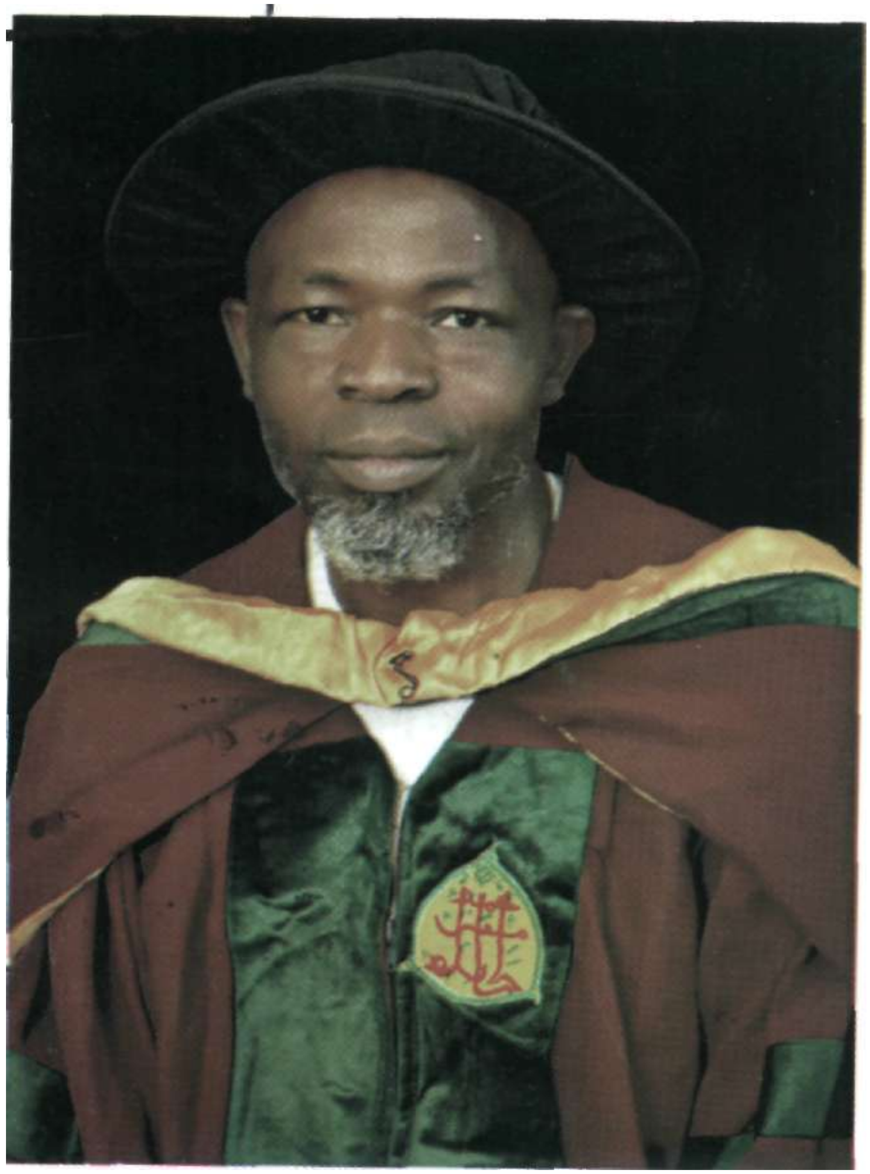

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PTDF Chair Professor of Chemical Engineering

Materials Development: Frontier of Technological Advancement

An Inaugural Lecture

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1.0 Introduction

Technology, general term for the processes by which human beings fashion tools and machines to increase their control and understanding of the material environment. The term is derived from the Greek words *tekhnē,* which refers to an art or craft, and *logia,* meaning an area of study; thus, technology means, literally, the study, or science, of crafting (Encarta, 2009).

Many historians of science argue not only that technology is an essential condition of advanced, industrial civilization but also that the rate of technological change has developed its own momentum in recent centuries.

Materials innovation has been associated with early phase of technological development. For example, it was wide accepted that improved steel products have been important source of improved vehicles, even though it was not clear as to what proportion of the overall technology development in real quantity can be accounted for by materials innovation. Recently, workers have attempted to quantify the role of materials innovation in technological progress. One approach was to analyze major innovations over time from journal articles, key patents and commercialized processes that involved new materials.

2.0 Overview of Trends in Technological Advancement

The trend in technological advancement in the recent past can be discussed for the Energy and Information sectors as illustrations. Energy sector may be sub-divided into energy storage, energy transport and energy transformation while information sector may be sub-divided into information storage, information transport and information transformation.

Figure 1 presents an example of functional performance metric (FPM) for energy transformation in specific power (watts/litre of fuel) from 1890 to 2002. The plots showed the various innovations achieved over time and the exponential improvements in energy transformation over this period (Koh and Magee, 2008). Figure 2 presents a second example of FPM for generic function of information storage in megabit/cc from 1890 to 2004. The plots also showed continuous exponential curve at a greater progress rate than for energy transformation. Figures 3 to 6 present the FPM for the other sub-divisions of the two sectors.

