THE OIL-EATING MICROBE: A REMEDY TO THE MENACE OF OIL POLLUTION

by

Professor Dan-Israel Amund

UNIVERSITY OF LAGOS PRESS - 2000
INAUGURAL LECTURE SERIES

THE OIL-EATING MICROBE: A REMEDY TO THE MENACE OF OIL POLLUTION

An inaugural lecture delivered at the University of Lagos on Wednesday, the 19th of January, 2000

Delivered by

Professor Dan-Israel Amund

B.Sc (Lagos), Ph.D (Cranfield)
Department of Botany and Microbiology
University of Lagos

University of Lagos Press
2000

First Published 2000

By

University of Lagos Press,
Unilag P.O. Box 132,
University of Lagos,
Akoka, Yaba - Lagos
Nigeria.

ISSN 1119 - 4456

INTRODUCTION

Exactly ten years ago, when I was yet a Senior Lecturer, a very distinguished colleague and a good friend of mine in the person of Dr (Mrs.) Nwadiuto Esiobu asked me what would be the title of my inaugural lecture. I told her innocently that I would' love to speak on the African perspectives of Biotechnology since my doctorate degree was in that subject. 'Why don't you speak on a topic like "The Oil-Eating Microbe" which fits perfectly into your area of research in Petroleum Microbiology?,' she asked After a brief reflection, I took the suggestion very seriously as a prophetic message which, today, is coming to pass before our very eyes.

I thank the Almighty God for the ordination of this day, the enabling grace to stand before this unique audience and to have gone this far in my academic career. I also wish to express my gratitude to the University authorities, especially, the action Vice-Chancellor, Professor Jelili Adebisi Omotola OON, SAN, for creating the enabling environment for inaugural lectures in this University. In the very recent past, inaugural lectures were rather epileptic occurrences as a result of which there were unending backlogs. Many Professors inadvertently or willingly could not defend their chairs before leaving the University system. Inaugural lectures are very important in university life as they create avenue for a public proclamation of a new chair after the appointee must have presented his case notes to justify his appointment. They also afford the opportunity to bring the town and gown together in a celebration of academic excellence. If I may borrow the words of our dear Vice-Chancellor, at his book launch in 1994, "a professor who didn't give an inaugural lecture is like a new-born child without a naming ceremony". This is because an inaugural lecture is the main mode of celebration of a new chair in the

University environment. Today, it is on record that this is the second inaugural lecture to be given by a professor in the area of Microbiology in Biological Sciences of the University of Lagos. Professor J.A. Ekundayo gave the first one in 1978. It is, therefore, my good pleasure and honour to stand before this august gathering to present my inaugural lecture entitled " The Oil-Eating Microbe: A Remedy to the Menace of Oil Pollution".

What is Microbiology?

Microbiology can be defined as the study of organisms (i.e., living things) too small to be seen clearly, as individuals, by the unaided human eye. Such organisms are commonly spoken of as "microbes" or more exactly "micro-organisms". Hence, the word "microbiology" is an amalgam of two words, "microbe" and "biology".

Micro-organisms constitute a large and diverse group of free-living forms that exist as single cells or cell clusters. Microbial cells are therefore distinct from the cells of animals and plants that cannot live alone in nature but can exist as part of multicellular organisms. Thus, a single microbial cell is, generally, capable of carrying out various life processes such as growth, respiration and reproduction, independently of other cells, either of the same or different kinds. Although these processes are the general norms, there are some microbial groups called *Rickettsiae* and *Chlamydia*e, as well as some nucleoprotein particles called viruses that cannot exist independently of other living organisms. The cellular micro-organisms of interest to the microbiologist include bacteria, blue-green algae, protozoans, microfungi and algae. These organisms are grouped into the kingdom *Protista* (i.e, protists) because of their unicellular nature as distinct from higher plants and animals of the kingdom *plantae* and *animalia* respectively.

The history of microbiology is as old as the invention of the microscope. The very best human eyes, unaided, fail to see objects less than 100 µm or 0.1 mm in diameter. Micro-organisms are much smaller as they range downward in diameter from about 1-5 µm (bacteria) to 0.25 µm (viruses). Simple magnifying glasses (hand lenses) are only capable of enlargements up to about 10 times the size of comparatively enormous, multicellular organisms. The micro-organisms of interest to the microbiologist are absolutely invisible at magnifications of 10 X or even 100 X as they are unimaginably minute. Therefore, the professional microbiologist of today customarily uses compound microscopes giving magnifications of from about 400 X to 1,200 X. For greater magnifications, he must rely on electron microscopes, giving magnifications of from about 2,500 to 1,000,000 X or more. It is noteworthy that the first person to see micro-organisms in any detail was the Dutch amateur microscope builder, Antoni van Leeuwenhoek (1632-1723), who used simple microscopes he constructed to see micro-organisms as small as bacteria. The epoch-making observations of Leeuwenhoek were reported in the proceedings of the Royal Society of London in 1674 and he was elected a fellow. Although other workers confirmed his observations, progress in the science of Microbiology took greater steps forward when better microscopes had been developed, for these enabled scientists to penetrate ever deeper into the mysteries of the cell.

Apart from Antoni van Leeuwenhoek, other curious scientists contributed immensely to the early growth and development of microbiology, especially in the nineteenth century when two perplexing questions about spontaneous generation *(abiogenesis)* and the nature of contagious diseases pervaded their minds. The proponents of the doctrine of spontaneous generation believed that the was that even very perishable plant or animal infusions do not undergo putrefaction (decay) or fermentation when they have been rendered free of micro-organisms. Corroboratory evidence was also provided in the early 19th century by a French scientist, Francis Appert who found that he could preserve foods by enclosing them in airtight containers and heating the containers. In this way, he was able to preserve highly perishable foodstuffs indefinitely and this original canning process was called '**appertization**' as it involves heating of foods with the exclusion of oxygen.

By 1860, some scientists had begun to realise that there is a causal relationship between the development of micro-organisms in organic infusions and the chemical changes that take place in these infusions. The great pioneer in these studies was Louis Pasteur (1822-1895), one of the most famous French scientists. In his contribution to the arguments on spontaneous generation, Pasteur demonstrated that air really does contain microscopically observable "organised bodies" He did this by aspirating large quantities of air through a tube that contained a plug of guncotton to serve as a filter. The guncotton was then removed and dissolved in a mixture of alcohol and ether and the sediment was examined microscopically. In addition to inorganic matters, it contained considerable number of small round oval bodies indistinguishable from micro-organisms. Pasteur also showed that heated air can be supplied to a boiled infusion without giving rise to microbial development while the addition of a piece of germ-laden guncotton to a sterile infusion invariably provoked microbial growth. An elegant experiment of Pasteur in this regard was the use of bent-necked flasks. It was shown that heated infusions will remain sterile indefinitely in open flasks, provided that the neck of the flask is drawn out and bent down in such a way that germs from the air cannot ascend it. If the neck of such a flask were broken off, microbes rapidly populated the microscopic organisms seen by Leeuwenhoek as well as those of plants and animals occurred spontaneously from non-living matter As knowledge of living organisms developed, it became evident that spontaneous generation of plants and animals does not occur. A decisive step in the abandonment of the doctrine as applied to animals took place as a result of experiments performed around 1665 by an Italian physician, Francesco Redi (1626-1679). Before then, it was supposed that the maggots in decaying meat were derived spontaneously from the transformation of the putrid meat itself. Francesco Redi disproved this hypothesis by placing meat and fish in jars covered with fine gauze and he saw flies approach the jars and crawl on the gauze. He saw the eggs of flies caught on the gauze and observed that the meat decayed without maggots developing. Maggots were only able to develop when the flies' eggs were deposited on the meat itself. Obviously, the meat did not turn into maggots. With this observation, Francesco Redi defeated the doctrine of abiogenesis.

