



**FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA**

**WASTE PLASTICS' ENVIRONMENTAL
POLLUTION: PROFFERING A HOLISTIC
SOLUTION USING BIODEGRADABLE
POLYMER BLENDS AND COMPOSITES**

BY:

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**INAUGURAL LECTURE
SERIES 120**

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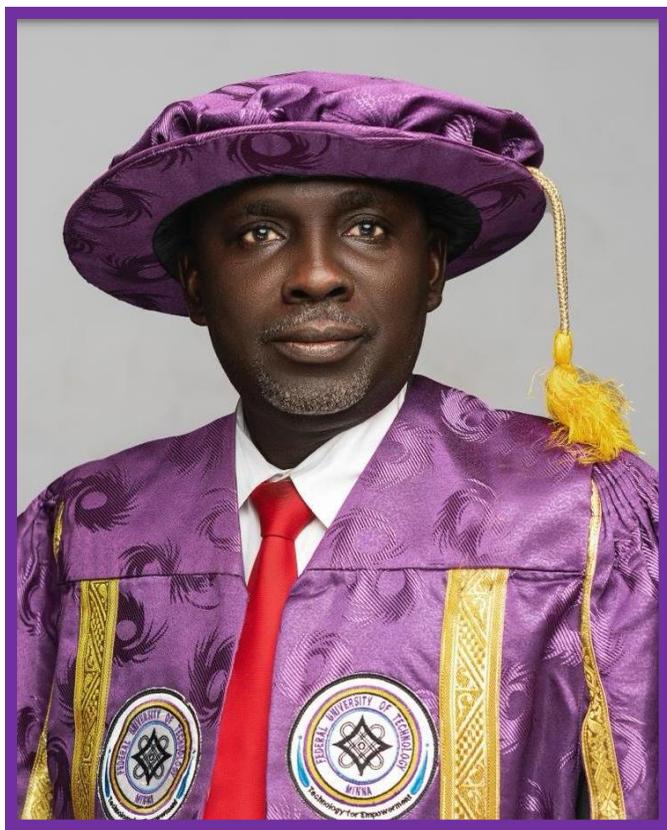
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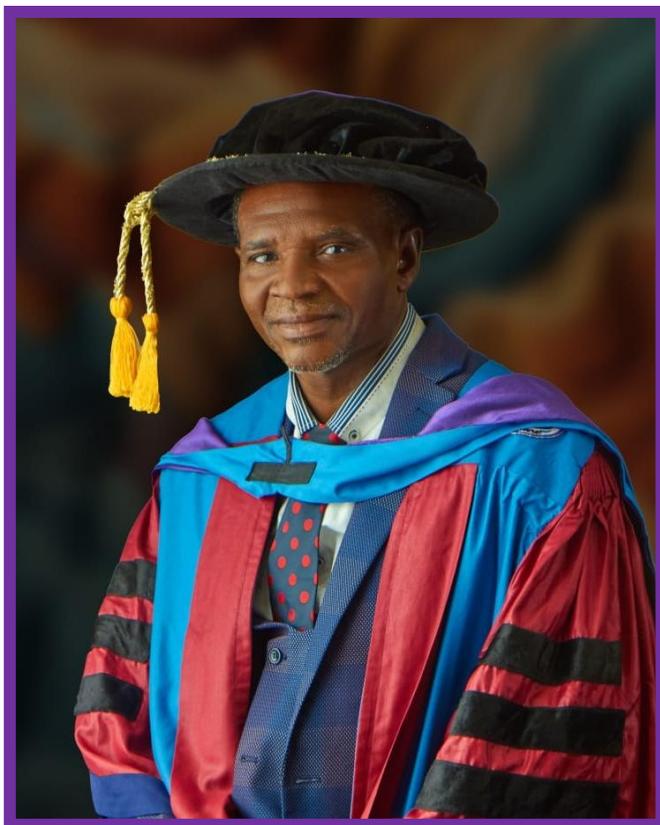
Professor of Polymer Chemistry

INAUGURAL LECTURE SERIES 120

THURSDAY 26th FEBRUARY, 2026



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B.Sc. (UDUS), M.Tech. (FUTMIN), PhD (ATBU)
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PROTOCOL

The Vice-Chancellor, Prof. Faruk Adamu Kuta; Deputy Vice-Chancellor (Academics), Engr. Prof. Abdullahi Mohammed; Deputy Vice-Chancellor (Administration), Prof. Uno Essang Uno; University Librarian, Prof. Katamba Abubakar Saka; Bursar, Dr. (Mrs.) Hadiza Goje, Registrar, Mr. Danladi Mallam; Deans of Faculties and Directors of Centres here present; all past Inaugural Lecturers here present; all Professors here present; all academic and non-academic staff here present; other members of the university here present; our esteemed scholars of my department; Cations and Anions, in particular; Distinguished Ladies and Gentlemen; Special Guests of Honour from various strata of life; online audiences; etc., all other protocols duly observed.

I am thrilled, humbled and privileged to deliver the **120th** Inaugural Lecture of this great citadel of learning, and the **6th** in series from the Department of Chemistry. The number “120” is so significant for me and this is how it is: Deuteronomy 34:7 reads thus: “And Moses was an hundred and twenty years old when he died: his eye was not dim, nor his natural force abated.” This is a divine arrangement to have the coincidence of the number of years of Moses’ life time and of the serial number of this lecture. This suggests to me that I might live up to 120 years. In other words, I am just about to reach half-life! Amen!

1.0 INTRODUCTION

Inaugural lectures are an essential part of university academic life. This event celebrates the inaugural lecturer's appointment to a full professorship. First and foremost, the inaugural lecture provides a platform for academics to present the body of research that they have been focusing on during their career. Furthermore, from the original meaning of the word ‘**Inaugural**’, which is derived from the Latin verb *augurare* meaning, ‘to take omens’, this first, formal speech by an academic appointed to the rank of professor is intended also to give his or her audience an idea of what he or she might achieve in the

future. This point is cogent because, achieving the status of a full professor does not signal the end of research but rather an entry into a phase of expanding research frontiers. The tendency to rest on one's oars or digress to seek political appointment so as to dissociate from the lifestyles of research that brought one up to the professorial rank is an aberration, and no doubt it is because of the poor financial remuneration for academics, especially in our climes. Therefore, achieving professorial status should be viewed as the beginning of even greater intellectual achievements. Also, the inaugural lecture serves as a platform for the lecturer's host institution to present its academics and share its research with members of the university community and general public in an accessible manner. Hence, it is often described as a forum between '**town and gown**'. According to Professor Uzodinma Nwala during his inaugural lecture at the University of Nigeria, this kind of lecture is so very important in academia for the following reasons: respect for academic tradition; for the sake of intellectual history ("unless the younger generation understands the point their predecessors have reached they will not know the significance of their own contributions"); for the sake of one's mentor; students and associates; and in order to engage in public discourse on one's work (UCT, 2013). Therefore, in a nutshell, 'Inaugural lectures provide newly appointed professors with the opportunity to inform their **colleagues, campus' congregations and community-at-large** of their **concluded, current and coming-up** research works.'

1.1 Profile of Polymers vs. Plastics

The term 'Polymer', which is from two Greek roots, *poly* (meaning 'many') and *meros* (meaning 'small molecules or units'), refers to a large molecule constructed from small, simple chemical units called 'monomers' (*mono*, being a Greek word for 'one') by a process known as 'polymerization'. Linear repetition is often observed, as can be seen in Table 1, which shows typical linear polymer structures (Reusch, 2024). Sometimes the chains are branched or interconnected to form

three-dimensional networks (in a similar way to a gel) (Billmeyer, 2005), which are difficult to represent structurally. An example is Bakelite, a polymer created by polycondensing phenol and formaldehyde. Bakelite became one of the first commercially available synthetic plastics around 1910.

A polymer is also called a macromolecule or large molecule because, unlike a conventional molecule, it must have a molecular mass of at least 3000 g/mol. The concept of 'macromolecules' was first suggested in 1920 by Hermann Staudinger, who was a Professor of Organic Chemistry at the Eigenössische Technische Hochschule in Zurich at the time. In a paper entitled "Über Polymerisation," Staudinger presented several reactions that form high molecular weight (>5000 g/mole) molecules by linking together a large number of small molecules. Thus, Staudinger established the concept of "macromolecules" in 1922 to describe the products. He formulated a polymeric structure for rubber, based on a repeating isoprene unit (referred to as a monomer). Despite backing up his concept with impressive experimental evidence, Staudinger encountered very strong opposition from leading organic chemists for nearly two decades. For instance, Heinrich Wieland, 1927 Nobel laureate in chemistry, wrote to Staudinger, "Dear colleague, drop the idea of large molecules; organic molecules with a molecular weight higher than 5000 g/mole do not exist." Purify your products, such as rubber, then they will crystallize and prove to be low molecular compounds!" At long last, on December 10, 1953, Staudinger received his reward for the concept of macromolecules and his prolonged effort to establish the science of large molecules when he was awarded the Nobel Prize for chemistry. Recognition that polymeric macromolecules make up many important natural materials was followed by the creation of synthetic analogues having a variety of properties and uses.