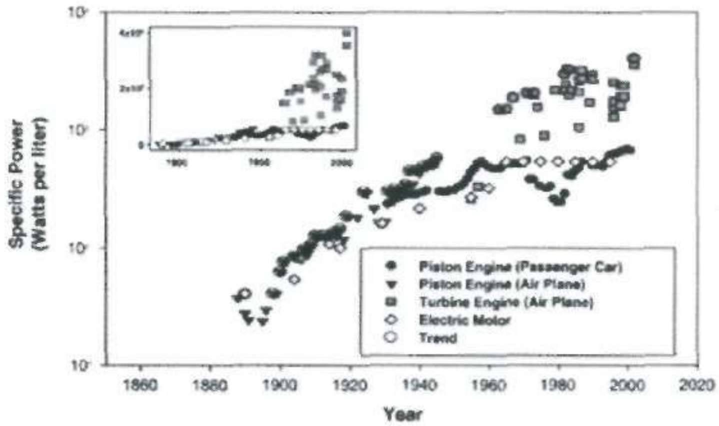


Figure 1: Functional performance metric for energy transformation (Koh and Magee, 2008)

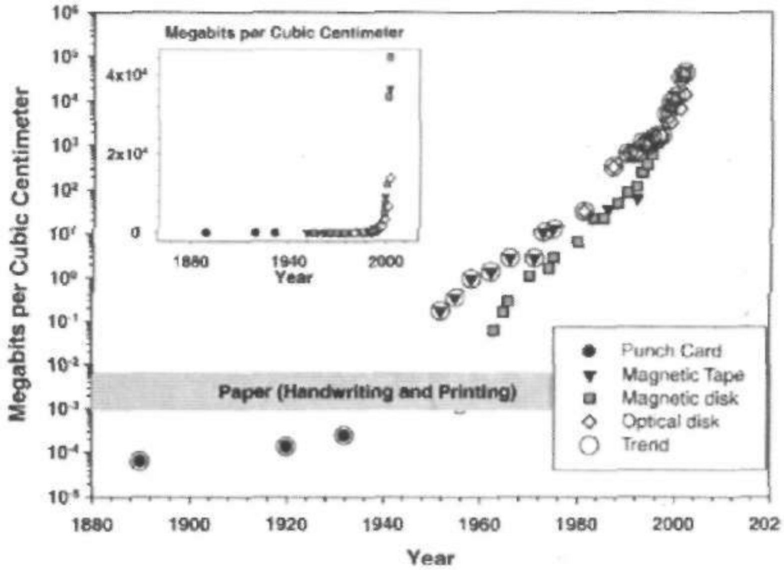


Figure 2: Functional performance metric for generic function of information storage (Koh and Magee, 2008)

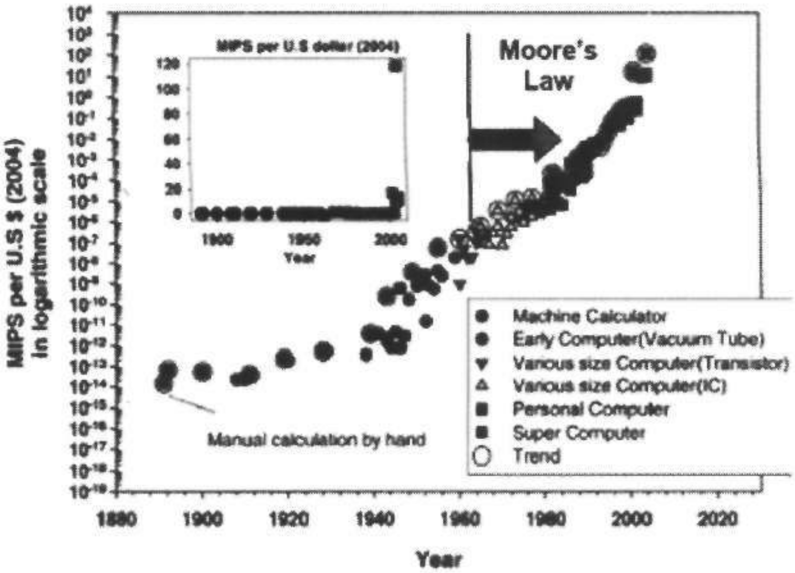


Figure 3: Functional performance metric for information transformation in millions of computations per second per dollar with time

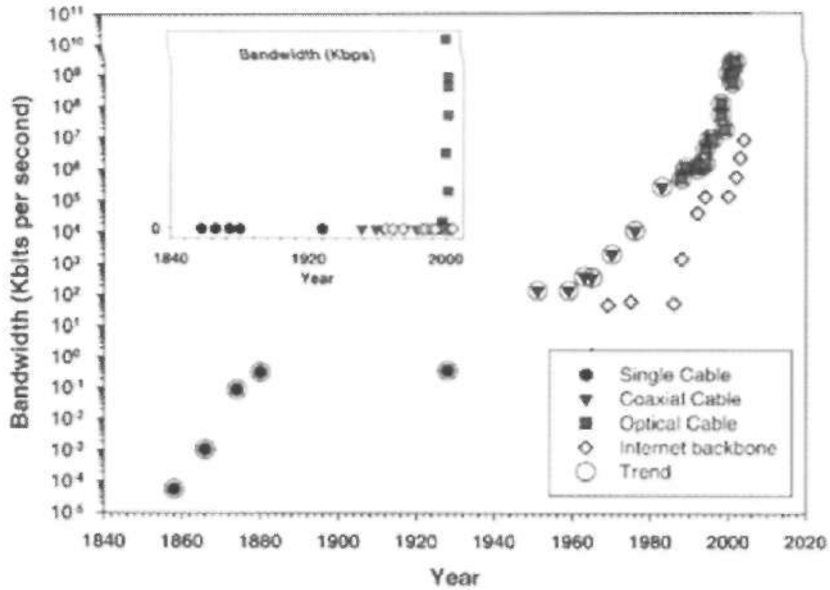


Figure 4: The change in bandwidth for the underseacable system over the past150 years (Koh and Magee, 2008)