However, it was far more difficult at that time to show that micro-organisms are not generated spontaneously based on the 'mysterious' appearance of these simplest forms of life· in organic infusions (i.e., plant and animal extracts). The departure from this erroneous belief came from the experimental evidence provided by the Italian naturalist Lazzaro Spallanzani (1729-1799) who showed that repeated heating can prevent the appearance of micro-organisms (called *animalcules* at that time) in infusions. From his observations, Spallanzani concluded that micro-organisms can be carried into infusions by the air and this explained their supposed spontaneous generation in well-heated infusions. If the containers of infusions are hermetically sealed by excluding air, they remain barren (uncontaminated) for a long time unless contaminated via a tiny crack. The bottom line of Spallanzani's contribution infusion. Apart from the pioneering work on the doctrine of spontaneous generation, Pasteur was also regarded as the father of fermentation in that he devised the process for the preservation of beer and wine technically known as **pasteurisation**. Disproving the doctrine of spontaneous generation thus led to the development of effective sterilisation procedures without which microbiology as a science could not have developed.

The final onslaught to the doctrine of spontaneous generation was made by an English physicist, John Tyndall (1820-1893), who fortuitously came across the heat-resistant forms (resting bodies) of microbes later identified as endospores and developed a method of sterilisation by discontinuous heating called **tyndallization**.

A major impetus for the development of microbiology as a science was provided by the proof that micro-organisms are the causative agents of contagious diseases. The main scholar in this arena, the German scientist, Robert Koch (1843-1910) studied the anthrax disease of cattle, which, sometimes also occurs in man. Anthrax is caused by spore-forming bacterium called *Bacillus anthracis* and the blood of an infected animal contains millions of cells of this bacterium. Koch was able to establish the presence of these organisms in the blood by careful microscopy. He then showed that a move could be infected with material from a diseased animal. He transmitted the disease through a series of 20 mice by successive inoculation, at each transfer, the characteristic disease symptoms were observed and the blood of all infected mice contained the causal organism. Koch further showed that the bacteria could also be cultivated in nutrient fluids (e.g., sterile serum) outside the animal body and even after many transfers in culture, the bacteria could still cause the disease when reinoculated into an animal. These series of experiments brought to the fore the necessary criteria for establishing the causal relationship between a specific micro-organism and a specific disease. These criteria are: (1) the micro-organism should always be found in animals suffering from the disease and should not be present in healthy individuals; (2) the organism must be isolated from the diseased host and grown in pure culture; (3) such a culture when inoculated into susceptible animals, should initiate the characteristic disease symptoms; (4) the organism should be re-isolated from experimental animals and cultured again in the laboratory after which it should be the same as the original organism. Since Koch was the first to apply these criteria experimentally, they are generally known as Koch's postulates. Apart from supplying a means of demonstrating that micro-organisms cause specific diseases, Koch also highlighted the importance of laboratory culture in microbiology.

Microbiology has come a long way since the early days and today, it is one of the most sophisticated of the biological sciences. Because of the special laboratory requirements for the study of micro-organisms, microbiology is an independent discipline, but it is first of all a biological science. Micro-organisms have played important roles as model systems for the study of basic biological processes. In fact, much of our understanding of molecular biology has come from studies with microbes. It is therefore not surprising that the modern day biotechnology emanated from microbiology. As knowledge increased, it became more apparent that scientists can only specialise or study only a small portion of microbiology, as no one can know everything. This specialisation has led to the development of subdisciplines of microbiology as classified in Table 1 below.

Table 1: Subdisciplines of Microbiology

Taxonomically oriented	Habitat oriented	Problem oriented	General areas
Virology	Aquatic microbiology	Microbial ecology	Microbial genetics
Bacteriology	Soil microbiology	Medical microbiology	Microbial physiology
Phycology	Marine microbiology	Agricultural microbiology	Microbial biochemistry
Mycology	Air microbiology	Industrial microbiology	Immunology
Protozoology	Microbiology of extreme environments (salt lakes)	Pharmaceutical microbiology	
		Food Microbiology	
		Geomicrobiology	
		Petroleum microbiology	
		Environmental microbiology	

It is noteworthy that some of the subdisciplines may overlap in some areas while some are offshoots of one another. The undergraduate curriculum in microbiology, typified by what we run at the University of Lagos ensures that students are exposed to all subdiciplines while specialisation is left to the postgraduate level. It is not an overstatement to emphasise that the applicability of microbiology to many areas of human endeavour especially in industry and healthcare delivery, has made the subject the most popular of all biological disciplines amongst students. Thus, microbiology is an exceptionally broad discipline encompassing specialties as diverse as biochemistry, cell biology, genetics, taxonomy, pathogenic bacteriology, food and industrial microbiology and ecology.

Petroleum microbiology as an area of specialisation

Petroleum microbiology deals with microbial activities related to petroleum technology. It is the study of interactions between micro-organisms and petroleum. The microbiologist has joined the many other technologists serving the petroleum industry to find a fruitful field of research since the interactions between microbes and petroleum were first recognised by a Japanese botanist, Miyoshi in 1895 who reported that paraffin was attacked by the fungus *Botrytis cinerea*. Sohngen who worked at Beijerink's laboratory at Delft in the Netherlands followed this in 1906 by a series of publications on hydrocarbon microbiology. In these papers, it was noted that microbial decomposition of hydrocarbons explains the disappearance of petroleum daily brought to the surface of canals by motor boats and other spillages. Other pioneering works were led by Claude E. Zobell, who in 1944 was the Director of an American Petroleum Institute's research project on the role of bacteria in petroleum origin. His works came up with ideas of using micro-organisms in petroleum release from reservoir formations, as well as the role of microbes in the environmental fate of petroleum hydrocarbons.

Petroleum microbiology is a rapidly expanding field of research in the light of successes recorded in the application of microbial systems in the cleanup of oil-impacted sites and in chemical transformations in the petrochemical industry. For convenience, petroleum microbiology is grouped into three main sections listed hereunder:

1. Microbial activities related to petroleum geology and geochemistry.

   This aspect deals with the role of microbes in petroleum formation and the use of microbes as tools for petroleum exploration and tertiary recovery of petroleum.

2. Microbial activities beneficially oriented.

   This aspect covers the bioconversion of petroleum feedstock into various chemical products and food supplements such as amino acids, vitamins and single cell protein. It also involves the microbial removal of spilled oils from natural ecosystems.

3. Microbial activities detrimental to the petroleum industry.

This includes the activities of microbes in the deterioration of refined petroleum products such as lubricants and fuel oils, corrosion of pipelines and storage tanks and reservoir souring.

It is therefore apparent from the foregoing that the basic tools for petroleum microbiology cut across many subject disciplines including chemistry, biochemistry, geology, reservoir engineering, biochemical engineering, economics genetics and molecular biology.

Microbiology of oil pollution

Pollution of the environment by petroleum products is an inevitable manifestation of oil production, transportation and distribution activities. Large amounts of petroleum products handled on land every year create the possibility for land contamination. In addition, large volumes of crude oil and/or refined products are transported across the world's oceans from producing areas to consumer countries. Consequently, a substantial fraction of this oil is released into the sea either by accident or during normal tanker operations. It has been estimated that approximately 0.1 % of transported crude oil (about 35 million metric tons) enters the sea annually from tankers alone (*Energy Information Administration*, 1992). Other pollution sources include ballast water discharges, natural seepage, blowout of wells, leakages from pipelines and storage tanks, industrial wastes and runoffs and sometimes sabotage. Some of the celebrated cases of oil spills around the world are summarised in Table 2.

Since oil production, offshore and onshore, have increased in magnitude in recent years, oil will continue to contribute towards environmental pollution. Therefore, an understanding of the fate and effects of spilled oils in both aquatic and terrestrial ecosystems had become imperative. However, existing and emerging information have shown that the spilled oil is subject to considerable destruction leading to the absence of gross pollution in the environment. Micro-organisms have been implicated as the main agents for the removal of petroleum hydrocarbons from the environment. As we shall see in the course of this lecture, microbiological approaches to the problem of oil pollution are based on the knowledge of the interactions between micro-organisms and petroleum hydrocarbons as well as the metabolic consumption of these substrates as reflected in the title of this inaugural lecture.