Table 1. Some Common Addition (Linear) Polymers

| Name(s) | Formula | Monomer | Properties | Uses |
|--|---|---|--|---|
| Polyethylene low density (LDPE) | $-(\text{CH}_2-\text{CH}_2)_n-$ | ethylene $\text{CH}_2=\text{CH}_2$ | soft, waxy solid | film wrap, plastic bags |
| Polypropylene (PP) different grades | $-(\text{CH}_2-\text{CH}(\text{CH}_3))_n-$ | propylene $\text{CH}_2=\text{CHCH}_3$ | <u>atactic</u> : soft, elastic solid <u>isotactic</u> : hard, strong solid | similar to LDPE carpet, upholstery |
| Poly (vinyl chloride) (PVC) | $-(\text{CH}_2-\text{CHCl})_n-$ | vinyl chloride $\text{CH}_2=\text{CHCl}$ | strong rigid solid | pipes, siding, flooring |
| Poly (vinylidene chloride) (Saran A) | $-(\text{CH}_2-\text{CCl}_2)_n-$ | vinylidene chloride $\text{CH}_2=\text{CCl}_2$ | dense, high- melting solid | seat covers, films |
| Polystyrene (PS) | $-(\text{CH}_2-\text{CH}(\text{C}_6\text{H}_5))_n-$ | styrene $\text{CH}_2=\text{CHC}_6\text{H}_5$ | hard, rigid, clear solid soluble in organic solvents | toys, cabinets packaging (foamed) |
| Polyacrylonit rile (PAN, Orlon, Acrilan) | $-(\text{CH}_2-\text{CHCN})_n-$ | acrylonitrile $\text{CH}_2=\text{CHCN}$ | high- melting solid soluble in organic solvents | rugs, blankets clothing |
| Poly (methyl methacrylate) (PMMA, Lucite, Plexiglas) | $-(\text{CH}_2-\text{C}(\text{CH}_3)\text{CO}_2\text{CH}_3)_n-$ | methyl methacrylate $\text{CH}_2=\text{C}(\text{CH}_3)\text{CO}_2\text{CH}_3$ | hard, transparent solid | lighting covers, signs skylights |
| Poly (vinyl acetate) (PVAc) | $-(\text{CH}_2-\text{CHOCOCH}_3)_n-$ | vinyl acetate $\text{CH}_2=\text{CHOCOCH}_3$ | soft, sticky solid | latex paints, adhesives |
| cis- Polyisoprene natural rubber | $-(\text{CH}_2-\text{CH}=\text{C}(\text{CH}_3)-\text{CH}_2)_n-$ | isoprene $\text{CH}_2=\text{CH}-\text{C}(\text{CH}_3)=\text{CH}_2$ | soft, sticky solid | requires vulcanizatio n for practical use |

The term "plastic", on the other hand, was derived from the Greek word "*plastikos*," meaning mouldable. The term was coined to describe the behaviour of the first macromolecular substance known as 'Bakelite', invented by Leo Hendrik Baekeland in 1907 and patented on December 7, 1909 (US Patent 942,699; Baekeland, 1909; Vlachopoulos & Strutt, 2003). Generally speaking, plastics are manufactured from raw natural or synthetic polymers via both compounding (adding modification agents) and fabrication (shaping). Among their unique physical properties are their ease of shaping, low density, corrosion resistance, electrical and thermal insulation, rigidity, toughness, and durability. In fact, it is this property of durability that has led to the practice of recycling them (Morton-Jones, 1989). Comparatively to paper and most cellulose based products, plastics have transparency and barrier properties against gaseous and waterborne microorganisms (Billmeyer, 2005; Arvanitoyannis *et al.*, 1997).

Based on their responses to heat, plastics are described as either 'thermoplastic' or 'thermosetting'. Thermoplastics (by far the largest volume) can be melted by heating, solidified by cooling and re-melted repeatedly. Major types are polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polycarbonate (PC), poly (methyl methacrylate) (PMMA), polyethylene terephthalate (PET) and polyamide (PA, nylon). Thermoplastics can be further classified according to their performance as 'Commodity' (low performance, such as PE, PP, PS and PVC), 'Engineering' (such as PC, nylon and PET) or 'Advanced' (highest performance, such as liquid crystal polymers (LCPs), polyphenylene sulphide (PPS) and polyetheretherketone (PEEK)). On the contrary, thermosets are hardened by the application of heat and pressure, owing to crosslinking, i.e. the creation of permanent three-dimensional networks. They cannot be softened by heating for reprocessing. Bakelite, epoxies and most polyurethanes are thermosets. Conventional plastics are commonly processed from synthetic polymers whose feedstocks are petroleum-based.

Apart from plastics, polymers are also encountered in our daily lives in other forms as 'fibres' and 'rubbers' (also known as 'elastomers'). Fibres and rubbers, unlike plastics, can be naturally obtained or synthesized. Natural fibres include cotton derived from the *Gossypium hirsutum* plant and wool obtained from animals, such as sheep. Natural rubber is obtained in the form of latex ('plant milk') from rubber trees, particularly the species '*Hevea brasiliensis*', which is abundantly cultivated in the Niger Delta region, in the South-West zone of Nigeria. The world's first fully synthetic (man-made) fibre is 'nylon'; it was created in 1939 by Wallace Carothers' group in DuPont in Seaford, Delaware, using common raw materials such as coal, water and air, and was first commercialized at the New York World's Fair of 1939-40, in Flushing Meadow Park in Queens, . Synthetic rubber, usually termed 'elastomer', emanated first in Germany in 1920 as an alternative to natural rubbers, which became inaccessible during World War I. The first elastomer, called **Buna S** by Germans but known as **SBR** (styrene-butadiene rubber) by the British, used essentially for manufacturing tires, was a copolymer obtained by simultaneous polymerization of styrene and butadiene using an emulsion process.

There is, however, no firm dividing line between synthetic fibres, elastomers ('synthetic rubbers') and plastics. A synthetic polymer normally used as a fibre may make a perfectly good plastic if no attempt is made to draw it into a filament. Similarly, a plastic, if used at a temperature above its glass transition and suitably crosslinked, may make a perfectly acceptable elastomer. By examining the stress-strain characteristics of plastics, fibres, and rubbers under mechanical testing conditions, it is possible to distinguish them more thoroughly (Cowie, 1973). Fibres, which usually consist of filaments or strands are resistant to deformation when acted upon by stress/heat. A plastic material, on the other hand, is relatively susceptible to deformation, whereas an elastomer or rubber material exhibits large reversible elongations under small-applied stresses, or elasticity.

1.2 Public Perception of the Profits of Plastics

A few decades ago, Lord Tedd, President of the Royal Society of London, in answer to the question, “*What do you think has been Chemistry’s biggest contribution to science, to society?*” responded thus: “*I am inclined to think that the development of polymerization is perhaps the biggest thing chemistry has done, where it has had the biggest effect on everyday life. The world would be a totally different place without artificial fibres, plastics, elastomers, etc. Even in the field of electronics, what would you do without insulation? And there you come back to polymers again*”.

Plastics, the most common polymer in general, are used everywhere, in a variety of ways. Whether it's the small throwaway candy wrapper, diverse shopping plastic carriers, artificial tissues for organ replacements (‘tissue engineering’) or drug delivery systems to deliver drugs to their targets, plastics touch our lives like no other class of materials, and there are no limits to the benefits and uses of this material. Plastics have virtually replaced metals, wood and other materials in various commodities of life. Meats are packaged on plastic trays, and the specialty cheese counter uses plastic cling wrap. Only beer and wine are bottled in glass, and even then, wine corks are often made of plastics. Clothing industries use polyester fabrics extensively. Without plastics, skiers won’t have access to synthetic insulation that wicks away sweat; bikers won’t have those ubiquitous form-fitting outfits or colourful helmets, and garments that are “all cotton” will wrinkle. Maybe three-piece, all-wool suits will still sell well in New England (because of the prevailing extremely cold climate) but something lighter and cooler is required in the Southwest. Further, plastics are used widely in the construction industry, as well as in durable items like appliances, furniture, and lead-acid battery casings. Most carpeting is made of synthetic fibres. Vinyl plank flooring, as well as foam insulation, are synthetic plastics. Plumbing and modern room ceilings are mostly polyvinyl chloride (PVC) plastics. They are also seen in nondurable products, such as disposable diapers that work because of their polypropylene content that draws moisture away from baby’s skin; trash bags (made from HDPE or LDPE); cups; utensils; medical devices, such as surgical gloves,

serum bags and intravenous (IV) tubes and household items, such as shower curtains, which are all intended as single-use products.

In all of these uses, plastics used for packaging purposes are the most ubiquitous. It is estimated that 41 % of synthetic plastics are used in packaging, and that almost half of that volume is to package food products (Kumar *et al.*, 2011). This development is attributed to our fast-paced lifestyles which demand convenience and single-serving pre-packaged foods. Overall, plastic use worldwide is projected to almost triple by 2060.

1.3 Problem of Plastics' Pollution in the Environments

By plastic pollution is meant the ubiquitous hazards of plastic wastes arising mainly from their indiscriminate disposal in our environments. Ecologically, the term “Environment” is the sum of all external conditions and influence affecting the life and development of organisms. Two main aspects of the environment are usually considered, namely the ‘abiotic’ and the ‘biotic’. Abiotic or physical environment includes all those physical and non-living chemical aspects which exert an influence on living organisms. Among these factors are soils, water, and the atmosphere, as well as energy from various sources (gravity, pressure, sound, and so on). On the other hand, the ‘biotic environment’ consists of living organisms, which both interact with each other and are inseparably interrelated with their abiotic environment’. Both categories of the environment are affected by plastic pollution. Rich Gower, a senior economist at Tearfund, said: “The signs of environmental breakdown are all around us...” By this, he was actually referring indirectly to the effect of plastic waste on our environment. Most plastic pollution comes from inadequate collection and disposal of large plastic debris known as “macroplastics”, but leakage of micro-plastics (synthetic polymers smaller than 5 mm in diameter) from things like industrial plastic pellets, synthetic textiles, road markings and tyre wear, and worse still, recent reports indicate nanoplastics are also a serious concern. It is observed that 50 % of plastics produced are meant for use on a single basis, meaning that

they cannot be re-used again and, because they are synthetic plastics derived from petroleum, they are durable, non-biodegradable and hence, can remain in existence for hundreds of years in the environment leading to increase in the volume of street litters or municipal solid. Nearly $\frac{2}{3}$ of plastic waste comes from plastics with lifetime under 5 years, with 40% coming from packaging, 12% from consumer goods and 11% from clothing and textiles. Examples of such plastics include PET used for soda bottles and cloth fibres; PET plastics account for half of the clothing fibre the world produces. Polystyrene for packaging, LDPE for cling wrap and grocery bags, and HDPE for shampoo bottles and milk jugs are major sources of waste plastics. Almost on daily basis, used items and wrappings are casually discarded and replaced in a never-ending cycle. Some municipalities have designated certain areas as dumpsites where all the trash or municipal solids are disposed of, such as the one shown in **Figure 1**. “Much of the plastic being used in sub-Saharan Africa is plastic packaging and ends up being dumped and burned,” according to Rich Gower. Burning of these plastics leads to the release of obnoxious gases into the atmosphere, aggravating air pollution.