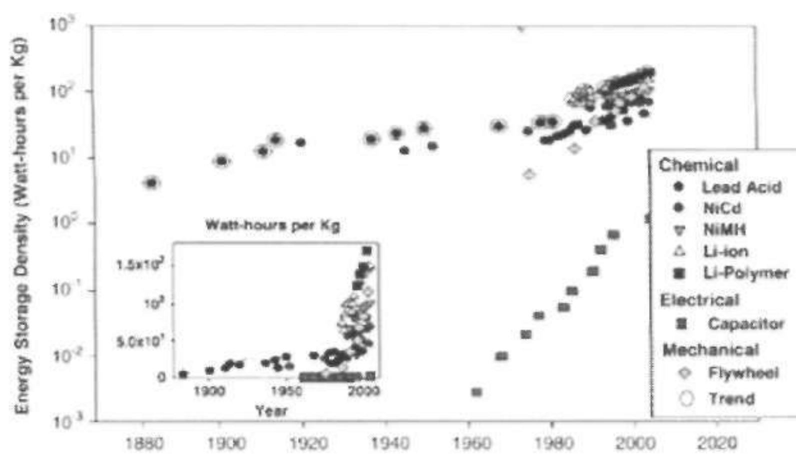


Figure 5: Energy stored per kilogram from 1880 to the present (Koh and Magee,2008)

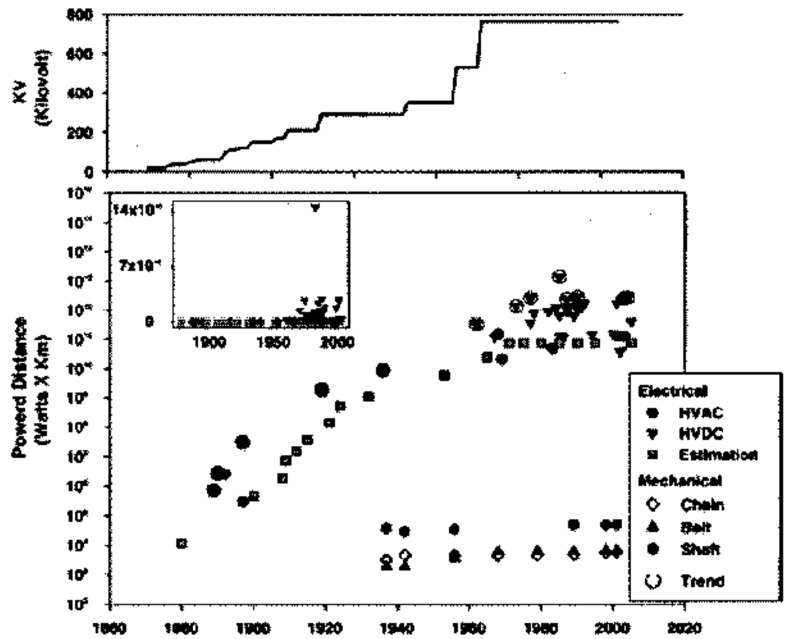


Figure 6: Improvement in feasible power x distance (powered distance) for energy transportation (Koh and Magee, 2008)

3.0 Materials Innovation and its Relationship to Overall Innovation

3.1 Models for Product and Process Innovation

Abernath and Utterback (1996) first differentiated innovation in assembled goods from innovation in homogeneous products, like chemicals and materials which are products of process industries. They found that immediately after the introduction of a product there are a large number of innovations, usually involving new product textures or configurations. And that a dominant design may emerge to, some degree, standardize the product features and configurations in a way that satisfies large number of users. Cost and efficiency then become the competitive basis for increase in product innovation in that industry.

Figure 7 presents Utterback's model for innovation in materials industry in 1996 while Figure 8 presents the Linton-Walsh's model for the same materials industry in 2007. It was clear that product innovation was always ahead of process innovation. It was also observed that the time lag between product innovation and process innovation was significant in the 1996 study but by 2007 the time difference between the two was very short.

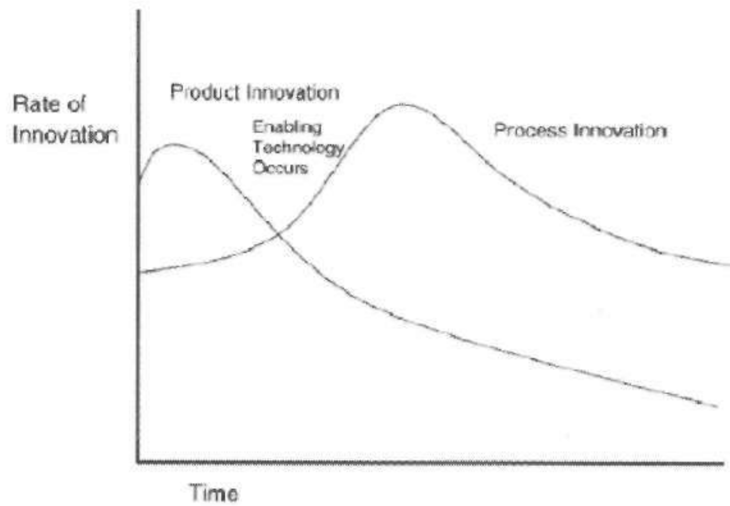


Figure 7: Utterback (1996) model for innovation in materials industry.