Table 2: Some notable oil spill incidents around the world

Source	Place	Date	Amount spilled X 10^3 tons	Cause
Torrey Canyon	Cornwall, England	March 1967	117	Tanker accident
Florida barge	West Falmouth, Mass.	September 1969	0.6	Grounding
Amoco Cadiz	Brittany, France	March 1978	223	Tanker accident
IXTOC-1 Well	Campeche Bay, Mexico	June 1979	350	Blowout
Funiwa-5 Well	Niger Delta, Nigeria	January 1980	28	Blowout
Castillo de Bellver	Cape Town, S.A	August 1983	265	Tanker accident
Exxon Valdez	Southern Alaska	March 1989	33	Tanker accident
Arthur Kill	New York Harbor	January 1990	1.9	Pipeline rupture
The Gulf War	Persian Gulf	February 1991	1000	War sabotage
Komi	Russia (near Moscow)	1994	100	Pipeline rupture
Sea Empress	Milford Haven, Wales	February 1996	30	Tanker accident
Mobil's Idoho	Offshore Southern Nigeria	January 1998	5.7	Pipeline rupture

Behaviour and effects of spilled oil

Petroleum upon leaking or spilling is subject to a series of diverse physical and chemical changes that are dependent on the chemical nature of the oil and environmental conditions. These processes include spreading, drifting, emulsification, mousse formation, dispersion, sedimentation, re-suspension from sediment, adsorption, dissolution, evaporation, tar ball formation, photooxidation and microbial degradation. These processes are collectively known as weathering. Oil spilled on land moves laterally and vertically through the soil column depending on the soil texture and permeability characteristics. Other factors affecting oil distribution in the environment include the spill volume, oil viscosity, temperature and windspeed. Of all the weathering processes, only photooxidation and microbial degradation seem to have significant capacity to destroy the major components of petroleum.

Introduction of petroleum into the environment is associated with substantial ecological damage. In polluted seas, there is an immediate detrimental effect on marine animal and plant life. One of the most publicised aspects is the effect of oil pollution on seabirds of which tens of thousands are lost each year. There have been cases of toxicity to oysters, crabs, shrimps, fish and planktonic algae that act as primary producers in the marine food chain. On land, oil spills result in the breakdown of soil particles leading to a reduction in water percolation and water retention ability as the soils assume dry and waxy appearances. Plant communities exposed to petroleum spills suffer pronounced effects that manifest as wilting and leaf chlorosis in most cases. On recovery from the effect of oil spillage, oil polluted soils generally show large increases in organic nitrogen and carbon relative to normal soils. (Ellis and Adams, 1961; Amund *et al.*, 1993). Contact toxicity of low-boiling petroleum components has an adverse effect on soil animals especially the earthworms and other burrowing arthropods (insects) by blocking their respiratory channels. However, the residence time of spilled oil is drastically reduced in the environment by various physico-chemical and biological destructive mechanisms, the most important of which is microbial degradation.

Microbial degradation of oil pollutants

Microbial degradation of hydrocarbons is acknowledged to be the natural process by which the bulk of polluting oil is eliminated from the environment. Perhaps, this may be the reason why the oceans are not entirely covered with oil today despite the large inputs of petroleum hydrocarbons and incessant spillage incidents. The ability of a wide range of micro-organisms to utilise petroleum hydrocarbons as sole sources of carbon and energy was first recognised in some detail by Zobell (1946) who worked at the American Petroleum Institute, Washington. To date over 100 microbial species that include bacteria, fungi, yeasts and algae capable of utilising hydrocarbons have been isolated from the environment. Most workers consider bacteria to be the most important group of petroleum degrading organisms while the most prominent species include *Pseudomonas, Achromobacter, Alcaligenes, Flavobacterium, Mycobacterium, Acinetobacter, Corynebacterium, Bacillus* and *Arthrobacter* (Atlas and Bartha, 1972; Soli and Bens, 1972).

Hydrocarbon-degrading microbes are widely distributed in the marine, freshwater and soil habitats either polluted or unpolluted. The distribution of hydrocarbon-oxidising microbes in natural environments is of tremendous importance from the point of view of the potential use of these organisms in the treatment of oil spills. Studies have shown sizeable increases in populations of oil-degrading microbes in oil-polluted sites (Lode, 1986; Atlas, 1981; Amund and Igiri, 1990) and these organisms may represent 1-10% of the total microbial community.

Microbial interaction with hydrocarbon substrates

Petroleum is a complex mixture of hydrocarbons and non-hydrocarbon components which contain distinct groups of chemical compounds. The main classes of hydrocarbons found in crude oil are the straight chain alkanes, branched chain alkanes, cycloalkanes (naphthenes) and aromatics. The non-hydrocarbon compounds are represented by pyridines, quinolines, thiophenes, phenols and naphthenic acids. Trace elements (nickel and vanadium) may also be made complex with these constituents.

By nature of its composition, petroleum is a heterogeneous and water-insoluble substrate that presents special problems to micro-organisms. Consequently, microbes that grow on crude oil or other hydrocarbon sources, as of necessity, have developed special traits to overcome the solubility problems. An oil-degrading microbe has been defined by its possession of three special characteristics that endows it with the ability to proliferate on hydrocarbon substrates (Gutnick and Rosenberg, 1977) as listed below.

1. An efficient hydrocarbon uptake system (special receptor sites for binding hydrocarbons and/or production of unique chemicals that assist in the emulsification and transport of hydrocarbons into the cell).

2. Possession of group-specific oxygenases (i.e., genetic potential of the micro-organism to produce enzymes that will introduce molecular oxygen into the hydrocarbon and generate intermediates that subsequently enter the common energy-yielding catabolic pathways).

3. Inducer specificity (i.e. the positive response of the micro-organism to petroleum and its constituents in inducing the first two systems).

Hydrocarbon-utilising micro-organisms act mainly at the oil-water interface. Microscopic observations have shown that these organisms grow over the entire surface of an oil droplet. Increased surface area provided by the dispersion of oil in the water phase should therefore accelerate biodegradation (Gatterlier *et al.*, 1973). Two general biological strategies have been identified as responsible for contact between bacterial cells and water-insoluble hydrocarbons:

1. Specific adhesion to hydrocarbon substrates;
2. Emulsification of the hydrocarbon.

These strategies are made apparent by the fact that the first step in hydrocarbon degradation involves membrane-bound oxygenase enzymes making it essential for microbes to come into direct contact with hydrocarbon substrates. The ability of microbes to adhere to hydrocarbons is inherent in their possession of surface features such as outer membranes, fimbriae, surface proteins and lipids that are collectively known as "hydrophobins". A classical case of adhesion due to hydrophobic fimbriae has been reported for *Acinetobacter calcoaceticus* RAG-1 (Rosenberg *et al.*, 1982). The adhered cells are also capable of detaching from depleted oil droplets through a reverse mechanism.

Many micro-organisms that grow on hydrocarbon substrates produce emulsifying or surface-active agents which bring about a greater dispersion or solubilisation of hydrocarbons and oils in the aqueous phase. Examples of emulsifying agents include glycolipids, phospholipids, neutral lipids, fatty acids, peptidolipids and lipopolysaccharides. Thus, adhesion and bioemulsification mechanisms represent the first steps in the process of microbial hydrocarbon degradation.

Ultrastructural studies of hydrocarbon degrading bacteria have revealed the presence of electron-dense inclusion bodies containing the unmodified hydrocarbon (Kennedy *et al.*, 1975; Scott *et al.*, 1976). Similarly, large numbers of microbodies (peroxisomes) have also been observed in alkane-grown yeasts (*Candida* spp) and the fungus *Cladosporium resinae*. (Osumi *et al.*. Snucker and Cooney, 1981). Appearance of these microbodies had been correlated to elevated cellular catalase activities.