Figure 1. Waste pickers scour the Kasese dump site in Kisumu, Kenya for valuable items Photograph: Edwin Ndeke/The Guardian, Wednesday, 8 November, 2023

During heavy rains or wind storms, some waste plastics at dumpsites get swept away, causing blockages in waterways intended to control erosion or ending up in the ocean. It is estimated that about 20 tons of plastic waste gets dumped into the oceans and seas every minute. Every year, the ocean is polluted with up to 13 million tons of plastics. Only 1% of them are seen floating with 99% eventually sinking and collecting in ocean gyres where they get broken up into unrecoverable microparticles, resembling planktons and so are ingested by marine wildlife at the detriment of their survival. 1 out of 3 fish caught for human consumption contains plastic. 100% of baby sea turtles have plastic in their stomachs. Some of the most obvious victims are the dead seabirds washing ashore in startling numbers, their bodies packed with plastic: things such as bottle caps, cigarette lighters, tampon applicators, and colour scraps that, to a foraging bird, resemble baitfish, as illustrated in **Figure 2**. (One animal dissected by Dutch researchers contained 1,603 pieces of plastic.) More than a million seabirds, 100,000 marine mammals, and countless fish die in the North Pacific each year, either from mistakenly eating this junk or from being ensnared in it and drowning.



Figure 2: Impact of plastic consumption on animals and marine life
(Source: seagoinggreen.org, as cited in Rai, 2023)

Furthermore, these waste plastics in the oceans hinder aquatic navigation and smother coral reefs. Charles Moore, an American oceanographer, in 1997 discovered an enormous stew of trash, estimated at nearly 100 million tons, floating in the Pacific Ocean between San Francisco and Hawaii. Named the "Great Pacific Garbage Patch", this stew of trash is composed largely (80%) of bits and pieces of plastic that outweigh the plankton 6: 1, in a region over twice the size of Texas. Although some of this flotsam originates from ships at sea, at least 80% comes from land generated trash. At the rate we are using plastic, the problem of waste it generates is set to increase tenfold. In 'The Guardian Newspaper' of Wednesday, November 8th, 2023, as reported by Karen McVeigh, plastic waste is "spiralling out of control" across Africa, where it is growing faster than any other region. At current levels, enough plastic waste to cover a football pitch is openly dumped or burned in sub-Saharan Africa every minute, according to charity Tearfund. If the trend continues unabated, the region is projected to end up with 116m tonnes of plastic waste by 2060, six times more than the 18m tonnes of waste produced in 2019. Plastics account for 34% of global GHGs (greenhouse gases), which are believed to be the cause of impending apocalypse. The presence of GHGs beyond required threshold is what is exacerbating global warming and climate change. These GHGs are carbon dioxide (CO₂), water vapour (H₂O), methane (CH₄), nitrous oxide (N₂O) and industrial gases, namely, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF₆), and nitrogen trifluoride (NF₃), which are collectively known as 'F-gases', and ozone (O₃) in the lower atmosphere, to mention a few important ones. Among these gases, CO₂ is the largest contributor to global warming, followed by methane and nitrous oxide (typically <20%), with F-gases contributing the least (<5% of the total) in spite of their high Global Warming Potentials. Water vapour's level is linked to the temperature and so is called 'feedback'. Unlike CO₂ which can last for several years, water vapour is only temporary.

2.0 PRESCRIPTIONS AGAINST PLASTICS' POLLUTION

a) Directive on the Practice of Circular Economy:

A circular economy, illustrated in Figure 3, involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products as long as possible. In other words, it is a system of resource utilisation in which elements are reduced, reused, and recycled. In this way, the life cycle of products is extended. In practical terms, it implies waste reduction to the barest minimum achievable.



Figure 3. Illustration of circular economy (Source: futurerecycling.com.au, as cited in Rai, 2023)

This is a departure from the traditional ‘*linear economy*’, which advocates a take-make-consume-throw away pattern. The application of the circular economy in the current management of plastics globally revolves around the following practices, each of which, nonetheless, has its peculiar shortcomings which are also highlighted alongside each discourse.

(i) Reuse

There used to be a popular maxim, “If you can’t re-use it, refuse it”. Unfortunately, because polymeric substances generally overtime undergo oxidative degradation leading to leaching out of its

constituent additives originally used in processing them, re-use of old plastics pose risks of contamination into what is contained inside them. Moreover, reuse plastics are more susceptible to contaminations of pathogenic bacteria and also heavy metals than their corresponding virgin plastics as obtained from manufacturing source (Aliyu *et al.*, 2017).

(ii) *Reduce*

In some countries, there is stringent environmental legislation against manufacturers of plastic products that imposes on them to adopt reduction approach by producing less than the operational capacity their set-ups would require. This in some way constitute economic loss when weighed against the investment costs expended on the acquired processing machinery. Moreover, with soaring population, the demand to satisfy the conveniences offered by single-use plastics could not be met under the circumstances.

(iii) *Recovery of Energy*

The energy potential of plastic waste is relatively significant, ranging from 10.2 to 30.7 MJkg⁻¹, suggesting application as an energy source and temperature stabilizer in municipal incinerators, thermal power plants and cement kilns. This, however, depends on using appropriate materials since inadequate control of combustion, especially for plastics containing chlorine, fluorine and bromine, constitutes a risk of emitting toxic pollutants.

(iv) *Recycle*

To date, in the United States, despite her technological advancement, less than 10 % of plastic products are recycled at the end of their useful life (Kumar *et al.*, 2011). This low level of recycling is attributed to the difficulty experienced in sorting out contaminants as much of the waste plastic is mixed up with other materials in the domestic and industrial waste streams. One serious problem in recycling is posed by the many additives found in plastic waste. These include pigments for colouring, solid fibres in composites, stabilizers and plasticizers. Consequently, this approach tends to be economically not feasible due to the high cost of collection, separation and cleaning of the recycled

materials. Furthermore, recycling is almost exclusively applicable to thermoplastics as against the thermosets (e.g. Bakelite, epoxies and most polyurethanes) which are almost unrecyclable. Currently, most of the thermoset composite waste is not properly recycled and it is either incinerated (42.6%) or diverted to land fill (24.9%). There are several strategies being implemented to extend plastic recycling. Recently, the University of Limerick, Ireland, as part of EU project, is researching using bio-based bonding materials (BBM) to find new ways to improve the recyclability of thermoset composite materials. In another recent development, new knowledge about molecular mechanisms that make biocatalysis possible is opening up biotechnological processes that allow new way of recycling of plastics possible. A research project led by a team from the Universitat Jaume I, Spain, has made it possible to degrade widely used PET plastics through natural enzyme, CALB, by modifying the pH of the medium. They are also now exploring a means to advance in the degradation of other plastics such as polyurethanes, another type of synthetic polymer widely used today
(www.reinforcedplastics.com/content/features/biobased-composite-recycling).

Recycling in manufacturing has taken the form of using recycled plastic as filler in cement blocks, ropes, and household goods as baskets and mats. At larger scale, manufacturers are using recycled plastics and textiles to make clothing and furniture. The plastics industry is keenly exploring on chemical recycling where additives are used to alter the chemical structure of waste plastic, turning it back into substances that can be used as raw materials, perhaps for making fuel like petrol and diesel. Pyrolysis, the thermal disintegration of carbonaceous material in an oxygen-starved atmosphere applied to plastics results in the conversion of plastic into value added fuel products (Mohana Jeya Valli *et al.*, 2012). When optimized, the most likely compounds to form are methane, carbon monoxide, hydrogen, carbon dioxide and water molecules. However, this approach has been criticized by environmental groups preferring non-carbon-based

renewable energy sources, besides being costly and inefficient. Furthermore, the approach is unsuitable for polymeric wastes that contain halogenated component, such as PVC, as it can lead to generation of products with varying molecular weights and uncontrolled Cl content. The Cl component must be removed from any waste plastic derived gas or oil before it can be used. One possible means to achieve this is by catalytic dichlorination, which converts the Cl component to HCl, which is easily separated from the target product (s).

Recently, a new recycling technique was evolved by Professor Erwin Reisner of Cambridge University. The technique transforms CO₂ and plastic into **syngas**, or 'synthetic gas, also known as 'water gas'. Syngas is a mixture of carbon monoxide and hydrogen and is used as a fuel gas; it is so named because it is used for synthesis of a number of hydrocarbons and a wide range of chemicals including glycolic acid which is widely used in the cosmetics industry.

Whether used as fuels or a source of recycled plastic, plastic waste must be separated into different categories. To this end, an identification coding system was developed by the Society of the Plastics Industry (SPI) in 1988 and is used internationally. This code, shown in **Figure 4**, is a set of symbols placed on plastics to identify the polymer type, for the purpose of allowing efficient separation of different polymer types for recycling. The abbreviations of the code are explained in **Table 2**.