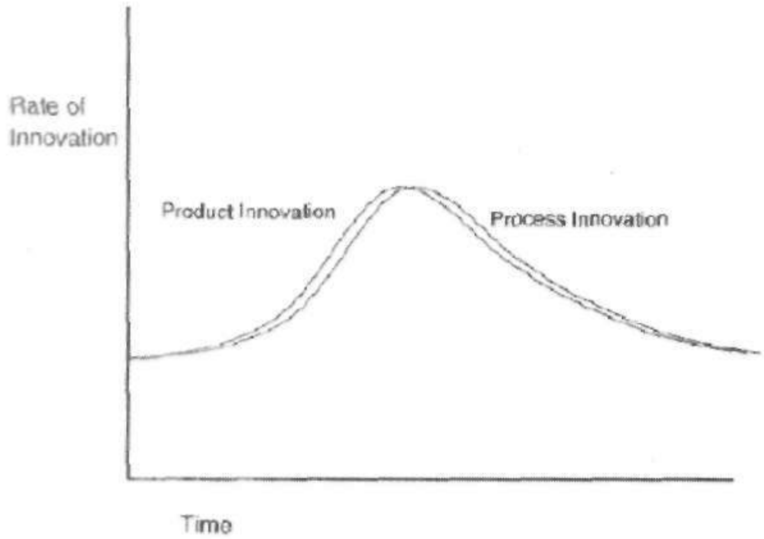


Figure 8: Linton-Walsh (2007) model for innovation in materials industry.

3.2 Hierarchy of Levels of Innovation

A generic hierarchy to describe elements of the changes that occur for improving an overall technical system has been suggested in ascending order as follows:

i. Incremental improvement in material or process that make up devices and components in the technical system can improve the overall system performance (i.e. material/process improvement).
ii. Discrete change in the choice of material or process can improve the system (i.e. material/process substitution).
iii. Changes in (non-material or process) parameters that are internal to various devices and components can be made to improve the overall system (i.e. component design).

iv. Changes in relationships among different components and devices that make up the system can be a source of improvement in the overall system (i.e. system redesign).

v. The basic scientific phenomenon being utilized in the system or in devices that are part of the system can be changed in order to improve the overall system (i.e. phenomenon change).

vi. Theoperating procedures for the overall system can be changed to improve the overall system (i.e. system operation).

From the listing material/process changes are ranked the lowest in hierarchies and therefore, easy to miss in identifyingthe most vital changes that resulted in the technological advancement. Tables 1 to 5 present the typical materials innovations for the energy and information sector.

Table 1: Examples of technical changes in the information transport functional category arrayed in the technical change hierarchy

Category of Change	Examples
Materials/Process Improvement	Coatings on glass fibers; purity of glass
Materials/Process Substitution	Glass fibers vs metallic conductors
Component Redesign	optical "solitons"
System Redesign	optical amplification
Phenomenon Change	Wireless vs wired transmission
System Operation	TCP/IP; wavelength division multiplexing

Table 2: Examples of technical changes in the energy storage functional category arrayed in the technical change hierarchy

Category of Change	Examples
Materials/Process Improvement	Lead casting techniques
Materials/Process Substitution	Lead to Ni-Cad to Li-ion
Component Redesign	Honeycomb structures for anodes
System Redesign	Parallel cells
Phenomenon Change	Batteries to capacitors
System Operation	Charge sensing

Table 3: Examples of technical changes in the energy transport functional category arrayed in the technical change hierarchy

Category of Change	Examples
Materials/Process Improvement	Al purity
Materials/Process Substitution	Insulators to allow higher AC voltage
Component Redesign	Ball bearings
System Redesign	Transformers and voltage step-down
Phenomenon Change	Mechanical to electrical transmission
System Operation	AC vs DC power

Table 4: Examples of technical changes in the information storage functional category arrayed in the technical change hierarchy.

Category of Change	Examples
Materials/Process Improvement	Improvements in integrated circuit technology
Materials/Process *Substitution*	New optical and magnetic materials *and processes*
Component Redesign	Magnetic disks vs. magnetic tape
System Redesign	Magneto/optical storage
Phenomenon Change	Mechanical to electronic and magnetic optical
System Operation	Database architecture

Table 5: Examples of technical changes in the energy transformation functional category arrayed in the technical change hierarchy.

Category of Change	Examples
Materials/Process Improvement	Improvements in high temperature alloys – Ni based, etc
Materials/Process Substitution	Ni for Fe, ceramics for metals
Component Redesign	Fuel injectors
System Redesign	Feedback control for combustion
Phenomenon Change	Electric motors vs. combustion engines
System Operation	Control strategies for engines and motors

Magee (2010) adopted quantification methodology and found that about 2/3 of the total progress in computation over the past 40 years has been due to materials/process innovations. He also found that the contribution of materials/process innovations in energy storage were possibly 80% or higher and that the relative contribution of materials/process innovation to overall technological progress had grown in the past few decades.

4.0 Indigeneous Efforts in Materials Development

Efforts are continuously going on in Nigeria to research into new and advanced materials among the tertiary institutions and research centers. Raw Materials Research and Development Council (RMRDC), Abuja at various times set up three teams of expert between November 2007 and June 2009 to develop a blueprintdraft blue-print for the development and utilization of new and advanced materials in Nigeria. The expert groups, in succession, finally produced a document which spelt out possible intervention strategies in the short, medium and long term.

In Ahmadu Bello University several research and development works have been carried out in many departments, includingthe Department of Chemical Engineering.

