

OBAFEMI AWOLowo UNIVERSITY, ILE-IFE, NIGERIA.

Inaugural Lecture Series 185

**RECREATING THE AIR OF EDEN
A CHEMICAL ENGINEER'S ADVENTURE
INTO AIR POLLUTION CONTROL**

By

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**An Inaugural Lecture Delivered at Oduduwa Hall,
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I. Introduction

Mr Vice Chancellor Sir, history is being made here today! University of Ife Student #71/185 is this day presenting the 185th Inaugural Lecture of this great citadel of learning as the first Chemical Engineering alumnus of Obafemi Awolowo University to be elevated to the Chair of Professor by his alma mater. It is the third Inaugural Lecture to be given by our Department in her 36 years since establishment. Expectedly, Professor S.A. Sanni who is the first Professor of Chemical Engineering in Black Africa gave the first, in 1979. Professor S.K Layokun, the incumbent head of department, gave the second in 1998. The third is being given today in the *Environmental Engineering* research field and specifically on *Air Pollution Control*. It is also the first inaugural lecture on Environmental Engineering in this University.

Kudos to the bright vision of the founding Fathers of the University of Ife! The staff development programme they pursued was very futuristic indeed. I am a beneficiary of that programme. Several individuals had played key roles in shaping my own academic career. Some of them are here today, and I would like to take this opportunity to doff my hat to them.

II. Special Dedication

This lecture is dedicated in general to all educators and in particular to **Miss Margot Trevelyan**, a Canadian Peace Corp volunteer deployed to my Secondary School, Annunciation School, Ikere-Ekiti (1968-70) for being such a dedicated teacher and builder of lives.

“Mademoiselle, tu es tres joli”!

III. My Adventure

From A Place “For Learning and Culture” to “A Place of Useful Learning”

After Annunciation School and a brief stint at Government College Ibadan, I got an admission to the University of Ife (affectionately

called “Unife”) to study Chemical Technology. Unife met all my dreams and aspirations through value-added education, the nostalgic sceneries, brightly painted buildings and people-friendly accommodation. It was truly “learning and culture”!

I joined the staff of Unife, as a Graduate Assistant, on August 15, 1977. After two weeks of being on ground at Ife (talk about how efficient the bureaucracy was at that time!), I proceeded to Strathclyde University, Glasgow for a Masters’ Degree in Plant and Process Design. It was there that I got exposed to Air Pollution Control, the subject of my PhD and my main focus of research since then. The learning I got there was certainly useful! At this juncture, a 19th Century quote is relevant to you my dear students in the audience:

‘To students - “Don’t specialize too early, one’s views are narrowed. Professional work supplies the special knowledge!”’

– Ernst Werner von Siemens, Engineer and inventor (1816-1892)

Mr. Vice Chancellor, Sir, with your permission, I wish to reiterate that in the academic tradition we have inherited, an Inaugural Lecture may serve to define the scope of a particular discipline or area of specialization of a scholar recently elevated to the status of a Professor. It has sometimes also been the occasion for “the formal presentation of an entirely new discipline, which has been afforded official academic recognition by the creation of a chair relative to that discipline, and the designation of its pioneering scholar for its open and systematic profession.” Although the peculiar circumstances of academic life in our environment may have modified to some extent the conception and purpose of the ritual, it is not supposed to be an *Iwuye ceremony*.

The title of an Inaugural Lecture is clearly very important. illustrates this point.

“The late Professor A.V. Johnson, FRS, (Chemistry Department, University of Sussex, UK) chose a title to discuss the specialist nature of Pheromones for which he is world acclaimed. The audience was filled to capacity with largely teenagers for he titled his lecture with a rather appealing heading - ‘Sex And Violence In The Insect World’”¹

Similarly, Professor Olu Ogboja of the Department of Chemical Engineering, University of Lagos, captivatingly, titled his inaugural lecture: “The Making of a Wealth Plant”. In today’s lecture, **“Recreating the Air of Eden - A Chemical Engineer’s Adventure into Air Pollution Control”**, what I propose to accomplish are:

- To share some of the exciting work which have facilitated my elevation as “Professor of Chemical Engineering” – *A Chemical Engineer’s Adventure into Air Pollution Control*
- To show how important clean air is to our survival and to outline the mechanisms for translating our desire for it into reality - *Recreating the Air of Eden*