Figure 4. Identification codes for various recyclable plastics

Table 2. Abbreviations and meanings of common recyclable thermoplastics

| ABBREVIATION | MEANING |
|--------------|---|
| PETE | Polyethylene terephthalate |
| PP | Polypropylene |
| HDPE | High density polyethylene |
| PS | Polystyrene |
| V | Polyvinyl chloride |
| LDPE | Low density polyethylene |
| Other | Polyesters, acrylics, polyamides, Teflon etc. |

The plastic trash from most households, even with some user separation, is a mixture of unidentified pieces. Recycling of such mixtures is a challenging problem. A float/sink process has proven useful as a first step. When placed in a medium of intermediate density, particles of different densities separate-lower density particles float while those of higher density sink. Various separation media have been used, including water or water solutions of known density (alcohol, NaCl, CaCl₂ or ZnCl₂). The cylindroconical cyclone device, shown in **Figure 5**, provides a continuous feed procedure in which the material to be separated is pumped into the vessel at the same time as the separating media. Some polymers, such as polystyrene and polyurethane, are commonly formed into foamed solids that have a much lower density than the solid material (<https://www2.chemistry.msu.edu/faculty/reusch/virttxtjml/polymers.htm#radical2>).

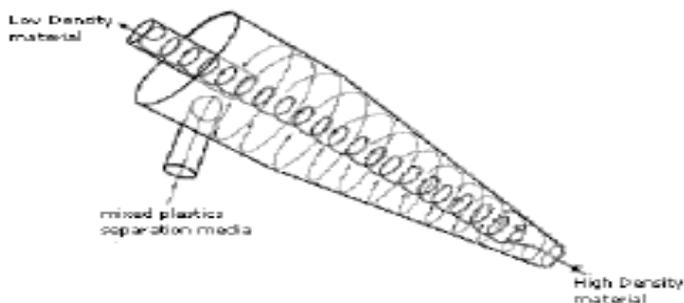


Figure 5. A cylindroconical cyclone device for separation of different plastics based on differences in densities

Despite its many challenges, recycling still remains to date the most recommended way of effectively controlling synthetic plastic waste in the context of circular economic model. In any case, recycling must be recognized as a disposal technique, not a final goal for material development.

b) Land Fill Sites

Up to 60% of the waste plastic generated in Europe still goes to landfills. Worldwide, 79% of plastic waste ends up in landfills or the ocean, while only 9% is recycled, and 12% is burned. Around 10% of all landfill waste in the world is from the fashion and textile industries, most of which cannot be recycled (Corbley, 2024). It is reported that 30 lorry loads of plastic waste are dumped every day at the Dandora landfill site in Kenya. The site has become a breeding ground for mosquitoes, flies and vermin, increasing the risk of malaria, cholera, diarrhoeal disease and other illnesses (McVeigh, 2023). Similar scenarios are replicated in various countries located in sub-Saharan Africa.

c) Global Regulations by Governments and NGOs

Concerted campaigns, legislations, taxations, etc., are being put in place by governmental and non-governmental organizations against plastics production and disposal. Some countries, including Germany, South Africa, and Australia, have banned, taxed, or restricted the use of plastic bags because they clog sewers and lodge in the throats of livestock. Some few years ago, China has insisted to ban hypermarket operators from providing free-of-charge plastic bags to consumers (Rahmat *et al.*, 2009). There are a number of European Directives in place (notably the Waste Packaging, End of Life Vehicle and Electrical/Electronic Equipment Directives) that set increasingly stringent standards to minimize environmental impact due to waste plastic (Aguado *et al.*, 2006). In a bid to tackle plastic pollution, the European Commission proposed a plastic strategy in January 2018 with the aims of ensuring that by 2030 every piece of plastic packaging can be reused or recycled, as well as of reducing the consumption of single-use plastics and the use of micro-plastics.

These Directives particularly target a decrease in plastic waste sent to landfill and encourage an integrated approach to encompass prevention of waste at the production stage (reduction), reuse to extend productive lifetime, recycling and energy recovery. A treaty under the auspices of the UNEP is also underway to combat plastic pollution. This treaty aims to curb plastic crises and improve the lives of billions of people by proposing the Zero Draft policy on eradication of plastics pollution, including in the marine environment. The Zero Draft policy was prepared by the Intergovernmental Negotiating Committee (INC) under the observation of UNEP on September 4, 2023, after approximately a year of deliberations. According to the Draft, all countries must take necessary measures to prevent and mitigate the potential for adverse impacts on human health or the environment arising from production of primary plastic polymers, including their feedstock and precursors. UNEP, an intergovernmental organization consisting of 175-member nations with headquarter at Nairobi, Kenya, met there from November 13 to 19, 2023 to adopt the policy. The meeting in Nairobi was supposed to advance the process by fine-tuning the draft treaty and starting discussions about what concrete measures should target pollution from plastic, which is made from fossil fuels. However, the terms of the treaty weren't really discussed; Iran, Saudi Arabia and Russia were accused of employing stalling tactics to impede progress during previous round of negotiations. The European Parliament approved new rules in April 2024 to reduce, reuse, and recycle packaging. The new rules specify that EU countries should ensure: that by 2029, 90% of single-use plastic and metal beverage containers must be collected separately; efficient recycling processes; a 5% reduction in packaging waste by 2030 compared to 2018, then a reduction of 10% by 2035 and 15% by 2040; that from January 2030, specific types of single-use plastic packaging will be banned, including plastic bags used for unprocessed fresh fruit and vegetables, or packaging for foods and beverages consumed in cafés and restaurants; that any packaging made from plastic will have to include a minimum percentage of recycled content

from plastic waste. *The stark reality of these meeting outcomes is that single-use plastics have become so part and parcel of our conveniences in life that banning them, which zero plastic pollution aims at, is much easier said than done.*

d) Nigeria's Government Actions

Nigeria first announced a national policy to curb plastic waste pollution in 2020 when total annual plastic waste was around 1.5 million metric tonnes. Since then, plastic waste has risen sharply in fast growing cities like Lagos, with an estimated population of between 17-20 million, and where research by the United Nations Environment Programme (UNEP) this year found that an estimated 50-60 million used water sachets are thrown into the streets daily. Nigeria government has been vigorously advocating for the recycling option. The Federal Government of Nigeria (FGN) is collaborating with states to establish plastic waste recycling plants under the community-based waste management programme of the Federal Ministry of Environment. Two plants have been completed; one in Ilorin, Kwara State and another in Lokoja, Kogi State, while work is ongoing for another in Karu LGA of Nasarawa State. FGN via the National Agency for Science and Engineering Infrastructure (NASENI) has signed a partnership deal with Alon Green Recycling which will focus on the design, fabrication and production of plastic recycling machinery and equipment. The 5-year MOU pact was sealed on Wednesday April 26, 2023, in Abuja. In further commitment to mitigate plastic pollution, Nigeria made good its promises on Thursday May 18, 2023, by joining the World Economic Forum's Global Plastic Action Partnership, when she launched her own domestic form of the platform known as National Plastic Action Partnership (NPAP). Nigeria's NPAP shall work with government, businesses and civil society to address plastic pollution by promoting circular economy practices and collaborating with various stakeholders to take care of plastic waste from production to consumption and reuse. Furthermore, the National Environmental Standards and Regulation Enforcement Agency (NESREA) in

collaboration with the Forestry Research Institute of Nigeria (FRIN) has intensified efforts to reduce plastic pollution in Nigeria. This was the highpoint of their talks in this 2023 World Environmental Day which has as its theme, 'Beat the Plastic Pollution' as similar to 2018.

In January 21, 2024, Lagos State, through Tokunbo Wahab, the Commissioner of the Ministry of the Environment and Water Resources for Lagos State announced a ban on the usage and distribution of Styrofoam and other single-use plastics widely used in food service and delivery by street vendors. Styrofoam is a trade name of a type of polystyrene used mostly for food packaging in Nigeria. Single-use items include bread plastic bags, diapers, condoms, straws, etc., which are discarded after they are used once. The reason for this action is that they clog drains and water channels. In the Daily Trust of 25 June 2024, it was reported that the Federal Government of Nigeria has banned the use of single-use plastics, otherwise known as disposable plastics, across all Ministries, Departments, and agencies (MDAs). Clearly, the option of bans on plastics is hitherto unpopular and seems to create greater problems than it is intended to solve. Matt Seaholm, a former Executive Director of the American Recyclable Plastic Bag Alliance, has stated that government bans drive up costs and interfere with decisions that should be made by consumers and business owners.

3.0 PLASTICS POLLUTION PREVENTIVE PILL: BIODEGRADABLE POLYMER BLENDS & COMPOSITES

3.1 Preview of Biodegradable Blends and Composites

The term "biodegradable" refers to their ability to be subject to chemical degradation provoked by the action of naturally occurring micro-organisms such as bacteria, fungi, and algae (Leja and Lewandowicz, 2010). Biodegradable materials degrade into biomass, carbon dioxide and methane, which are all stable products found also in nature. Thus, the end-products of degradation of biodegradable materials are environmentally benign. A material is biodegradable

when oxygen (O) and nitrogen (N) are present in its molecular structure, which makes it hydrolysable, whereas synthetic petroleum-based polymers are not biodegradable due to their lack of these atoms. The inherent biodegradability of these polymers also means that it is important to control the environment in which the polymers are used, to prevent premature degradation. Natural polymeric materials from plants, such as carbohydrate, lignin, cotton, natural rubber, protein, or from animals, as for example, wool, chitin, chitosan and protein (muscle fibre) are biodegradable.