4.1 History of the Department of Chemical Engineering

The Department of Chemical Engineering at Ahmadu Bello University, Zaria was established in 1973 initially as the Industrial Chemistry Section of Chemistry Department in the Faculty of Science and then later transformed into the full fledged Chemical Engineering Department in the Faculty of Engineering in October 1976. The Department was established with the assistance of the Dutch Government through Twente University of Technology, Enschede, the Netherlands, under a ten-year (1972 – 1982) cooperation programme between Ahmadu Bello University and the Netherlands University Foundation for International Cooperation (NUFFIC).

The philosophy of the research programme of the department was to focus on appropriate technology, particularly relevant to the Nigerian situation. At the beginning of the postgraduate programme in the department specialization at M.Sc. level was either in Process Engineering or Materials Engineering. Through this programme many research activities on advanced materials were carried out. Some of these are discussed here.

4.2 Crashworthiness Automobile Vehicle Body

Crashworthiness is the ability of a structure to protect its occupants during an impact. This is commonly tested when investigating the safety of vehicles (Wikipedia, 2009).The crashworthy systems and devices installed in modern vehicles to prevent or reduce the severity of injuries when a crash is imminent or actually happening are as follows:

- Seatbelts
- Airbags
- Laminated windshields
- Tempered glass
- Automatic brake system
- Anti-intrusion bars
- Pedestrian protection systems
- Collapsible steering columns

Bumpers
Safety cells
Cargo barriers
Crumple zones
Roadworthiness
Internal Padding
Driverless vehicles
Self-sealing fuel tanks

Table 6 presents a fatality analysis which showed that the countries implementing these measures were achieving safety performance improvements over time. However, Figure 9 showed that in Nigeria the casualties from vehicular road accidents increased from 2004 to 2009.

Table 6: Fatality Analysis Report of Some Countries.

	1979 Fatalities	2002 Fatalities	Percent Change
United States	51,093	42,815	-16.2%
Great Britain	6,352	3,431	-46.0%
Canada	5,863	2,936	-49.9%
Australia	3,508	1,715	-51.1%

There was a need to adopt a better strategy. A glass fibre reinforced carbon-natural rubber composite was being developed for the automobile body. Figures 10 and 11 present the mechanical properties of the composites with varying carbon and glass fibre contents. Figure 10 showed that a body composition with 21wt% had optimum strength properties while Figure 11 showed that 25wt% glass fibre content was equally considered as optimum. Further tests are ongoing in the areas of re-bounce and energy recoverable capacities to ascertain their suitability to replace the present automobile bodies. This is the first time natural rubber would be investigated for automobile body use and it is futuristic.

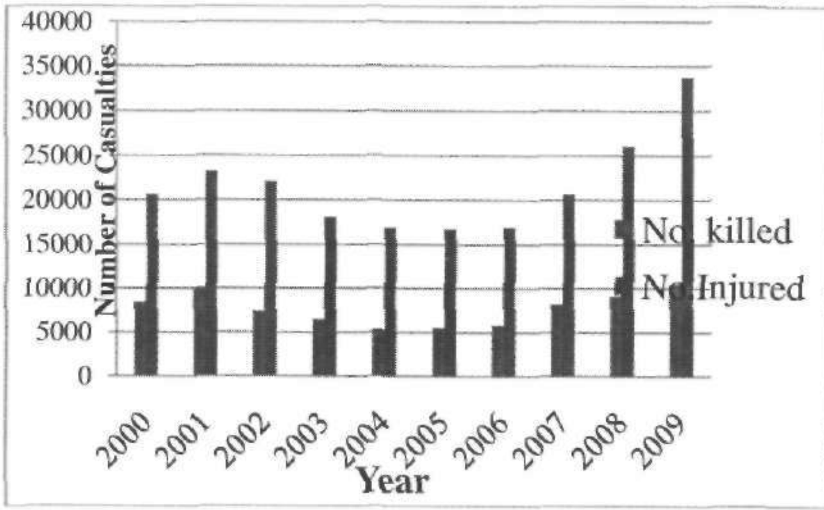


Figure 9: Number of Casualties on Yearly Basis (FRSC, 2010)

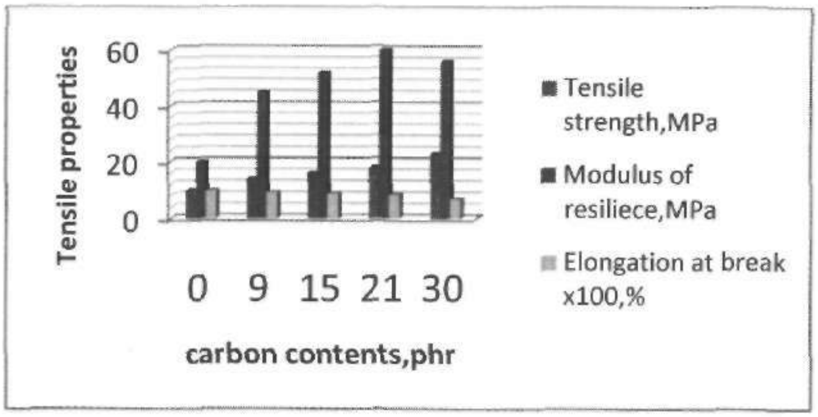


Figure 10: The Mechanical Properties of Glass fibre Reinforced Carbon-Rubber Composite with varying Carbon Content.