IV. The Adventurer’s Craft: Chemical Engineering

Chemical Engineering is a unique discipline, even if sometimes little understood. The American Institute of Chemical Engineering (A.I.Ch.E) defined it as

“ The application of the principles of the physical sciences as well as those of economics and human resources to the design and operation of processes and process equipment in which matter is changed in composition, state or energy level”
(A.I.Ch.E Constitution)

¹ Professor Adimado of the Department of Chemistry, Kumasi National University of Science and Technology, Ghana in his inaugural lecture titled: “From Imaginative Conjectures To Tangible Realities in The World of Chemistry”

Consistent with her synonym, "Process Engineering", chemical engineering curricula generally prepare graduates with a focus on the process as a whole, rather than on segments of it. Little wonder then, that industry responds to that process-oriented paradigm by placing the chemical engineer at top of the pay scale for engineers in several countries (see Table 1).

George E. Davis, considered to be the father of Chemical Engineering, wrote in his book: "The first public recognition of the chemical engineer seems to have been made in 1880 in which an attempt was made to found the Society of Chemical Engineers in London". Having for the first time defined what Chemical Engineering was, distinct from Applied Chemistry and also from Chemical Technology, Davis realized that the subject had to be taught. His lectures were compiled into the historic *Handbook of Chemical Engineering* in 1901 (Finn, 2000).

Table 1: Typical take-home pays in Europe and Asia

Profession	UK Salary (£/yr.) ^a	Singapore salary (S\$ /month) ^b
Doctor, dentistry	52000	
Solicitor	40794	
Chemical Engineer	35700	4475
Chartered chemist	34100	2629
Chartered accountant	32417	3731
Electronic engineer	31460	2946
Electrical engineer	31252	3098
Software engineer	30784	
Civil engineer	29000	
Mechanical engineer	29000	3010

a 2000 figure b 1998 figure

The first Nigerian oil well was discovered at Oloibiri in 1956. It was not until 13 years later that the first move to train indigenous manpower to run the upcoming industry was conceived. Chemical Engineering training in Nigeria started in this University in 1969. The first set graduated in 1973. The Nigerian National Petroleum Company absorbed virtually all the 1974 set of graduates.

The academic programmes of Chemical Engineering Department (Unife) were top-rated and moderated by world-class external examiners². While at Strathclyde University in Glasgow, I found their Chemical Engineering programme very comparable with Unife's.

In all my travels for academic purposes to fourteen countries in four continents, I had always found my academic preparation very adequate. For many years, the performance of Ife graduates at job interviews and on the job performance was exceptionally good. Having returned to Ife as lecturer for 23 years, I feel constrained to express that the standards are declining. Also, the recent feedback reaching the University from some employers of our graduates suggests the need to address output quality. For the avoidance of doubt, OAU's graduates still shine, compared with others. Last year, Prof Duncan Fraser visited our Department from the University of Cape Town, South Africa. He had nothing but glowing reports about the five products of our department who were pursuing higher degrees with them. Nevertheless we must not be complacent!

V. On The Air

Air is very central to life. A man may survive weeks without food, days without water but hardly can he survive minutes without air. Thus, the average man breathes in 11.5 m³ per day of air³. Some 250 different volatile substances have been found in human breath⁴.

² Professors D.C. Freshwater, Gordon S. Beveridge and Collin D. Grant came at different times

³ At rest, a person breathes 12-15 times per minute 500 ml, per breath and therefore 6-8 l/min is inspired and expired. Each minute, 250 ml of oxygen enters the body and 200 ml of CO₂ is excreted.

⁴ <http://www.e-breathing.com/>

In Greek mythology, air was one of the "elements" recognized by the ancient philosophers and those forerunners of science (Marks, 1998). According to *Empedocles*, all matter is comprised of four "roots" or elements of earth, air, fire and water. Fire and air are outwardly reaching elements, reaching up and out, whereas earth and water turn inward and downward. In his *Tetrasomia*, or *Doctrine of the Four Elements*, *Empedocles* described these elements not only as physical manifestations or material substances, but also as spiritual essences. He associated these elements with four gods and goddesses - air with Zeus, earth with Hera, fire with Hades, and water with Nestis (believed to be Persephone). Aristotle further expanded the same doctrines in his *Metaphysics*. Could these philosophers have known the connection between air pollution and combustion?

To the chemical engineer, air is a most important process raw material. Air is a mixture of gases with the typical composition as shown in Table 2.