However, to make biodegradable polymers usable commercially, they must be processed into their corresponding blends or composites. Blending refers to the physical mixing of two or sometimes more pre-existing polymers. Although, blends are physical mixtures nominally, in practice, the process can result in some covalent chemical bonding between the component polymers, i.e., some grafting could occur which is often beneficial and encouraged. Blending is one of the most active areas of growth in polymer work in industries and academia and provides a fastest means of new product development without going through synthesis. In contrast, polymer composites involve the addition of fillers (fibres or particulates) into polymers to achieve reinforcement or bulk. Depending on the nature and type of fillers, their incorporation affects properties such as opacity, mechanical, thermal, electrical, etc., and cost effectiveness. Furthermore, the fillers can be in sizes ranging from micro- to nano-scale dimensions, which again make a significant impact on the properties of the final products. Using nano-scale fillers via nanotechnology results in products with a unique and wide spectrum of properties that offer to meet a broad range of applications.

Biodegradable polymer blends or composites can be processed into **plastics**, fibres and elastomers, using extrusion and moulding technologies much like the synthetic polymers derived from petroleum, while the former still retain their advantages of environmental friendliness.

3.2 Possibilities of Biodegradable Blends and Composites

The history of the beginning of application of biodegradable polymer composites can aptly be traced to the Book of the beginning (Genesis) in the Holy Bible. In Genesis 6: 14, in order to save Noah and his household prior to destruction of the world because of detestable corruption and violence in the world of that time, God instructed Noah to **“Make thee an ark of gopher wood; rooms shalt thou make in the ark, and shalt pitch it within and without with pitch”** (Plate I). Also in the biblical Book of Exodus (Exodus 2: 3-6), the mother of Moses, as a means to save his life from extant edict by Pharaoh to destroy all the males of the captive Hebrews, **“took for him an ark of bulrushes, and daubed it with slime and with pitch, and put the child therein; and she laid it in the flags by the river’s brink”** (Plate II) The both arks were kinds of cellulose fibre-reinforced composites. From these two Biblical accounts, the life-saving potential of natural polymers is thus established from creation.

The first secular documented interest in producing plastic from renewable resources, however, came from Henry Ford around 1910 and finally in 1941, using soybean waste as raw material, in combination with other components as reinforcing fillers, Ford successfully produced a “plastic car” (Plate III.) (Farrin, 2005).



Plate I. Noah’s Ark made from cellulosic-fibre reinforced composite



Plate II. Moses’ basket of bulrushes based on cellulose fibre-reinforced composite



Plate III. Henry Ford's plastic car made from renewable and biodegradable resources

Nevertheless, public enthusiasm for biodegradable plastics did not gain momentum until 1960s when the negative impact of plastic wastes from synthetic polymers began to assume a worrisome dimension. As a result, polymer blends and composites based on, for example, polysaccharides have been investigated for a wide range of applications, including (Khan *et al.*, 2021):

- (i) *Drug delivery*: Drug delivery refers to approaches, formulations, technologies, and systems for transporting a pharmaceutical compound into the body as needed to safely achieve its desired therapeutic purposes. With these systems, you can precisely target where and how quickly a drug is released in the body. A key component of drug delivery systems is natural polymers.
- (ii) *Tissue Engineering*: Tissue engineering encompasses the creation of biomaterial scaffolds aimed at addressing or renewing impaired tissue (Adekunle, 2015).
- (iii) *Wound healing*: Wounds manifest as irregular disruptions in the skin, resulting from thermal/physical trauma or ongoing health conditions (Karaky *et al.*, 2019). Numerous biopolymers, such as fibrous proteins and diverse polysaccharides, play crucial roles in wound management and therapy. These biocompatible, biodegradable polymeric matrices mimic the extracellular

environment, expediting the typically sluggish wound healing process (Mohan & Kanny, 2019).

- (iv) *Packaging*: Starch-based plastics have been favoured for development of biodegradable plastics for packaging. Also, derived from starch are foam materials which exhibit insulation properties akin to commercially produced polystyrene foam (Kalambur & Rizvi, 2006). However, starch-based foams are susceptible to moisture when stored in high relative humidity environments. To address this issue, blends of thermoplastic starch (TPS) with hydrophobic polymers are being employed as oxygen barriers on a commercial scale (Alavi & Rizvi, 2005). Blends containing starch with higher amylose content demonstrate enhanced dimensional stability (Lescher *et al.*, 2012).
- (v) *Aerospace industry*: The biocomposites, with advantage of their lightweights, find utility in crafting various components of aircraft interiors, including seats, decks, and flooring, as well as external body panels. However, for integration into aircraft structures, biocomposites must exhibit robust characteristics such as high moisture resistance, flame retardancy, and superior specific strength (Kuram, 2022). Despite their lower flame retardancy, which raises concerns about their suitability for aircraft use, biocomposites can be judiciously applied in crafting interior structures like cabin components, decks, seats, and flooring, where fire hazards are comparatively reduced. Notably, cabin interior panels have been fabricated using phenolic resin and woven flax (John *et al.*, 2008).
- (vi) *Construction industry and interior decorations*: Biocomposites find extensive application in the construction industry, where they are utilized for crafting windows, doors, window frames, ceilings, floor mats, and roof tiles. Examples of load-bearing applications include floor slabs, beams, pipes, and tanks (Zwawi, 2021). Wood-plastic composites (WPCs) contribute to the fabrication of tables, decks, benches, floorings, and landscape

timbers. Furthermore, biocomposites play a crucial role in the repair and rehabilitation of various structural components (Mosallam, 2014). Natural fibre composites serve as effective insulating and soundproofing materials, owing to their superior thermal and acoustic properties. However, before integrating biocomposites into construction practices, considerations such as life cycle assessment, durability, and environmental impact are paramount. Achieving low weight and mechanical properties equivalent to synthetic composites is crucial in processing biocomposites for building applications.

In contrast to the circular economy strategy, landfills, and international legislation/regulations that focus on disposing of waste plastics, biodegradable polymer composites and blends offer a new product development strategy that promises to address waste plastics' environmental problems holistically.

4.0 PERSONAL CONTRIBUTIONS

The assessment of an academic for an appointment to the rank of professor involves three perspectives:

(i) *Teaching*

(ii) *Research*, and

(iii) *Community services*

Teaching: This is the practice of imparting knowledge to learners through processes that consist essentially of instruction, demonstration and involvement. Over the past three decades, I have been and am still involved in teaching various polymer-based courses at both undergraduate and postgraduate levels. I was a key player in the Committee set up in the early 90's for the introduction of the current Industrial Chemistry Option of our department. Moreover, Vice-Chancellor Sir, with the utmost humility, I wish to inform you that the course contents for our Master of Technology in Polymer Chemistry postgraduate degree programme were put together solely by me. In 2016/2017, during my sabbatical at Baze University, Abuja,

I replicated a similar feat by introducing postgraduate programmes in the Department of Chemistry.

Completed Research Work: Polymer Science and Technology, in general, is an interdisciplinary field of knowledge, with research work spanning wide spectrum of subject disciplines, such as Biology, Physics, Engineering, Microbiology, etc., to mention a few of them. And indeed, Mr Vice-Chancellor, Sir, so has been my research voyage. However, for the purpose of this inaugural lecture, I have delimited the presentation of my contributions to those that are cognate to the topic of the Day. In the past years of my research work falling within the purview of the lecture, I laid emphasis on the utilisation of our (Nigerian) abundant local resources that have great potential, but remains under-exploited, both in research and development. These resources are to be harnessed into useful products for the well-being of our nation's citizens. Nigeria is endowed with extensive raw materials, derived from animals, as for example, the hides and skins from cattle, and from plants, as for example, natural rubber from rubber trees in the Niger Delta region, starch from tubers (cassava, potatoes, yams, etc.) and grains (rice, maize, millet), cotton, etc. as well as lipids, which are present in both plants and animals. These natural resources are repositories of latent opportunities both for academic research and industrial exploitation, for national development.

My first major work (Ochigbo & Ibemesi, 1994), in this field of local resources, was focused on the investigation of highly promising locally sourced vegetable oils (rubber seed, watermelon seed, and soyabean) in order to find a species or blends among them to substitute imported linseed oil, a drying oil favoured for development of alkyd resin binders for oil paints. In carrying out the investigation, oxygen-induced polymerisation of blends of fatty acids from rubber sees (RSA), watermelon seed (MSA), soyabean (SBA), and linseed (LSA) was done with a view to optimising the drying performance of the semidrying ones. The amount of oxygen absorbed by the fatty acid is directly proportional to the drying tendency, measured in terms of

iodine value, of the corresponding oils. This work resulted in the identification of rubber seed oil as a near substitute to linseed oil as seen from the iodine values displayed (**Table 3**). Also, the results obtained showed two types of behaviour in oxygen absorption: a linear response by LSA/RSA and SBA/RSA blends in which there is steady increase in oxygen absorption with increase in the amount of the more drying fatty acid (**Figures 6 & 7**), and a synergistic response by blends containing MSA, in which there is dramatic increase in oxygen absorption in the region of 40-50 per cent MSA followed by a fall (**Figures 8 & 9**). This behaviour is termed 'synergistic' because the blending effect is greater than the sum of the individual.