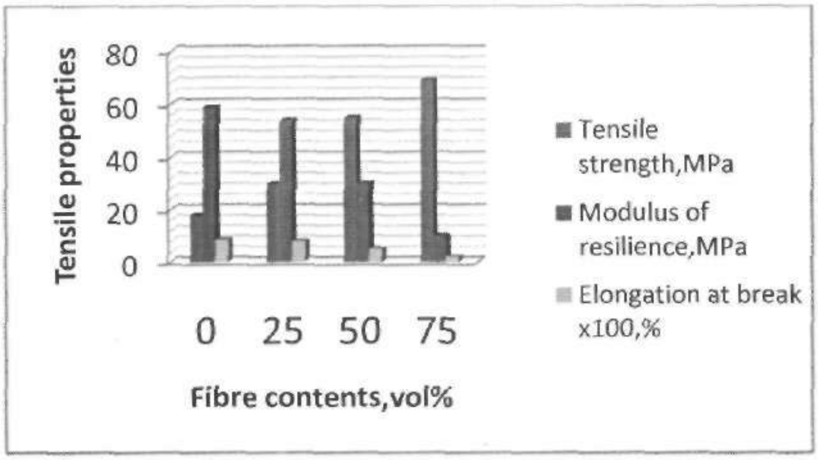


Figure 11: The Mechanical Properties of Glass fibre Reinforced Carbon-Rubber Composite with varying Glass Fibre Content.

4.3 Zeolite Catalysts

Zeolite catalysts are commonly used in the petroleum refining and petrochemical industry for a variety of applications, ranging from catalytic cracking of heavy fuels to isomerization and aromatization of petrochemical feedstock. Zeolite Y was first synthesized in the sixties and introduced to the fluid catalytic cracking of heavy fuels in the seventies. At that time the zeolite Y was produced by partial de-alumination of kaolin. Currently, higher quality zeolite Y is produced either by incorporation method from high purity chemicals or by the patented Engelhard method from kaolin and high purity chemicals.

The research team at the PTDF Professorial Chair in Chemical Engineering has developed new process route through which high quality zeolites (zeolite Y and ZSM-5) were produced from kaolin from Kankara town in Katsina State of Nigeria. The ZSM-5 prepared also had shorter crystallization time of 4 days when compared to 7 days for conventional methods. The zeolites were compounded into catalysts and tested both within and outside the country. The characterization and performance tests carried out revealed that a blend of the two catalysts prepared outperformed the commercial catalyst presently used at Kaduna Refining and Petrochemical Company. Pilot plant units have been designed and fabricated to produce the catalysts. The units are due to be commissioned before the end of the year 2014. The data and images generated from the studies are presented in Tables 7 to 9, Figures 12 to 16 and Plates 1 to 5.

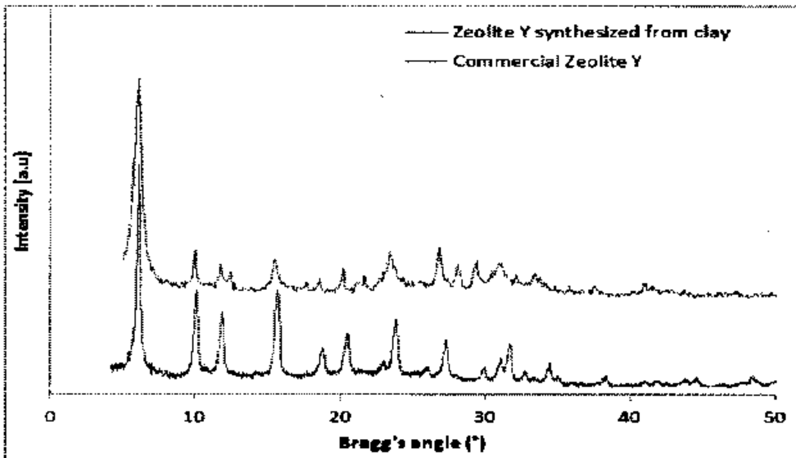


Figure 12: X-ray diffraction patterns of the zeolite Y synthesized from kaolin using the novel processing method and a commercial zeolite Y.

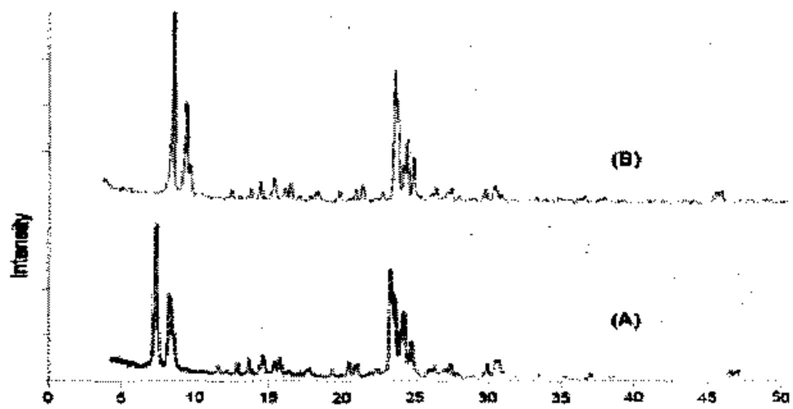


Figure 13: XRD patterns of (A) reference ZSM-5 and (B) ZSM-5 prepared from kaolin

Table 7: Chemical composition of the zeolite Y prepared from kaolin using the novel processing method

Oxide	Al_2O_3	SiO_2	CaO	TiO_2	Cr_2O_3	Fe_2O_3	SO_3	LOI
wt%	20.48	51.32	0.3	0.04	0.04	0.71	ND	26.5

Table 8: BET surface area and pore sizes of the zeolite Y synthesized from kaolin using the novel processing method

SAMPLE	SURFACE AREA (m^2/g)	PORE VOLUME (cm^3/g)	PORE DIAMETER (Å)
Zeo-AY: NaY	732.0	0.2611	14.26

Table 9: Physicochemical properties of ZSM-5 synthesized from kaolin

Component	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	CaO	TiO_2	External surface area (m^2/g)	BET surface area (m^2/g)
Kaolin ZSM-5 (wt.%)	98.06	1.27	0.065	0.27	0.269	0.019	160.37	415