Metabolic transformation of hydrocarbons

The diversity of chemical constituents of petroleum has warranted the evolution of diverse biochemical processes in the breakdown of these materials. An extensive literature exists on the metabolic dissimilation of petroleum (Atlas, 1981). It is evident that no single microbial species will completely degrade any particular oil (Colwell and Walker, 1977). Therefore, the biodegradation of both crude and refined oils involves a consortium of organisms due to substrate specificity exhibited by these microbial species. Each class of chemical compounds in petroleum is also broken down via distinct metabolic pathways discussed as follows:

Aliphatic hydrocarbons (*n*-alkanes)

Metabolism of *n*-alkanes normally proceeds by a monoterminal attack, usually leading to the formation of a primary alcohol followed by an aldehyde and a carboxylic acid. Further degradation of the carboxylic acid proceeds by β-oxidation with the subsequent formation of two carbon unit shorter fatty acids and acetyl-coenzyme A, with eventual liberation of carbon dioxide (CO_2). Subterminal oxidation sometimes occurs, with the formation of a secondary alcohol and a ketone, although this mechanism is not primarily used by most *n*-alkane-utilising micro-organisms. Highly branched isoprenoid alkanes, such as pristane, have been found to undergo ω-oxidation, with the formation of dicarboxylic acids as the major end products of biodegradation. This is because methyl branching greatly increases the resistance of hydrocarbons to microbial attack.

Alicyclic hydrocarbons (Cycloalkanes)

Cycloalkanes are particularly resistant to microbial attack. For example, complex alicyclic compounds, such as hopanes (Tripentacyclic compounds), are among the most persistent components of petroleum spillages in the environment. There have been several reports of direct oxidative and co-oxidative degradation of both substituted and unsubstituted cycloalkanes (De Klerk and Van der Linden, 1974; Norris and Trudgill, 1971; Stirling *et al.* 1977).

Several unsubstituted cycloalkanes, including condensed cycloalkanes, have been reported to be substrates for co-oxidation leading to the formation of ketone or alcohol. Once oxygenated, degradation can proceed with ring cleavage.

Aromatic hydrocarbons

The biodegradation of aromatic components of petroleum had been extensively investigated (Dagley, 1971; Stanier and Ornston, 1973; Hopper, 1977). The degradation normally involves the formation of the cis, cis-diol that spontaneously converts into catechol. This catechol is subsequently subjected to two types of aromatic ring cleavage pathways called 'ortho' and 'meta' cleavages that are catalysed by dioxygenase enzymes. In the ortho pathway, catechol, in the presence of the enzyme 1,2-dioxygenase is converted to cis, cis-muconic acid that is further transformed to β-ketoadipic acid. This product is cleaved to produce succinate and acetyl CoA, intermediates of the tricarboxylic acid (TCA) cycle. In the meta pathway, the enzyme 2,3-dioxygenase cleaves the aromatic ring of catechol in the 2,3 position to produce an intermediate called hydroxymuconic semialdehyde, which proceeds to give a mixture of pyruvate and acetaldehyde as final products. The breakdown products of the 'ortho' and 'meta' pathways are then utilised by the organism for biosynthesis of cell materials or oxidised to carbon dioxide (CO_2) yielding energy during the process. In a nutshell, the products of hydrocarbon breakdown in microbial cells are cell biomass, energy, CO_2 and water.

Environmental factors affecting oil degradation

Microbial degradation of hydrocarbons in the environment is largely determined by a combination of abiotic factors, which limit the rate of petroleum degradation. Such factors include temperature, oxygen, nutrients (nitrates and phosphates), pressure, salinity and chemical composition of the oil pollutant.

Temperature affects the rate of oil degradation by stimulating evaporation and weathering of lighter components which may be toxic to exposed microbial strains. Oil degradation is faster at the mesophilic temperature of 25°C than at 5°C. However, some micro-organisms associated with the deep sea and ice water are known to degrade oil under low temperature conditions and such organisms are very sensitive to high temperature conditions.

The initial steps in the degradation of hydrocarbons by bacteria and fungi involve the oxidation of the substrate by oxygenating enzymes for which molecular oxygen is needed. Availability of oxygen in soils, sediments and aquifers is often limiting thereby requiring artificial aeration for the purpose of rehabilitating those areas after an oil spill. However, the normal concentrations of oxygen found in surface water (6-12 mg/l.) are probably adequate to support microbial growth on thin oil slicks.

Crude oil supplies excess of carbon but the micro-organism also requires other elements for growth, especially nitrogen and phosphorus that notoriously limiting in the aquatic environment. The possibility of adding mineral nutrients in the form of oleophilic fertilisers had been considered in pilot and actual field situations for oil spill abatement.

Polluting petroleum, upon mixing with suspended particles tend to sink to the bottom of the sea, where high hydrostatic pressures, in combination with low temperatures, drastically reduce the rate of microbial metabolism.

Studies have shown that the low-molecular weight saturate fractions are more readily degraded than the high-molecular weight aromatics, resins and asphaltenes which are considered as recalcitrant. However, low-molecular weight alkanes with carbon chain length under ten may be toxic to microbial cells due to their membrane disruption capability. Highly viscous oils are also not readily degradable as oils of low viscosity.

The effect of salinity on hydrocarbon degradation has been studied in saline lakes and deep seas and the results showed a general decrease in the rate of hydrocarbon metabolism with increase in salinity.

Environmental applications of oil-degrading microbes

In view of the natural endowment of micro-organisms with petroleum-degrading ability, it is possible to exploit these capacities in finding solutions to problems arising from environmental pollution. There are three main areas of current usage including bioremediation, waste management and biodegradability testing.

Bioremediation of Oil Spills

Bioremediation can be defined as the process by which micro-organisms are stimulated to rapidly degrade hazardous organic contaminants to environmentally safe levels in soils, subsurface materials, water, sludge and residues. Microbial stimulation is achieved by the addition of nutrients and a terminal electron acceptor, usually oxygen, because most biological reactions occur faster under aerobic than anaerobic conditions. In this process, the micro-organisms, especially bacteria, feed directly on the contaminant (i.e., petroleum), using the material as an energy source for growth and the production of cell material. As a result, the petroleum hydrocarbons are broken down to carbon dioxide and water. For natural biodegradation to be enhanced, enough nitrogen, phosphorus and oxygen is required to balance the available hydrocarbon contaminants in order for microbial growth and hydrocarbon dissimilation to occur. The main advantage of bioremediation is that it can be cost-effective. This is due to the fact that adding fertiliser, other nutrients and even selected micro-organisms to contaminated soil or water, or otherwise manipulating the microbial environment, can often be much less expensive than alternative processes such as incineration, use of adsorbents and catalytic destruction. It is also possible to construct genetically engineered strains with enhanced capabilities to degrade organic compounds and which can be used in the bioremediation process.

Two main approaches have been considered for the bioremediation of marine oil spills: seeding with oil-degrading bacteria and environmental modification by fertiliser application. Genetically engineered micro-organisms that degrade petroleum hydrocarbons have been developed, although they are yet to be applied in actual oil spill remediation due to government regulations that restrict the deliberate release of genetically engineered microbes into the environment. Several companies have developed mixed cultures of hydrocarbon utilisers for use in the treatment of oil spills.

The ability of environmental modification to stimulate microbial degradation of oil by indigenous micro-organisms has been demonstrated in the case of the much-publicised *Exxon-Valdez* oil spill in Prince William Sound, Alaska in 1989. Approximately 200,000 barrels of oil was spilled. The primary response was to evacuate the remaining cargo and to mop up as much oil as possible from the water surface and contaminated beaches using skimmers and adsorbents. However, washing of the shoreline with high-pressure water was expensive and cleaned shoreline became oiled forcing recleaning. Bioremediation was therefore considered as a method to augment other cleaning procedures. This historic bioremediation field trial involved the addition of an oleophilic fertiliser Inipol EAP22, a microemulsion of oleic acid, lauryl phosphate, 2-butoxy-1-ethanol and water. The initial results of the treatment obtained from visual observations showed substantial removal of oil from test plots along beaches and cobblestones when compared to untreated control plots within two weeks. Residual oil measurements indicated an approximately 75% removal of extractable oil in the treated plots compared to 50% removal in control plots. The use of Inipol was subsequently approved for shoreline treatment in the US as a major part of the cleaning effort. This successful trial has encouraged the adoption of bioremediation as an applicable technique in the cleanup of oil spills worldwide and has also been tested in the Niger-Delta.