Table 3. Iodine values and fatty acid composition of the oils

| Oil | Iodine* value | Fatty acid composition (%) | | | | Source |
|------------|------------------|----------------------------|-------|----------|-----------|----------------------|
| | | Satd. acids | Oleic | Linoleic | Linolenic | |
| Linseed | 175.45 | 10.00 | 20.00 | 17.00 | 53.00 | Hilditch (1947) |
| Rubber | 137.54 | 15.30 | 21.90 | 38.20 | 24.30 | Eka (1977) |
| Soyabean | 128.80 | 13.70 | 24.90 | 52.70 | 7.90 | Shreve (1956) |
| Watermelon | 113.80 | 25.90 | 19.00 | 55.10 | - | Girgis & Said (1968) |

*Experimentally determined by us

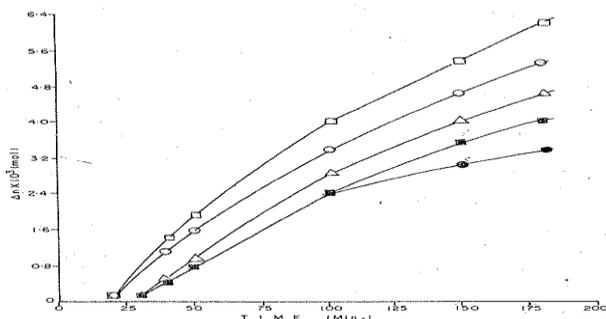


Figure 6. Plots of change in oxygen concentration Δn versus time for LSA/RSA blends: ● LSA 20/RSA 80; ■ LSA 40/RSA 60; △ LSA 50/RSA 50; ○ LSA 60/RSA 40; □ LSA 80/RSA 20 at 30 °C

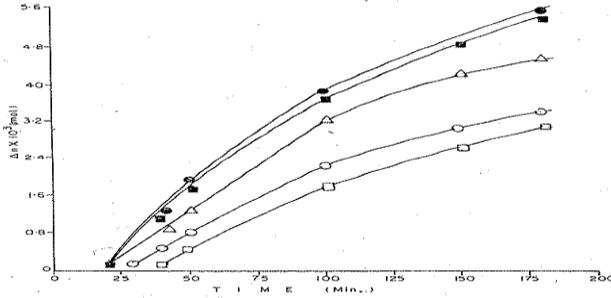


Figure 7. Plots of change in oxygen concentration Δn versus time for RSA/SBA blends: \square RSA 20SBA 80; \circ RSA 40/SBA 60; Δ RSA 50/SBA 50; \blacksquare RSA 60/SBA 40; \bullet RSA 80/SBA 20 at 30°C

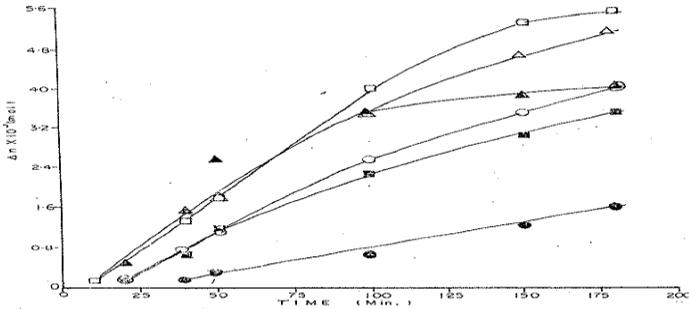


Figure 8. Plots of change in oxygen concentration Δn versus time for LSA/MSA blends: \bullet LSA 20MSA 80; \blacksquare LSA 40/MSA 60; \blacktriangle LSA 45/MSA 55; Δ LSA 50/MSA 50; \circ LSA 60/MSA 40; \square LSA 80/MSA 20 at 30°C

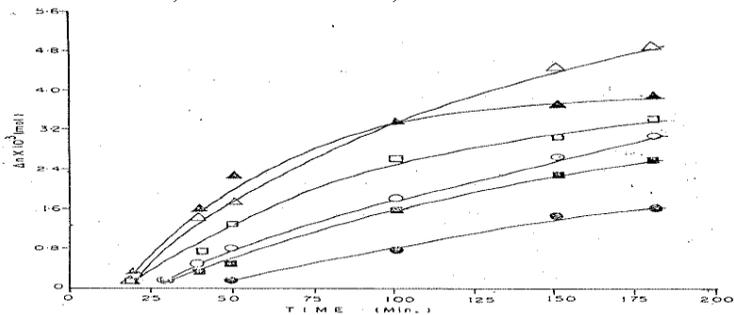


Figure 9. Plots of change in oxygen concentration Δn versus time for SBA/MSA blends: \bullet SBA 20MSA 80; \blacksquare SBA 40/MSA 60; \blacktriangle SBA 45/MSA 55; Δ SBA 50/MSA 50; \circ SBA 60/MSA 40; \square SBA 80/MSA 20 at 30°C

Further study was carried out in order to ascertain the actual drying/curing mechanism which is the essential characteristic required for deciding the suitability or not of an oil acting as an oleoresinous binders (i.e., binders for formulation of oil paint formulation). The study investigated the effect of the presence of excess fatty acids on the drying/curing behaviour of drying oil admixed with drying catalysts. The oxygen absorption behaviours of Linseed oil (LSO) and rubber seed oil (RSO) on one hand, and that of their corresponding free fatty acids, namely linseed fatty acids (LSA) and rubber seed fatty acids (RSA) on the other hand were first compared followed by drying tests of same samples using the set-to-touch method. Results obtained showed the following order of oxygen absorption behaviour: LSA>LSO>RSA>RSO (**Figure 10**). Although oxygen absorption is a stage subsequent to drying process, the drying behaviour, however, did not follow the same trend with the oxygen absorption pattern. Whereas the oils/drier mixtures underwent drying between 3 and 4 h after they were casted as thin films, the fatty acids did not at all even in presence of varying concentrations, up to maximum of 50 wt., % of the curing agent. Therefore, the presence of free fatty acids in drying oils is assumed to be capable of hampering the curing of the latter. Hence, it is recommended that drying oils intended as oleoresinous binders for surface coatings be refined so as to remove or reduce to the barest minimum of their free fatty acids content in order to obtain products with optimum drying rate at reasonable time period (Ochigbo & Ajai, 2011).

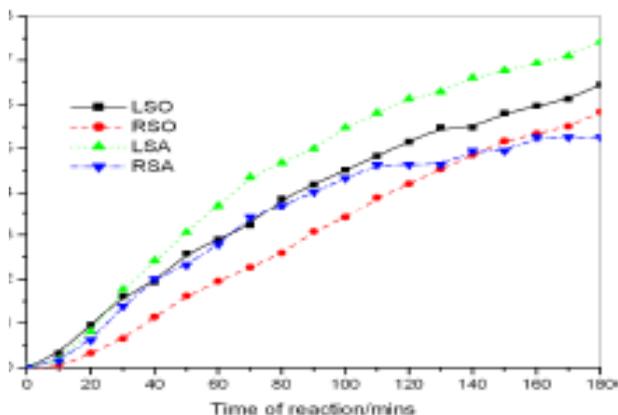


Figure 10. Plots of change in oxygen absorbed vs. time for pure oils and corresponding fatty acids

It is suggested that the drying/curing process is enhanced in the oils due to the three-dimensional structure of the triglyceride while the oxygen absorption more pronounced on the side of the fatty acids due to participation of the exposed carboxyl ion groups ($[COO^{2-}]$) in catalysing the process (Mraz & Silver, 1965). After this, several other works on latex from natural rubber tree were carried out which were reported in the literature (Ochigbo *et al.*, 2009; Ochigbo *et al.*, 2010; Ochigbo *et al.*, 2011^a; Ochigbo *et al.*, 2011^b; Ochigbo & Luyt, 2011; Ochigbo, 2013). Driven by the passion to transit from the laboratory to pre-industrial stage, also known as the Pilot plant stage, further efforts resulted in the development of a novel binder based on latex blends of the natural rubber (NR) latex with polyvinyl acetate (PVAc) emulsion which was used for production of waterborne paint (Ochigbo & Suleiman, 2014). This feat indeed became a milestone achievement as it clinched an award of national patent same year (Ochigbo *et al.*, 2014, Nig. Patent No.: NG/P/2014/212, Nig. Patent and Design Act; CAP 344 Law of the Federation of Nigeria 1990). The binder has successfully been evaluated according to NIS specifications through the Quality Control Laboratory of Nycil Ltd., Sango-Ota. Currently, it has a pilot plant at the Raw Materials Research and Development Council (RMRDC), Technology and

Innovation Complex, sited at the National Space Research and Development Agency (NASRDA), along Airport Road, Lugbe, in FCT, Abuja, Nigeria (**Plates IV-VII**). With an average production cycle of 45 minutes, the plant has demonstrated a capacity of 80-100 buckets of waterborne paint per batch.



Plate IV. Dr. S.S. Ochigbo (the researcher) and the Fabricator of the Paint Mixer, Mr. James S. Eniolorunda, Jaysecom Integrated Resources Ltd., No. 7 Olaide Street, Sango-Otta, Ogun State at RMRDC's Technology and Innovation Complex, located at the National Space Research and Development Agency (NASRDA), Lugbe, Airport Road, Abuja, Nigeria



Plate V. Staff of the RMRDC and those of RMRDC's Technology and Innovation Complex, located at the National Space Research and Development Agency (NASRDA), Lugbe, Airport Road, Abuja, Nigeria during a production process



Plate VI. L-R: Mr Namburu Vijay Kumar Bhaskar (General Manager-Operations, NYCIL LTD, Sango-Ota; Mr. Abimbolu Sunday Babatunde (FCSN, FICCON), CEO of BlendTech Ltd. Lagos & Chairman, Paint Manufacturers Association of Nigeria (PMAN) at NYCIL Complex, Sango-Ota



Plate VII. Prof. Nehemiah Maina, Department of Chemical Engineering, ABU Zaria, one of the External Evaluators of the Waterborne Paint Project at RMRDC's Technology and Innovation Complex, located at the National Space Research and Development Agency (NASRDA), Lugbe, Airport Road, Abuja, Nigeria

Afterwards, in further studies PVAC which is a petroleum resource was replaced by starch in the development of a waterborne paint binder based on starch and natural rubber latex blends (Ochigbo *et al.*, 2018). The resulting paints were comparable to two standard commercial acrylic-based paints and met the Nigeria Institute of Standards (NIS) specifications (**Table 4**).