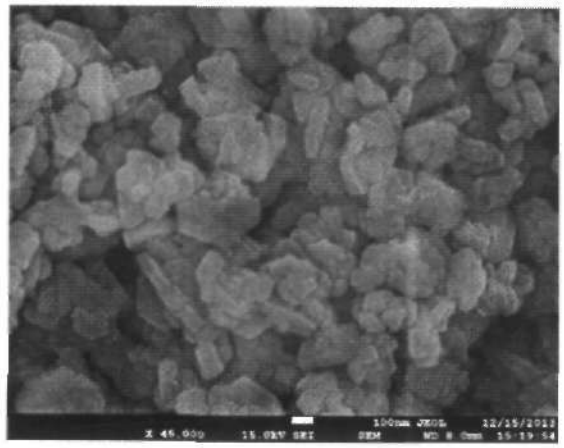
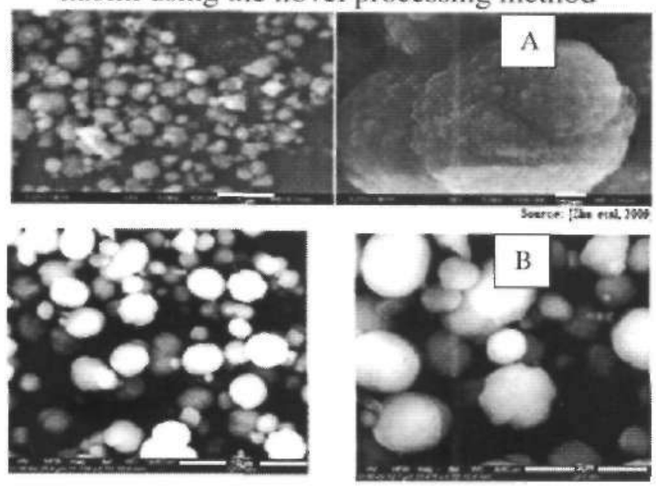


Figure 14: SEM image of the the zeolite Y prepared from kaolin using the novel processing method



Source: [Zhe et al, 2009

Figure 15: SEM images of (A) reference ZSM-5 and (B) ZSM-5 synthesized from kaolin

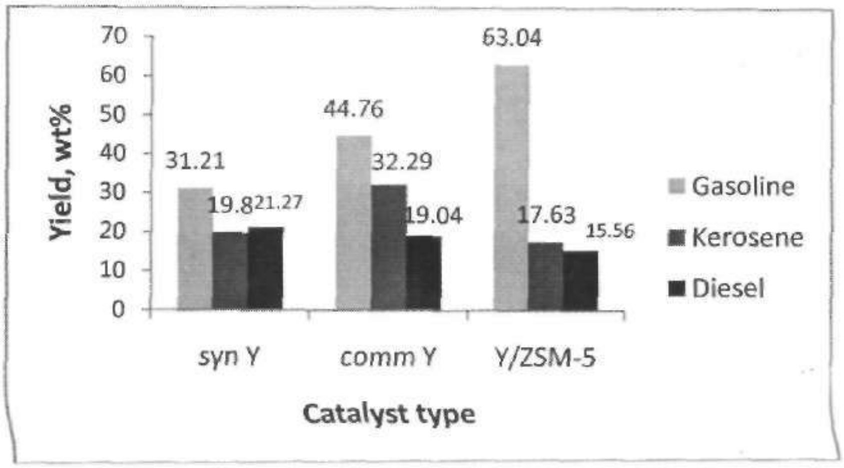


Figure 16: Comparative Product Yield from Fluid Catalytic Cracking of Heavy Gas Oil Using Different Catalysts