It is used in reactions (e.g. combustion, etc). When liquefied, Nitrogen and oxygen are produced from it. Nitrogen serves as an inert gas blanket in many process applications whilst oxygen serves medical purposes, or, as a feed for oxidation reactions where the use of pure oxygen is required for high yield. The atmosphere has been used as a "sink" for process by-products but in that role, its absorptive capacity must be borne in mind.

Table 2: The composition of unpolluted dry* atmospheric air

Gas	Concentration (ppm)	Gas	Concentration (ppm)
Nitrogen	780900	Methane	1.0
Oxygen	209400	Krypton	1.0
Argon	9300	Nitrous Oxide [#]	0.5
Carbon dioxide	315	Nitrogen dioxide [#]	0.02
Neon	18	Ozone [#]	0.01-0.04
Helium	5.2		

Notes: * Moisture increases the adverse effects of pollutants in air

These gases are termed as pollutants beyond acceptable concentrations

⁵ A Greek philosopher, scientist and healer who lived in Sicily in the fifth century B.C.

VI On Eden

EDEN, to the ordinary American, may mean 17 different places he had previously visited in USA (and perhaps with no air worthy of recreating!) or a location in New South Wales or yet another in Northern Ireland.⁶

This lecture does not presuppose that Eden's present location is known so that we can recreate its air! Theologians, historians, ordinary inquisitive people and men of science have tried for centuries to figure out where, geographically speaking, the Garden of Eden was. Eden has been "located" in as many diverse areas as has the "lost Atlantis". However, Hamblin (2001) reports that Dr. Zairns (an archeologist) may have found Eden's location.

Eden's Air At Creation

Eden is the Biblical garden of creation. It was a utopia in its description with its beauty surpassing that of the Arctic summer blooms. The vegetation (Gen 2:8-10), the animal life showed diversity and yet harmony (Gen 2:10-14), the water resources and aquatic life were rich (Gen 1:20-21); it was also well endowed in mineral resources (Gen 2:12). It is the **air quality** that interests me. There was an indication that God was visiting man in the cool of the day there (Gen 3:8). The air could not have been smog-filled! It is strange, but true, that now, there are oxygen-vending machines in some urban cities (Salazar, 2004)! Eden was man's universe but it was beautiful. It was man's factory but he suffered no occupational exposure to air toxics there. Can our planet have air with such a quality today? Can our factories now be in such perfect harmony with the environment like Eden?

For not keeping fully to the terms of use of that garden, man was, unfortunately, banished from the Garden of Eden (Genesis 3:23-24). There, it would appear that orderliness gave way to chaos in the

⁶ <http://en.wikipedia.org/wiki/Eden>

universe; entropy was introduced ... energy conversions and pollution too. Now, industrial conversion of a feed into desired products comes with by-products, which must be managed in an environmentally friendly manner. Great skill is required in order to leave the ambient air in the industrial environment pristine.

Pristine air is clean air but not vice-versa, for the term "clean air" is nowadays usually defined by regulatory agencies. Pristine air is still observed in remote or rural environments where anthropogenic air pollution contributions are low. By contrast, the urban air tends to be air "polluted" to a certain degree.

The environment is the part of the biosphere in which all human activities take place. It includes air/land/water compartments that are respectively referred to as the atmosphere, the hydrosphere and the terrestrial domains. The atmosphere is 85 km deep (as deducible from atmospheric pressure) and comprises the troposphere, tropopause, stratosphere, stratopause, mesosphere, mesopause and thermosphere in that order.

VIII The Desecration of Eden's Air

Adam's offspring has continued to emit substances that impair Eden's air. For instance ozone depletion has been widely reported to occur in faraway stratosphere (18-50 km aloft)!

Ecology and Exponential Growth

The single most important cause of air pollution is the expanding number of people in the world. A key relationship between humans and the accelerating change in their environment is the exponential growth. (Fig. 1). Suppose a lily starts with a leaf and doubles its number of leaves each succeeding day, it would take only weeks to get to the point when half of the pond surface will be covered. From that point, it only requires one additional day to get the whole pond surface covered. The difference between linear growth and exponential growth is the classical theory by Malthus (1798). His hypothesis was

that unchecked population would increase in geometric progression, while the means of subsistence would increase in an arithmetic progression. As a result, population would expand to the limit of subsistence and would be held thereafter by war, famine and ill health. The question about exponential growth is which side of the curve describes the phenomenon of interest – the "side that is almost flat" or the "side with the steep slope?"