Waste management

During the production and processing of petroleum, various kinds of wastes are generated thereby creating the need for environmentally acceptable and yet cost-effective approaches for their treatment. Moreover, there is a strong and insistent public demand for cleanup of toxic wastes with a desire to reducing general risks to human health and the overall environment. The main waste types from upstream and downstream petroleum industry are produced formation water, oily sludge and petroleum refinery effluents. Since these wastes differ in their physical and chemical characteristics, different treatment scenarios have been adopted for their treatment.
Produced formation water is the connate water pumped up with oil and gas from production wells. It is also referred to as oilfield brine effluent because of its high salt content Most hydrocarbons present in crude oil are also found in produced water either as floating oil or in the dispersed form at concentrations ranging from 20-1500 mg/l. Produced water, prior to discharge, is treated in a gravity separator that will usually remove the suspended oil and reduce its concentration to about 25 ppm. However, such treatment will not remove dissolved hydrocarbons, phenolic compounds, and simple fatty acids in the liquid phase. Such effluents, if discharged, can be toxic to aquatic life. However, it is gratifying that the inoculation of produced water with single or mixed cultures of marine micro-organisms resulted in the removal of many hydrocarbons as well as phenolics present in the complex mixture as successfully demonstrated in my laboratory.

Oily sludges are commonly found in oil storage tank bottoms and in sediment of oil-water separators. These sludges contain hydrocarbons, water and mineral solids in roughly equal proportions. A promising and relatively low-cost option for disposal of oily sludges and wastes is the use of soil as a "biological incinerator" in a process described as landfarming. In this process, the oily waste is spread thinly over the soil surface to facilitate natural biodegradation. Biodegradation is promoted by ploughing for oxygen circulation, nutrient amendment with artificial fertiliser or animal manure, aeration and sometimes, irrigation. Soil acidity or salinity may be controlled through the addition of lime or gypsum.

Refinery wastewater typically contains floating and emulsified hydrocarbons, suspended organic and inorganic particulates, dissolved NSO compounds, and sulfide. Ammonia, heavy metals, and inorganic salts. Treatment of refinery effluents is similar to the treatment of liquid waste from other industrial or domestic sources. The aim of treatment is to remove most of the biological oxygen demand (BOD) and toxic substances such as phenols and polynuclear aromatics from the effluent. After primary treatment that may involve sedimentation, filtration and skimming of floating oil, biological treatment of effluents takes place using the oxidation ponds, activated sludge or rotating biological contactors. In either of these processes, the organic matter in the effluent is brought into direct contact with micro-organisms, which degrade them into harmless substances that can be tolerated in the environment.

Biodegradability testing

In order to make a decision on the safety of a chemical in the environment, whether it is an existing product, or a complex waste, certain critical information must be available on the toxicity, exposure concentration and environmental persistence. Microbial degradation is being used extensively all over the world to arrive at an understanding of chemical exposure. Microcosm experiments are usually designed to test the biodegradable nature of chemicals using microbial isolates or known test strains. Such systems are used to test various products including drilling fluids, herbicides, lubricants, detergents and plasticizers before they are introduced into the environment. Oil degrading microbes have found tremendous applications in the biodegradability testing of many oil-based industrial products.

It is apparent from the foregoing that the ability of micro-organisms to utilise petroleum hydrocarbons as food can be exploited in ridding the environment of pollution from petroleum and petrochemical sources. This is what my inaugural lecture has aptly set out to demonstrate.

MY RESEARCH CONTRIBUTIONS

It is evident from the discussion in this lecture so far, that my main area of research interest by training is on the microbial degradation of oil pollutants in the environment. However, during the course of my academic pursuit at the University of Lagos, I have had the opportunity of making contributions in other areas of microbiology that are of environmental and industrial importance. The summary of my contributions is as follows:

Faecal Pollution Studies

My research involvement actually started as an undergraduate when I was privileged to join the Lagos lagoon pollution research team led by Prof. J.A. Ekundayo, the erstwhile Head of Biological Sciences and Dean of Science, University of Lagos. The results of my final year project entitled "Survival of *Escherichia coli* in the Lagos lagoon" which were reported in the *Journal of West African*

Science Association (Amund *et al.*, 1981), actually launched me into the mainstream of research. In this study we reported the seasonal variation in the population distribution and survival of the bacterial indicator of faecal pollution *Escherichia coli*. The organism was found to survive longer in the rainy season and under freshwater conditions obtainable at the Ogun River mouth than in the saline waters of the Lagos Harbour. The inhibitory effect of salinity on growth and proliferation of the organism was attributed to general osmotic effects and specific ion toxicity. Survival periods were also longer in autoclaved (sterilised) lagoon water than in the raw water. This is because the raw water contained ciliates that are known predators of bacteria. The results showed that the act of dumping sewage into saline waters would achieve greater destruction of pathogenic and other bacteria associated with sewage than in the use of freshwater areas.

Microbial degradation of Crude Oils

My entry into the field of petroleum biodegradation came in 1979 when I began my postgraduate training at the University of Kent at Canterbury, U.K. In my initial study, I had considered the degradation of the North Sea Forties crude oil by a marine microbial consortium from the Medway Estuary, Kent. In the study, it was observed that a mixed microbial *inoculum* of diverse metabolic potentials could effect a more extensive degradation of the crude oil than single species. In addition, there was a synthesis of novel alkanes of longer chain lengths than those originally present in the crude oil sample due to synergistic relationships in the microbial consortium (Amund, 1984a). These observations corroborated the work of other authors that micro-organisms could play a double role of destroying polluting hydrocarbons as well as prolonging the impact of these environmental contaminants through *de novo* synthesis of long chain hydrocarbons.

The knowledge acquired in my postgraduate training was then recruited to initiate the Lagos lagoon oil pollution research on my return to Nigeria in 1982. With the collaboration of a Ph.D. student and an M.Sc student, we measured the rates of degradation of different Nigerian crude oils using microcosm experiments performed *in situ* in the Lagos lagoon (Amund and Igiri, 1990; Amund and Akangbou, 1993). We observed a faster degradation of crude oils under freshwater conditions than under saline conditions and in the rainy season than in the dry season when salinity increases. Lighter oils (Bonny Light and Escravos Light) were also degraded faster than heavier oils (Bonny Medium and Focardos Blend). There was a positive correlation between hydrocarbon concentration and the population density of petroleum degrading bacteria. Apart from the oil degrading bacterial species of the Lagos lagoon that we described, yeasts were also found to contribute immensely to the breakdown of hydrocarbons in the Lagos lagoon (Amund and Nwokoye, 1993).

Hydrocarbon Metabolic Studies

My research training in the U.K also took me into the biochemistry of hydrocarbons. I took a look at the metabolic route for the breakdown of 1-phenylalkanes (alkylbenzenes) in a strain of *Acinetobacter lwoffi* isolated from the Canterbury Sewage Treatment Plant. Alkylbenzenes are important precursors in industrial production of synthetic detergents. Using a combination of metabolic product analysis by gas and thin layer chromatography, respirometric studies and enzyme assays, .the pathway for phenylalkane metabolism in the test strain was established (Amund and Higgins, 1985).

Molecular Genetics of Hydrocarbon Degradation

The main fancy at the time I entered into research in petroleum microbiology in the late 1970s was the molecular genetics of petroleum degradation. At that time, many research laboratories had established a role for plasmid DNA (extrachromosomal genetic elements) in the degradation of some hydrocarbons such as octane, toluene and naphthalene as well as some pesticides. I was therefore challenged to make a contribution on the role of plasmids in oil degradation. My studies showed that plasmids were not found in all oil-degrading bacteria. Where they were found, especially in the *Acinetobacter* species, they did not necessarily code for hydrocarbon degradation (Amund, 1984b). However, the plasmids reported in *Acinetobacter* species by my humble self could promote the transfer of chromosomal genes (Amund, 1995) and could therefore be used in genetic mapping. It was also possible to isolate mutant strains of hydrocarbon utilisers for use in fermentation processes. We have therefore used an arginine-deficient mutant of *Acinetobacter* to produce L-Ornithine, a drug-related amino acid from hydrocarbon substrates (Amund *et al.*, 1983). Three Ph.D graduates from my laboratory have similarly established that the genes for the degradation of major components of crude oil are chromosomally encoded, although the bacterial isolates used in their studies also carry plasmids of different molecular properties.