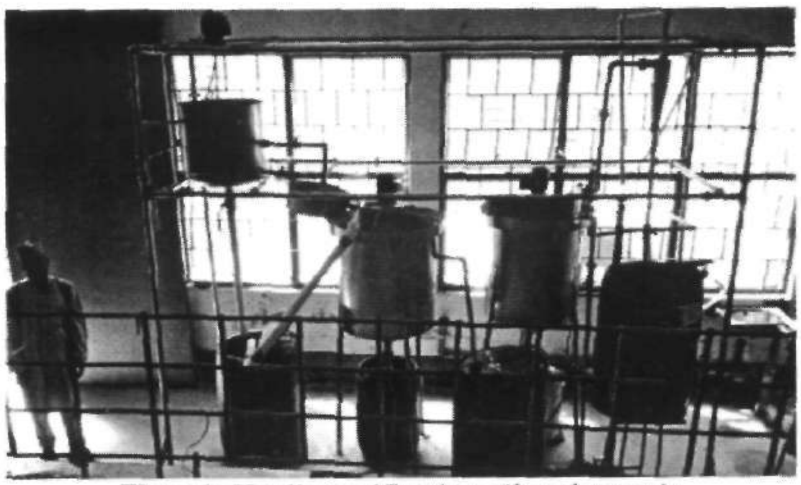


Plate 1: Kaolin purification pilot plant unit

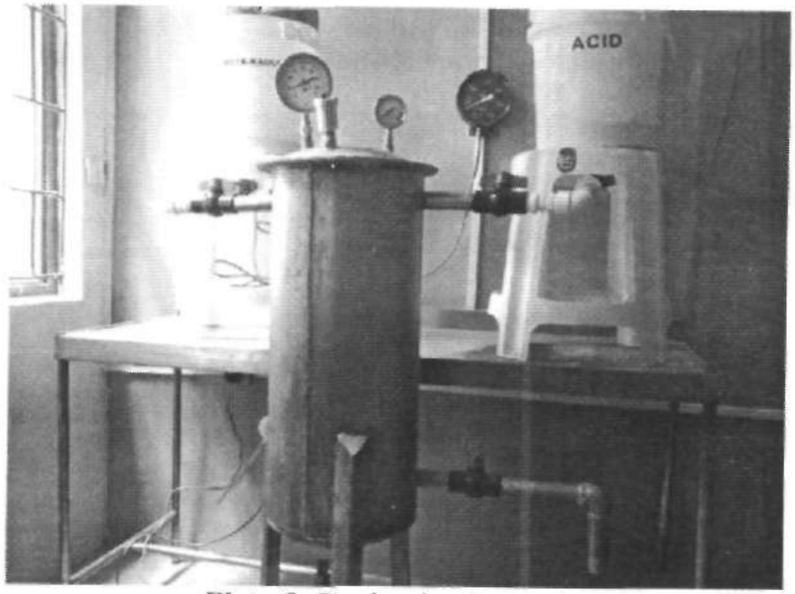


Plate 2: Dealumination unit

Plate3: Aluminium hydroxide reactor

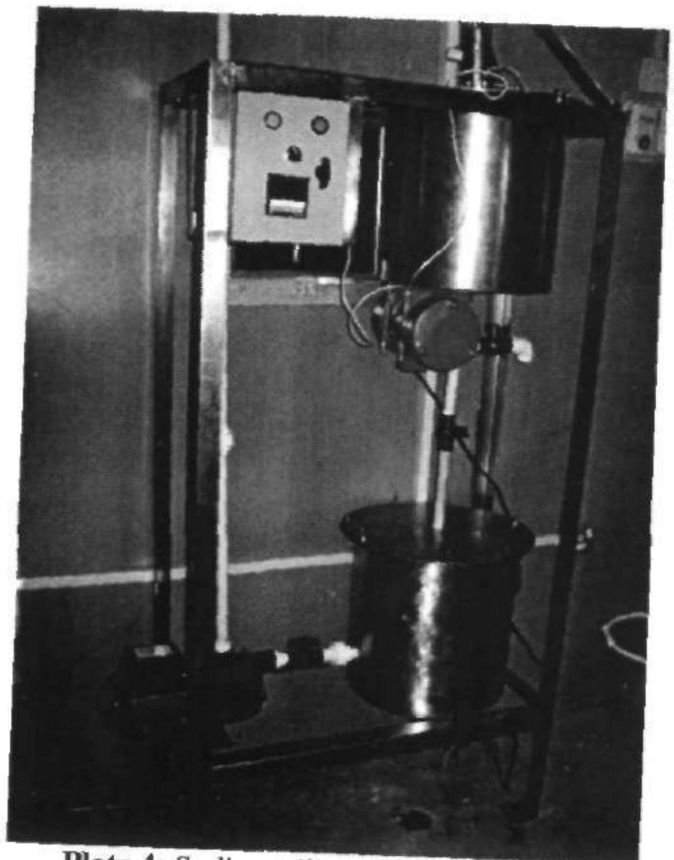


Plate 4: Sodium silicate production unit

Plate 5: Zeolite reactor

4.4 Personnel Armor

Personnel armor is any equipment of various materials, used to protect a body in combat. The oldest of protective devices is the shield; the earliest body armor was a wide belt to protect the abdomen. The modern personnel armor is made of thin layer of special metal, and of recent fibre reinforced composites. In the department research work has carried to develop fibre reinforced polymer composites that were found to withstand medium range velocity projectiles. Glass fibre, Nylon fibre, Kevlar fibre and Aramid fibre were used as the reinforcement fibres in various combinations. Polyester and acrylonitrile butadiene styrene (ABS) were also used as the matrix for the composites. ABS was also recycled from inner lining of used and discarded refrigerators; this could be used for producing cost effective armor materials to protect against projectiles from small fire arms.

4.5 Other Materials

Research and development works were also carried out in the areas of dense and insulating fireclay refractories, graphite crucibles and bentonites.

5.0 Conclusions

The following conclusions may be made from the works carried out so far.

- The dominant role of materials development in the technological advancement over 40 years was demonstrated. Quantification methodology estimated that materials innovations accounted for about 2/3 of the total technological progress in information transformation generic functional area in the last 40 years while the contribution of materials/process innovations in energy storage were possibly 80% or higher.

- An energy recoverable composite with anoptimum composition of 21 parts per hundred rubber (phr) carbon and 25vol% glass fibre contents giving tensile strength, MOR and elongation at break of 29MPa, 54MPa and 800% respectively was developed forautomobile vehicle body. These values compared well with those of reported commercially for similar reinforced polymers [tensile strength (8.3 to 15MPa), MOR (25 to 50MPa) and elongation at break (400 to 850%)]. The density of the composite was 1,900kg/m^3 which was lower than commonly used metals (Al 2,700kg/m^3 and mild steel 7,850kg/m^3).

- Zeolite Y and ZSM-5 catalysts were prepared from kaolin by a novel method which entailed clay-split method. A blend of the two catalysts prepared outperformed the commercial catalyst presently used at Kaduna Refining and Petrochemical Company. Pilot plant units have been designed and fabricated to produce the catalysts.

- Fibre reinforced polymer composites with various reinforcement and matrix materials were developed and found to withstand medium range velocity projectiles

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