Table 4. Characteristics of waterborne paints from starch/NR latex binders (Ochigbo *et al.*, 2018)

| Category of Starch/NR Latex Blends as Binder | Parameters | | | |
|--|----------------|------------------------------|-------------|-------------------------------|
| | Viscosity (cp) | Density (g/cm ³) | pH | Set-to-touch drying time/mins |
| Unmodified starch/NR Latex | 58.00 | 31.11 | 8.00 | 40.00 |
| Sodium acetate -modified starch/ NR Latex | 75.00 | 38.15 | 9.10 | 55.00 |
| Acetic anhydride -modified starch/ NR Latex | 65.00 | 35.88 | 8.50 | 50.00 |
| Maleic anhydride -modified starch/ NR Latex | 55.00 | 32.00 | 8.45 | 35.00 |
| Ginger -modified starch/ NR Latex | 52.00 | 29.74 | 8.25 | 35.00 |
| (Sodium acetate-adipic acid) -modified starch/ NR Latex | 30.00 | 24.92 | 9.00 | 28.00 |
| (Sodium acetate-fumaric acid) -modified starch/ NR Latex | 60.00 | 32.42 | 9.20 | 47.00 |
| Commercial acrylic paint-A | 59.00 | 30.00 | 8.55 | 52.00 |
| Commercial acrylic paint-B | 62.00 | 34.00 | 8.75 | 58.40 |
| Nigeria Institute of Standards (NIS) for waterborne paint | 60.00 | 25.00 | 9.00 | 48.00 |

Next, I focused solely on starch, an abundant and cheap local resource, which is also obtained from plants, much like natural rubber latex. Starch is widely distributed in various edible tubers (e.g. of cassava, potatoes) and grains (e.g., rice, maize corn, millet, guinea corn, etc.). As part of my research in starch (Ochigbo *et al.*, 2012; Ochigbo *et al.*, 2015; Adamu *et al.*, 2020; AbdulRasheed-Adeleke *et al.*, 2022), I focused on developing biodegradable thermoplastic films for food packaging, where I envision a potential for finding a holistic solution that addresses the negative environmental effects of petroleum-based single-use plastics (SUPs). The objective of Ochigbo *et al.*, (2012) was to create glycerol-plasticized starch films with lanthanum hydroxide nanoparticles as reinforcing fillers. It was expected that this

nanofiller, which shows an affinity toward OH groups, would strongly affect the physical properties of thermoplastic starch (TPS). The pure TPS and the TPS-La (OH)₃ nanocomposite films (with 1, 2, and 3 wt. % filler) were conditioned at various relative humidities (RHs) (35, 57, 75, and 99% RH). After conditioning at 99% RH, the pure TPS films exhibited higher affinity toward water than the nanocomposites. Differential scanning calorimetric (DSC) measurements showed that, due to retrogradation effects, the melting enthalpies of the films increased with increasing RH. Dynamic mechanical analysis (DMA) revealed that the mechanical properties in the linear range strongly depend on both the humidity conditions and the concentration of the filler. The results also show that La (OH)₃ nanoparticles are good reinforcement for TPS films. This work was carried out at the Department of Chemistry, University of the Free State (Qwaqwa Campus), South Africa, while undertaking my Postdoctoral fellowship in the Department's Polymer Research Group headed by Prof. A.S. Luyt (**Plate VIII**).



Plate VIII. Polymer Research Group, Department of Chemistry, UFS, Qwaqwa Campus, Phuthaditjhaba, South Africa

In the work by AbdulRasheed-Adeleke et al., (2015), cassava starch was used as the starch source. The study examined the effect of acetic acid and citric acid modification of cassava starch on the biodegradability of their films reinforced with lignin and nanofiber. Results showed that water absorption capacities and weight loss in soil due to enzyme degradation were significant with TPS (thermoplastic starch) while modified starches had slower and lower values. Thus, the acetic anhydride and citric acid modification improved the cross-linking of native starch, making it less susceptible to water absorption and less biodegradable but not affecting its overall biodegradability. Not only that, optimization of the production of the thermoplastic starch (TPS) films was carried out according to the Box-Wilson Central Composite Design (CCD) with one centre point, using Response Surface Methodology (RSM). The film identified to be optimum contained 4.81 wt. % lignin and 5.00 wt. % nanofiber. The moisture absorption (MAB), tensile strength (TS), Young modulus (YM) and percent elongation (PE) of the identified film were 17.80%, 21.51 MPa, 25.76 MPa and 48.81%, respectively. The addition of lignin and cellulose nanofiber to starch composite was found to have reduced the moisture-absorption tendency significantly and, as well, increased the mechanical properties of the films due to the good filler/matrix interfacial adhesion (AbdulRasheed-Adeleke *et al.*, 2022). In the Adamu *et al.*, (2020) study, the effects of locally sourced (Pyata village in Bosso LGA, Niger State, Nigeria) clay as a filler on the thermal properties (differential scanning calorimetry (DSC), thermogravimetric analysis (TGA)) of cassava-based thermoplastic composite films were studied. The study demonstrated that the sample with compositions of glycerol, starch and clay corresponding to 17.50 wt. %, 70.00 wt. % and 12.50 wt. %, respectively was the most thermally stable, having an onset degradation temperature of 245.68 °C and a maximum degradation temperature of 277.96 °C., based on the TGA. From the DSC of the films, it was revealed that the same sample also has the highest melting temperature of 119.47 °C, with a

corresponding enthalpy of 163.64 J/g. The films produced have shown the potential to be used for packaging.

In pursuit of advancing the development of biodegradable thermoplastic starch films to commercial scale, Prof. Egwim from our university and I have entered into a collaboration with other esteemed researchers at AUST, Abuja, for the fabrication of a locally produced biodegradable plastic manufacturing machine. As a result, a patent has already been issued in 2025 (Onwualu *et al.*, 2025, Nigerian Patent No.: RP: NG/PT/NC/O/2025/17179, Nigerian Patent and Design Act, 1990, CAP 344).

In addition to the development of biodegradable thermoplastic films, I have also collaborated with my colleagues to investigate the use of a biodegradable synthetic polymer, specifically polyhydroxybutyrate (PHB), as nanocomposites for the treatment of electroplating wastewater (Bankole *et al.*, 2017; Bankole *et al.*, 2019). We remain challenged in this part of our world by the lack of potable water for drinking and other needs. The synthetic polymer was functionalized with carbon nanotubes, making it a nanoadsorbent applicable to electroplating wastewater treatment.

On-going and Future Research Work

In 2021, three of us at this university were awarded an NRF-Tetfund grant to research water-resistant particle boards (PB), in which petroleum-based resins such as urea-formaldehyde and phenol-formaldehyde, were replaced with starch for wood adhesives. Petroleum-based plastic waste was converted into liquid using a novel, low-cost processing method and used to produce a water-repellent wood finish. As a result of the novelty of this on-going project, we were granted a patent in 2025 (Ochigbo *et al.*, 2025, RP: NG/NC/O/2025/17767; Nigerian Patent and Design Act; CAP 344 Laws of the Federation of Nigeria 1990), making it my third patent in series.

To develop TPS films, my previous studies and those of several others reported in the literature relied primarily on starch obtained from sources that serve as staple foods for human consumption. With an ever-growing population and a limited supply of food, it is imperative to find sources of starch that aren't directly involved in human consumption in order to produce non-edible food packaging plastics. Consequently, one of my current research involves the use of starch from the Amura plant (*Tacca involucrate*), a relatively unknown food source for humans, to produce biodegradable films for applications such as food packaging. In collaboration with Co-researcher Prof. W.W. Focke (Emeritus), who retired recently, preliminary investigations (XRD and SEM) have been conducted on this starch at the Institute of Applied Materials (IAM), University of Pretoria (UP), Republic of South Africa. In the study so far, results have shown the possibility of processing Amura starch into biodegradable thermoplastic films. It is anticipated that further work will be conducted with the Advanced Polymer Composite Laboratory of the Centre for Scientific and Industrial Research (CSIR), South Africa, with which this university has signed an agreement. This project is expected to receive funding attention from RMRDC, Abuja, Nigeria.

In my future research plans, I will continue to focus on the use of natural polymers, especially starch, to develop targeted drug delivery systems for the treatment of cancers and other diseases across the blood brain barrier, as well as applying nanotechnology to create smart coatings having extended and unique properties over and above conventional coatings, such as those that could serve in obscuring visibility by enemies in military combat operations. Investigation of the potential of biodegradable polymers in our locality for tissue engineering will also be part of my future research, if God permits.

Community Services: Traditionally, community services are services rendered by academics for the benefit of his or her local community using the knowledge and experience gained from the teaching process

and the research carried out over the years. This could be done within or outside of the university community with which he or she is familiar. A few of the services I have provided include external examiners for Masters and Doctoral theses at our country's universities and universities in South Africa, as well as free plastics consultancy services to individuals and managers. I also served as Editorial Advisors to various peer-reviewed journals, including Journal of Raw Materials (JORMAR), a publication of the Raw Materials Research and Development Council (RMRDC); Nigerian Journal of Polymer Science and Technology (NJPST), published by the Polymer Institute of Nigeria (PIN), to mention a few; and the donation of state-of-the-art research equipment to the department on 21st December, 2016. Recently, I chaired a strategic project meeting, which brought together distinguished academics from various institutions in Nigeria to develop a roadmap for the management of plastics' environmental problems in Nigeria. Occasionally, I also give guest lectures at school graduation ceremonies and professional societies' lecture series. Additionally, I am involved in a variety of community-based social responsibilities. Besides all these, I am also a Minister of the Gospel of Jesus Christ, providing moral guidance to my congregations for making them heaven-bound.