Microbial Degradation of Lubricating Oils

The indiscriminate disposal of used engine oils in Nigeria and elsewhere had warranted a study of the environmental fate of lubricating oils in my laboratory. We have been able to attribute the lack of accumulation of engine oils on soil and water surfaces despite the pollution incidents to microbial degradation (Amund *et al.*, 1987; 1993). We also observed that the biodegradation potential of lubricating oils is related to their viscosities (Amund and Adebiyi, 1991). While on sabbatical leave in the U.K, in early 1992, I took part in the biodegradability testing of an ester-based synthetic lubricant, EMKARATE DE155 that was produced by the Imperial Chemical Industries. Using an oil-degrading bacterium with esterase activity, it was shown that the oil is only partially biodegradable in that a non-metabolizable degradation product identified as trimethylolpropane (TMP) accumulated in the culture system (Amund, 1996). The environmental friendliness of the product was therefore discredited.

Termite-Microbial Relationships

On my return to the University of Lagos in 1982, I found no infrastructure for immediate continuation of research in petroleum microbiology. In the interim, I entered into collaboration with a senior colleague to undertake some work on the microbial ecology of local termites. In our study, we established that two advanced termites *Amitermes evuncifer* and *Macrotermes bellicosus* maintain a population of heterotrophic bacteria in their hindguts which aid in the digestion of cellulose derived from wood (Amund *et al.*, 1986). We also reported that the mound soil of *Macrotermes bellicosus* is a beehive of extensive microbial activity relative to the surrounding soils. We attributed the characteristic fertility of the mound soil to the predominance of nitrogen-fixing bacteria and the delignification potential of fungal species associated with this soil. The ability of our fungal isolates from the mound soil to delignify wood was suggested to be an asset to the termites by making the wood cellulose more readily available for consumption by termite species (Amund *et al.*, 1988).

Studies on Industrial Enzymes

Since the ban on the use of barley malt for beer brewing in Nigeria and the use of local grains such as sorghum and corn as substitutes, it had become necessary to import enzymes to achieve substantial conversion of starch in the local grains into sugars for alcohol production and to control the development of protein hazes in the brewing wort. The major enzymes of interest to the brewing industry are amylases and proteases. These enzymes are also used in textile and food industries. Our research team comprising, Dr Sesan Omidiji a postgraduate student, Matthew Ilori and me embarked on a search for amylase- and protease-producing local bacterial strains with a view to optimising enzyme production in these organisms. While we purified and characterised amylases and proteases in *Lactobacillus brevis* and *Micrococcus luteus*, we also developed a corn steep liquor-soya bean meal medium for amylase production in an industrial strain of *Bacillus stearothermophilus* as reported in our various publications (Amund and Ogunsina 1987;Amund *et al.* 1990; Ilori *et al.*, 1995; 1996a; 1996b; 1997 and Omidiji *et al.*, 1997). With our background research, we approached a number of brewing plants in Nigeria to show interest in the commercialisation of enzyme production but little success was achieved because enzyme importation was a thriving avenue to siphoning foreign exchange abroad. The little interest we received from a private entrepreneur culminated in the design of an enzyme plant by Dr R.A. Bello (now Professor) of the Chemical Engineering Department, University of Lagos and the production of a feasibility report by Coopers and Lybrand Associates in February 1991.

Mr. Vice-Chancellor, Sir, an enzyme plant that would have costed about 80 million naira to build in 1990, would cost a minimum of one billion naira going by today's value of the naira. An enzyme plant in Nigeria as at 1990 would have been the first and one of its kinds in Africa. By this development, we could see how brilliant ideas are frustrated in our country. Today, our feasibility report is lying on the shelf unutilised just like many others in the country.

Other Contributions

Apart from the major research titles listed hitherto, I have also had the opportunity of making contributions in other areas of economic or environmental importance. Such titles include: the microbial rotting and preservation of banana fruits (Okonkwo *et al.*, 1990); ecology of sulphate-reducing bacteria (Esiobu *et al.*, 1991); biodegradation of synthetic detergents (Amund *et al.*, 1997) and genotoxicity of produced water effluents (Odeigah *et al.*, 1997). My current research is centred on biosurfactant production in oil-degrading bacteria, biodeterioration of fuel oils and the fate of xenobiotic compounds in the environment.

FALLEN ACADEMIC PERFORMANCE IN TERTIARY INSTITUTIONS

Mr. Vice-Chancellor, Sir, kindly permit me to speak briefly on a contemporary issue in the Nigerian university system. This has to do with the systematic but unabated fall in academic standards and the quality of degrees now coming out of our universities. Having reflected deeply on the root causes, I have been able to identify four main attributable reasons which include (1) failure of the 6:3:3:4 system of education; (2) proliferation and underfunding of universities; (3) dampened morale of academic staff and brain drain, (4) incessant closure of tertiary institutions.

The 6:3:3:4 System of Education

The 6:3:3:4 system of education as entrenched in the national policy on education of 1981 became operational between 1984 and 1985 after some years of gestation. In all intent and purpose, the policy clearly spells out that a child of school age shall spend six years in the primary school ANSD secondary education, respectively. At the secondary level are two stages: the junior secondary school and the senior secondary school stages each stage running for three/years. It was also planned that the junior secondary school would be both pre-vocational and academic and students who leave at the junior school stage may then go on to an apprenticeship system or some other schemes for out of school vocational training. The senior secondary school would be for those willing to have a complete six-year secondary education. In effect, the Sixth Form colleges and Schools of Basic studies were phased out. It was therefore expected that universities would change their conditions for admission in the light of the new secondary school structure.

However, in the implementation of the new policy, vocational schools were not established. As. a result every graduate of the junior secondary school automatically proceeds into the senior secondary school. In addition, every student in the senior secondary school sees himself as a prospective university undergraduate. The subsequent rat race for the university has exacerbated the problems of examination malpractices especially in the Senior School Certificate Examinations and the University Matriculation Examinations.

One major fall out of the new educational system was the abolition of Sixth Form schools and Schools of Basic studies which used to provide a buffer between the secondary school and the university. Graduates of Sixth Form schools, in the past used to attain an average age of 19-21 before reaching the university system. The new system brings to the university a good crop of babies, with an average age of 16 years. They are yet to be independent of parental shield and are insensitive to the wide gap between the secondary higher education in Nigeria" I will only use this segment to recapitulate some of his observations.

Since the establishment of the University of Ibadan in 1948, Nigeria has witnessed a steady increase in the number of universities since independence in 1960 to cope with the surging population of Nigerian students who require higher education. The first generation universities apart from Ibadan are those of Lagos, Nsukka, Ife, Zaria and Benin. The number of universities grew under the military with the establishment of the second generation universities at Sokoto, Kano, Calabar, Maiduguri, Jos, Port-Harcourt and Ilorin between 1975 and 1977. However, with the second coming of the civilian administration in the country in 1979, the establishment of universities became a political issue leading to the emergence of many mushroom universities that can best be described as glorified secondary schools. While the Federal government established Federal universities of Technology in Bauchi, Minna, Owerri, Akure, Yola, Abeokuta (now Agriculture) and University of Agriculture in Makurdi, many states followed suit by establishing state-owned universities at Ago-Iwoye, Lagos, Uturu, Enugu, Okigwe and Ekpoma. Although the military administration under Major-General Mohammadu Buhari did some rationalisation of some universities in 1984 due to their non-viability, the number had continued on a steady increase. As at today, there are 37 universities including the Defence Academy and state-owned universities in Nigeria. This is without prejudice to some degree-awarding Colleges of education and three newly approved private universities.

