mr. & Mrs. Bode, OziYusuf, Oladimeji, Olaolu and Ariyo, I thank you all for our cordial relationship and friendship.

I thank the entire Unilorin Emirate Community, Ilorin Emirate Professors' Association, Kwara State Professors Association – Unilorin, Ilorin Emirate Descendants Progressive Union, ASUU Unilorin (Prof. M.S. Ajao – Chairperson & IPC, Dr. U.A. Raheem), Unilorin Alumni, Ilorin Anchor Men and Women Initiative, Vintage Kwara, The Moro Group, Bahjatul Islam Society of Nigeria (Mallam Tunde Babaita – President & Sheikh Imam Tajudeen Oniluru – Missioner, BISON), NACOMYO – Kwara State Chapter, Kwara State FOMWAN, Alore LSMB Old Pupils'Association (1981/82 set), Mount Carmel Old Boys Association, particularly 1986/87 set and Alore Central Development Association (Mr. Kayode S. Toyin – Chairman & IPC, Hon. Abdulrahman A. Sayuti) and Habeeb-

Rahman Society of Nigeria (Alhaji Abdulrahman Ipadeola & Sheikh Habeebullah Arikewuyo).

I sincerely appreciate my in-laws, *the Akewusola family of Ilorin*, especially my mother-in-law, Mrs Baedauh Oba Akewusola and her team, Alhaji Salman Ibrahim Akewusola and Mukadam Oba Abdulraheem Akewusola; my brothers and sisters-in-law who are all here today with their families. Thank you for giving me in marriage a preciously cute, dependable jewel from your family.

I want to express my deepest appreciation to *our children* for their love, patience, prayers, understanding and being sources of blessings: Taofeeqah, Ridwanullah, Ameenullah, Halimat and Mohammad-Nasir. Finally, I, wholeheartedly appreciate the continuous support and encouragement of my dear friend, my sister, my love, my wife: **Alhaja Mariam Alake Alafara (*Nee* Oba Akewusola).** Thank you for taking good care of my home, especially during my consistent absence in pursuance of my professional duties. Sweetheart; I love you and you are indeed a strong pillar of my success!

To all of you who have come to attend this inaugural lecture and to all who have extended a hand of fellowship to me, I pray that the Almighty Allah shower you with His abundant blessings and grant you journey mercies as you return to your various destinations.

Mr. Vice-Chancellor, sir, please permit me to end this inaugural lecture with this song: "*Olohun Oba ma l'Opetosi, Olohun Oba ma l'Ope ye ju; fun gbogbo ohunt'ose fun* **Alafara***; Oba Oluwa da kungb'Opemi***!** *Oba Oluwa dakungb'Ope-awa***!!!**

Thank you all for your attention and God bless you abundantly.

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