5.0 PERSONAL PROPHECY ON PROSPECTS OF PLASTICS

The reason there are so many plastic wastes is because plastics are widely used and popular due to their relevance in providing conveniences in line with contemporary fast-paced lifestyles. Plastics have gained popularity year after year due to their low cost, light weight, strength, and adaptability to a variety of applications. Due to their convenience, attractiveness, and flexibility, plastics are ubiquitous, unlike other commodities. As the demand for lightweight materials increases in sectors such as aeronautical, wind energy, transportation, automotive, construction, and other end-use industries, plastics will likely remain relevant despite their pollution-related challenges. As artificial intelligence (AI) is becoming a bigger part of

our daily lives, smart plastics will become more and more important. Therefore, instead of banning plastic altogether, we should promote improved methods for disposing of and recycling plastic waste, while also encouraging the production of biodegradable plastics. The point is that 'plastics themselves **are not the problem but how they are used and disposed of after use**' is the critical issue. So, I make the following recommendations for an effective waste plastics policy in Nigeria:

- SUPs (single-use plastics) which are the major contributors to plastic waste should be recycled into RUPs (regular use products).
- To facilitate the ease of sorting and recycling, legislation should be passed to permit the disposal of used plastics according to their different types in homes, offices, public places, etc.
- Free shopping plastics given out by retailers and shop operators should be prohibited under the laws. Purchasers of goods should pay for the plastic bags needed for their purchases. In this way, plastic bags can be reused and SUPs won't be disposed of indiscriminately.
- The government and wealthy individuals should provide research grants for novel proposals aimed at turning plastic waste into sustainable value-added products. One such initiative recently came from “UNDP Nigeria Global Plastics Innovation Programme” (GPIP) which made a Call for Proposals aimed at “*Reimagining Nigeria's Plastic Crises through Grassroots Innovation*”. 13th June, 2025, was the deadline given for proposals.
- Encourage R&D focused on the production of biodegradable single-use plastics.
- The Nigerian Government, in particular, should take into confidence experts' advice in the management of issues concerning plastics, through collaboration with the Polymer Institute of Nigeria (PIN).
“DON'T BLAME PLASTICS, rather DUMP BLAME ON PROFITEERS OF PLASTICS”

6.0 PROFILE OF THE PRESENTER: PROF. STEPHEN SHAIBU OCHIGBO

Stephen Shaibu Ochigbo was born on 8th September 1966, in Ojakpama-Adoka, Otukpo Local Government Area, Benue State. His parents were Mr Ochigbo Ameh and Madam Awa Okpanachi. His father was a farmer, a blacksmith and served as an arbitrator in disputes among community members during his days. Shaibu's mother sold smoked dry fish as a profession. Shaibu started his primary education in 1973 in his village and completed it at LEA Primary School, Okpaflo-Adoka, located about 4 kilometers from Ojakpama-Adoka. He attended post-primary education from 1978 to 1983 at St. John's Secondary, Amoke, Otukpo (now the 'Apa') Local Government Area, Benue State. He was admitted through JAMB to the MBBS programme at the University of Maiduguri, but by divine Providence ended up as a Chemist instead of a Medical Doctor with a Bachelor of Chemistry (Hons) in 1987. The Benue State of Nigeria supported Ochigbo Stephen Shaibu with a scholarship during his undergraduate studies. He undertook the one-year mandatory National Youth Service Scheme (NYSC) from 1987 to 1988 with a primary assignment as a Chemistry teacher at 4 Air-Borne Battalion Army Day Secondary School, Ogoja, Cross River State.

Mr. Ochigbo earned his Master of Science degree in Pure & Industrial Chemistry in 1992, with Polymer Chemistry as a specialization. The Federal University of Technology, Minna, appointed him as an Assistant Lecturer in 1994, when Dr (now, Prof.) E. R. Sadiku was Head of the Chemistry Department. He registered for his PhD part time in 2000, at the Federal University of Technology, Minna, and secured a grant from the Raw Materials Research and Development Council (RMRDC) in 2003, to develop a waterborne paint binder using natural rubber latex and this was related to his PhD research.

From January-June 2006, at the invitation of Dr. E.R. Sadiku who had relocated to South Africa, Mr. Ochigbo was offered a research

working visit to the Centre for Polymer Technology (CPT) of the Tshwane University of Technology (TUT), where he undertook his PhD laboratory work under the supervision of both Dr. E.R. Sadiku and Prof. W.W. Focke of the Department of Chemical Engineering, University of Pretoria (UP), South Africa. He completed his PhD in Polymer Chemistry in 2007, as the first PhD product of his department, under his home-based Major Supervisor, Dr. (now, Prof.) M.A.T. Suleiman.

Dr. Ochigbo was offered a postdoctoral research fellowship, from June 2008 to December 2009, at the Department of Chemistry, University of the Free State (Qwaqwa Campus), South Africa, within a Polymer Research Group led by Prof. A.S. Luyt. It was then that he pioneered research into the development of biodegradable thermoplastic films from starch, in collaboration with Prof. Vladimir Djoković, a Principal Research Fellow at the Vinča” Institute of Nuclear Sciences, University of Belgrade Laboratory for Radiation Chemistry and Physics, Serbia, who was a visiting scientist in that department during the same period.

In 2014, Dr. Ochigbo obtained a National Patent (RP: NG/P/2014/212) for development of a novel waterborne paint binder based on the RMRDC R & D project. In 2016, he won the first prize position at the 25th Convocation Ceremony's research exhibition of the Federal University of Technology, Minna, and the second prize position in the Science and Technology Exhibition at the 6th Edition of the Nigerian Universities Research and Development Fair (NURESDEF) organized by the National Universities Commission (NUC) in collaboration with the Nnamdi Azikiwe University, Awka, held from the 7th to 11th March, 2016.

Since his post-doctoral experience, Dr. Ochigbo has focused his research on developing biodegradable thermoplastic films using starches that are not derived from staple crops that serve as sources of

human food. Dr. Ochigbo was appointed Professor of Chemistry in October 2017. As a testament to his impressive research on starch-based films, Prof. Ochigbo, along with his co-researchers were credited with another National Patent in 2025 (RP: NG/PT/NC/O/2025/17179) for an innovative idea on the design of a “Starch-based biodegradable production machine”, as a step subsequent to commercialization. This was shortly followed by an additional patent for the novel development of a starch-based adhesive particle board with a water-resistant coating from synthetic waste plastics (RP: NG/NC/O/2025/17767).

From his appointment as Assistant Lecturer to date, the lecturer has served as a departmental Examination Officer, level advisor many times, an undergraduate and postgraduate Project Coordinator, a school SIWES Officer, and on various committees within the university to date. While on sabbatical leave at Baze University, Abuja, Prof. Ochigbo served as Head of Chemistry department. Prof. Ochigbo is the current Chairman of the Polymer Institute of Nigeria (PIN), Minna Chapter; was recently appointed an Editorial Adviser to *Journal of Raw Materials Research* (JORMAR), a publication of RMRDC; Associate Editor of the *Nigerian Journal of Polymer Science & Technology*, a publication of the Polymer Institute of Nigeria (PIN), among others. Professor Ochigbo has supervised four Ph.D. students, authored two book chapters for Elsevier and contributed to several national and international journals.

7.0 PRAISE-WORTHY PERSONALITIES (ACKNOWLEDGEMENTS)

First and foremost, I wish to thank my **Heavenly Father**, the Almighty God who bare me on eagles' wings and brought me up from cradle to contemporary times. Reflecting upon God's past deeds, I would say unequivocally that '**He hath done all things well**' in my life. My employment into FUT Minna was miraculous! Next, I would like to appreciate my father, Ochigbo Ameh of blessed memory, from

whom I learnt the virtue of firmness, courage and other qualities that go into the making of a man. “No man succeeds without a good woman behind him. Wife or mother, if it is both, he is twice blessed indeed” (**Godfrey Winn**). I thank God for my mother, Awa Okpanachi (**Plate IX**), who moulded me and set me in the path of God’s destiny for my life. I lack the time and space to elaborate on her contributions to my life.



Plate IX. My mother and I

I would also like to acknowledge my late sister, Regina, who was very supportive throughout my basic education (primary and secondary). It was through her connections that I was able to gain admission to St. John's Secondary School, Amoke, Apa (formerly 'Otukpo') LGA in Benue State, which was highly competitive at the time.

As you know, no significant success story has ever been achieved without the home front, in terms of a nuclear family. I got married to my wife here in Minna! God blessed me with a **wise, wonderful and**

winsome wife; a workaholic par excellence, a wealth-creator and warrior in prayer. After the demise of my mother, with whom I was very much attached to during her life time, my wife due to her companionship became a succour. In **Genesis 24:67**, it is written that *“And Isaac brought her into his mother Sarah’s tent, and took Rebekah, and she became his wife; and he loved her; and Isaac was comforted after his mother’s death”*. Proverbs 14: 1 says: **“Every wise woman buildeth her house but the foolish plucketh it down with her hands”**. Due to my wife's love and devotion to me and our children, even with the vicissitudes I have encountered, my success trajectory continues to blossom undeterred. I am referring to none other than the woman called "Mrs Harriet Ochigbo"; help me celebrate her! I pray, she lives on to eat the fruit of her labours in full satisfaction. I thank our children, namely Victoria, fondly called ‘Vicky’, Grace, aka, Virtue, Daniel, aka, Dankoko, Samuel or ‘Mesoma’ and last but not least, Divine, or ‘Ochanya’ meaning “the Queen of women”, for always being very cooperative through the many inconveniences due to my work demands. Whenever I went overseas on a research trip, their understanding and prayers kept me in good spirits.

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entrusted the onerous responsibility of the Head of Department of Chemistry and, with their cooperation coupled with divine assistance, before I left, NUC accreditation for the undergraduate programme and resource verifications for Masters' degree curriculum I put together for the department went through successfully.

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