Nigerian University system has witnessed an astronomical rise in student population being the terminal recipient of the poorly implemented 6:3:3:4 system, although this may justify the proliferation of universities. However, the funding pattern of universities gives a foremost impression school and the university. Although there are few exceptional cases of students that mature early and are therefore full of academic initiatives, the majority is immature and incapable of self-sustenance. The pressure to obtain university degrees for advantageous disposition in a materialistic society has had a negative toll on the quality of student intake into the university system. In order to reduce the attrition rate, the university system is always forced to hand over backwards in standard in order to accommodate the inadequacies of the students feed on which it has little control due to the monopoly of the Joint Admissions and Matriculation Board in the conduct of university entrance examinations. It has become a situation of "garbage in, garbage out". Prospective employers have no choice than to re-train graduates from Nigerian Universities and bring them to required standards.

In the recent past, the syllabus for G.C.E. Advanced level used to be a mirror of the university syllabus. Consequently, students in the Sixth Form schools used to study hard to succeed in "A"-level examinations. It was this study habit they used to bring into the university system. However, it is no usual fanciful to find classrooms and libraries fully occupied by university students who are reading to acquire knowledge. Many of their only study these days to pass examinations. Since the study habit is a thing of the past, students are now fully occupied with alcoholism, drug addiction and cult activities. It will only take the grace of God to reverse this trend.

Proliferation and Underfunding of Universities.

This subject has been exhaustively discussed by a professor of educational administration, Aloy Ejiogu in an article he published in 1994 and entitled "The changing fortunes of that governments are not aware of the capital-intensive nature of the running of universities. While the older universities don't receive enough capital grant from government to maintain their old and dilapidated structures, the newer universities cannot rise above the ground level due to inadequacy of funds. The manifestations of the financial misfortunes of universities are seen in overcrowded students' hostels, inadequacy of writing desks and chairs in lecture rooms (if available), ill-equipped laboratories, libraries and offices, cubicles as lecturers' offices, environmental degradation, lack of toilet facilities, blocked sewerage and inability to pay for electricity and water supplies.

Mr. Vice-Chancellor, Sir, What academic standard could be attained or maintained under the deplorable conditions that are characteristic of the Nigerian University system?

Dampened Morale of Academic Staff and Brain Drain

One of the main woes of the university establishment in Nigeria is the battered morale of the teaching staff. This is not to say that other governmental sectors are fairly treated, but the most unfortunate profession by the Nigerian Governments making is teaching at all levels including the universities. The catalogue of woes that befalls the average Nigerian academician is innumerable. Is it the ridiculous salary despite the current palliatives, the poor living conditions, lack of research and teaching facilities, inability to attend local and overseas conferences to update his knowledge or the bleak future after retirement? It is, in the Nigerian University system that a professor has no access to a typist, a messenger and an official car unless he is a Dean or Head of Department. It is therefore not surprising that the race for official positions has assumed a do or die dimension in the system. A lecturer who is financially handicapped to pay his children's school fees or meet simple domestic needs cannot be expected to perform wonders in an atmosphere of want and need. The Nigerian University system has therefore lost the cream of its academia to overseas countries where they are better valued and appreciated. This issue has been overflogged and it is only mentioned in this lecture in the context of its contribution to fallen academic standards of which the net cost to the nation will be disastrous in the long-term.

Incessant Closure of Tertiary Institutions

It would be highly hypocritical of anyone to assume that the regular closure of universities either due to students' unrest or industrial action would have no negative effect on the quantum of academic work done and the ultimate quality of degrees awarded from the system. These closures reached their peaks during the years of military interregnum. Academic sessions were obviously reduced in duration while the schemes of work were only half completed. In most instances, lecturers are forced to concentrate mainly on topics they have set for examinations. It got to a level that students took advantage of the permissiveness of the system to take delight in causing academic disruptions especially under weak university leaderships.

Mr. Vice-Chancellor, Sir, having catalogued the woes of the Nigerian University system, the solution lies in both the government and the people being alive to our responsibilities. If we all stop pretending that all is well then with God's help, the good old days in the Nigerian University system could be restored. I have only decided to lend my voice to this problem because university degrees from Nigerian universities no longer command international acclaim as they used to do in the past. Since the primary and secondary education had been destroyed by various government policies, the last on the line is the University system. All hands should therefore be on deck to preserve it.

CONCLUSIONS AND RECOMMENDATIONS

Mr. Vice-Chancellor, Sir, within the last couple of minutes of this discourse, I have been able to carry out an expository survey of the eminent position of microbiology as a biological science and its role in industry, healthcare delivery and pollution control with special reference to bioremediation of oil spills, waste management and testing of oil-based chemicals. The various contributions made by my humble self in some areas of microbiology that are of economic and environmental importance have also been highlighted. However, this inaugural lecture affords me the opportunity to comment and make recommendations in some areas of our university life.

Mr. Vice-Chancellor, Sir, it is by the ordination of God and by destiny that you are the helmsman in this great university at this point in time. Therefore, I wish to thank God for the monumental achievements of your administration in this university. However, there are still some areas of concern, which I wish to comment on upon in this lecture.

1. The university campus is getting congested as the available land for development is minimised due to the location of the university in a wetland environment. Consequently, our major structures are clustered and with little or no room for expansion. It has now got to a stage whereby we should be taking a critical look at the land use pattern on this campus vis-a-vis the master plan so as not to destroy the aesthetics. We may also need to look at the possibility of reclaiming some land by sandfilling from our endowment efforts. Reclamation, however, has to be done in a sustainable way because we

would not want to put our neighbours in jeopardy while solving our own problem. In this respect, an Environmental Impact Assessment should be carried out using internal experts to examine all possible options before any reclamation venture. We would also need to review the current land use on campus using experts from our departments of Surveying and Geoinformatics, Geography, Urban and Regional Planning, Architecture and Estate Management to prepare a blueprint for future development. I could understood the gigantic nature of this project but I believe it is a possibility.

2. The greatest problem Nigerian students are having today is non-availability of textbooks. This is because foreign authors write the majority of books needed for teaching and research. Consequently these books are very expensive to procure by students and the university libraries alike. Most of our students therefore obtain their degrees without purchasing a single textbook and they rely mainly on their inadequate lecture notes and the extensively vandalised libraries. As to the quality of degrees from such a system, your guess is as good as mine. At our level of development in the Nigerian University system, it is very shameful that we could not produce all the textbooks we need for our major courses and we rely on foreign authors who are not superior to us academically. It is in the Nigerian University system that most authors are in the junior academic staff cadre while the senior and experienced members hang their pens. It is high time we injected some level of moral standards into our academic life in Nigeria. On this note, I wish to commend the present administration for the robust book policy and the various incentives extended to authors in our university and most especially the well-furnished writers' resort in the main library. It is my opinion that this policy should be pursued with greater

vigour in the interest of students and the future generation of academic staff.

3. From the text of my lecture, it is apparent that microbiology is entirely a laboratory science. I wish to thank the Vice-Chancellor for the steps taken so far to establish a standard Microbiology Research Laboratory. We are looking forward to seeing the completion of this laudable project in due course.

4. It is on record that the University of Lagos is about the only university in Nigeria with a practical housing policy whereby the university administration has been involved the in sourcing of land for staff housing schemes. The first in the series is the Magodo housing scheme on which tremendous progress has been made. I will like to appeal to the Vice-Chancellor for further assistance in making Magodo Estate a model through the provision of motorable estate roads, drainage systems, temporary use of the undeveloped university land as recreational site for children and water supply. It is necessary to encourage other allotees in the estate to develop their plots with housing loans and other assistance in the procurement of building materials like at the Kaiyetoro scheme. By encouraging the older members of staff to own and live in their houses, the campus accommodation could be made available to young, active and developing members of staff.

ACKNOWLEDGEMENTS

I cannot but thank the Almighty God who has loved me with his everlasting love and counted me worthy to stand here today as a Professor of this great University. I also wish to thank all the people too numerous to mention whom God used to assist me in my tortuous journey to the present day.

Specifically, I want to mention my former principals at St John's Grammar School, Ile-Ife and St Gregory's College, Lagos, Rev. Fr. G. Cloutier and Mr Paul Amenechi. I want to acknowledge my biology teachers in the secondary and higher schools in the persons of Mr. M.F.Komolafe and Professor A.B.C. Nwosu for the personal interest they showed in me. I cannot forget the fatherly support I received from my mentor, Professor J.A. Ekundayo and a former Dean of Science, Professor C.I.O. Olaniyan at the University of Lagos. Worthy of note is my supervisor both at the University of Kent and at Cranfield University, Professor I.J. Higgins. It will be unfair of me not to mention my postgraduate students whose ambassador I am on this rostrum. To our indefatigable Vice-Chancellor whom God has used to touch the lives of everybody on this campus, I can only identify with the views expressed by a journalist, Mr. Femi Abbas in an article he wrote in "The Vanguard" newspaper on Friday 5th November 1999 and I quote as follows:

> *"In both UNILAG of today and Omotola its Vice-Chancellor, is a guide for those of other Nigerian universities who may need guidance either as a means of acquiring experience or as an encouragement for attaining expertise in academic management.*
>
> *I have never met Professor Omotola personally, but if a critic like me can be spurred by someone's performance to commend him to others, that person must have opened a file for himself in the palace of history.*
>
> *One does not have to agree with Omotola's method or approach, but no progressive mind will disagree with his achievements. If for bringing UNILAG to the forefront of other Nigerian universities, Professor Omotola's efforts are not acknowledged by today's generation, they will definitely be acknowledged by tomorrow's generations".*

It is the hand of God that is moving in this University through the Vice-Chancellor. Therefore, he needs to sustain the ovations by fulfilling every purpose for which God has put him on the seat.

Finally, I wish to acknowledge my one and only wife, Sweetlove, as well as my children Daniel, Paul, John and Benjamin. Also, I wish to mention the beloved family that God has used to touch my life.

Distinguished Ladies and gentlemen, I thank you for your love, patience and attention. Good night and God bless.

REFERENCES

1 Amund, O.O., Ekundayo, J.A., Ogunsanya, C.O. and Akpata, T.V.I. (1981). *J. West Afr. Sci. Assoc.* 26, 61-82.

2 Amund, O.O., MacKinnon, G. and Higgins, I.J. (1983). *J. Appl. Microbiol. Biotechnol.* 17, 252-253.

3 Amund, O.O. (1984a). *Biol. Afr.* 1, 7-12.

4 Amund, O.O. (1984b). *Nig. J. Microbiol.* 4, 134-143.

5 Amund, O.O. and Higgins, I.J. (1985). *Anton. van Leeuwen. J. Microbiol.* 51, 45- 56.

6 Amund, O.O., Yakubu, O.S. and Malaka, S.L.O. (1986) *Nig. J. Biol. Sci.* 1, 19-24.

7 Amund, O.O. and Ogunsina, O.A. (1987). *J. Industr. Microbiol.* 2, 123-127.

8 Amund, O.O., Adebowale, A.A. and Ugoji, E.O. (1987). *Indian J. Microbiol.* 27, 63-67.

9 Amund, O.O., Onumonu, M.N., Onawale, T.A. and Malaka, S.L.O. (1988). *Microbios Letts.* 37, 69-74.

10 Amund, O.O., Omidiji, O. and Ilori, M.O. (1990). *J. Biotechnol.* 13, 361-365.

11 Amund, O.O. and Igiri, C.O. (1990). *Wld. J. Microbiol. Biotechnol.* 6, 255-262.

12 Amund, O.O. and Adebiyi, A.G. (1991). *Tribol. Int.* 24, 235-237.

13 Amund, O.O. and Akangbou, T.S. (1993) *Letts. Appl. Microbiol.* 16, 118-121.

14 Amund, O.O., Omole, C.A., Ugoji, E.O. and Esiobu, N. (1993) *J. Sci. Res. Dev.* 1, 61-64.

15 Amund, O.O. and Nwokoye, N. (1993). *J.Sci. Res. Dev.* 1, 65-69.

16 Amund, O.O. (1995). *J. Sci. Res. Dev.* 2, 43-50.

17 Amund, O.O. (1996). *Biodegradation* 7, 91-95

18 Amund, O.O., Ilori, M.O. and Odetundun, F.R. (1997). *Folia Microbiol.* 42, 353- 356.

19 Atlas, R.M. and Bartha, R. (1972) *Biotechnol. Bioeng.* 14, 297-308.

20 Atlas, R.M. (1981). *Microbiol. Rev.* 45, 180-209

21 Colwell, R.E. and Walker, J.D. (1977) *Crit. Rev. Microbiol.* 5, 423-445

22 Dagley, S. (1971) *Adv. Microbial Physiol.* 6, 1-46.

23 De Klerk, H. and Van der Linden, A.C. (1974). *Anton van Leeuwen.* 40, 7-25.

24 Ellis, R.S. and Adams, R.S. (1961). *Adv. Agron.* 13, 197-216.

25 Energy Information Administration (1992) *International Energy Annual*, Department of Energy, Washington D.C.

26 Ejiogu, A. (1994) J. Appl. Res. Educ. 2, 47-59.

27 Esiobu, N., Amund, O.O., Fakile, O.I. and Popoola, O.H. (1991). *Biomedical Letts*. 46, 129-132.

28 Gatellier, C.R., Oudin, J.L., Fusey, P., Lacase, J.C. and Priou, M.L. (1973) *Proc. Of Joint Conf. On Prevention and Control of Oil Spills*. American Petroleun Institute, Washington D.C. pp 497-507.

29 Gutnick, D.L. and Rosenberg, E. (1977) *Annu. Rev. Microbiol* 31, 379-396.

30 Hopper, D.J. (1977). In: *Developments in the Biodegradation of Hydrocarbons*, R.J. Watkinson (Ed.), Applied Science, London, pp 80-112.

31 Ilori, M.O., Amund, O.O. and Omidiji, O. (1995) *Wld. J. Microbiol. Biotechnol.* 11, 595-596.

32 Ilori, M.O., Amund, O.O. and Omidiji, O. (1996). *Z. Naturforsch.* 51c, 429-431.

33 Ilori, M.O., Amund, O.O. and Omidiji, O. (1996). *Folia Microbiol.* 41, 339-340.

34 Ilori, M.O., Amund, O.O. and Omidiji, O. (1997). *Folia Microbiol.* 42, 445-449.

35 Kennedy, R.S., Finnerty, W.R., Surdasanan, K. and Young, R.A. (1975). *Arch. Microbiol.* 102, 75-83.

36 Lode, A. (1986). *Appl. Microbiol. Biotechnol.* 25, 295.

37 Norris, D.B. and Trudgill, P.W. (1971). Biochem. J. 121, 363-370.

38 Odeigah, P.G.C., Nurudeen, A.O. and Amund, O.O. (1997) *Hereditas* 126, 161-167

39 Okonkwo, S.N. Amund, O.O. and Ogunsanya, C.O. (1990). *Microbios Letts*. 44, 147-155.

40 Omidiji, O., Amund, O.O., Braimoh, A.A. and Ilori, M.O. (1997). *Microbios* 90, 155-162.

41 Osumi, M., Miwa, N., Teranishi, Y., Tanaka, A. and Fukui, S. (1974). *Arch. Microbiol.* 99, 181-201.

42 Rosenberg, M., Bayer, E.A., Delaria, J. and Rosenberg, E. (1982). *Appl. Environ. Microbiol.* 44, 929-937.

43 Scott, C.C.L., Makula, R.A. and Finnerty, W.R. (1976). *J. Bacteriol.* 127, 481-489.

44 Smucker, R.A. and Cooney, J.J. (1981). *Can. J. Microbiol.* 27, 1209-1218.

45 Soli, G. and Bens, E.M. (1972) *Biotechnol. Bioeng.* 14, 319-330.

46 Stanier, R.Y. and Ornston, L.N. (1973). *Adv. Microbial Physiol.* 9, 89-151.

47 Stirling, L.A., Watkinson, R.J. and Higgins I.J. (1977). *J. Gen. Microbiol.* 99, 119-125.
48 Zobell, C.E. (1946). *Bacteriol. Rev.* 10, 1-49.