An expanding population makes it essential that we reduce the per capita emission of pollutants. On the contrary, except when a deliberate policy mechanism is put in place, it is increasing (Fig. 2). There is a disparity in per capita energy consumption. It varies approximately linearly with the gross national product.

Typical values of exponential growth rate parameters have been computed for population as well as for energy consumption are shown in Table 3 (Heisohn and Kabel, 1998).

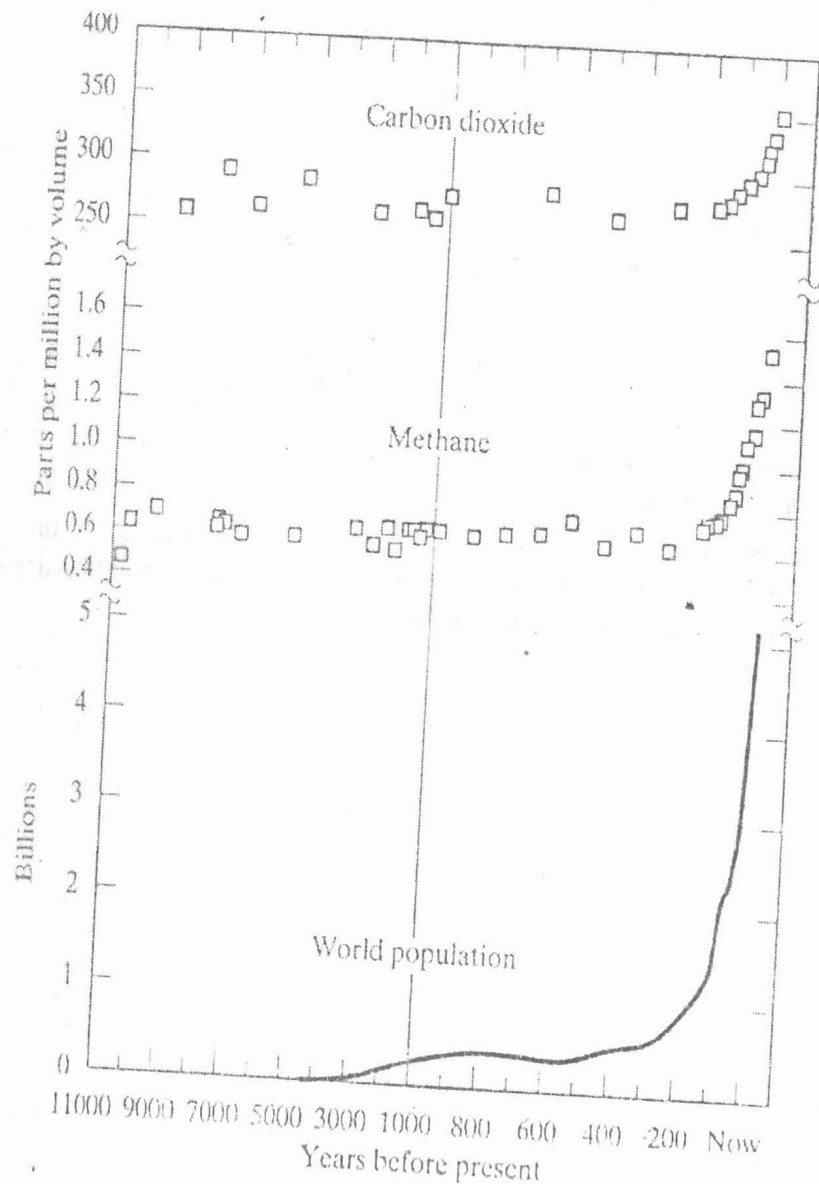


Fig. 1: Exponential Trends of World Population and Typical Anthropogenic Pollutants
(Source (Heisoehn and Kabel (1999))

Table 3: Average growth rates of population, per capita energy consumption and total energy consumption for the world

	Population (%/year)	Per capita Energy consumption (%/year)	Total energy consumption (%/year)
World	1.76	1.98	3.74
US	0.86	0.51	1.37

The predicted world energy consumption rate versus time for various growth rates are shown in Fig. 3.

Two issues arise—reduction in energy consumption requires both reductions in per capita energy consumption (a task that technological innovation can aim at) and population growth rate, which is more difficult to check. The second is that the exponential growth rate in the consumption of energy is the dominant anthropogenic factor that affects climate. When increased pollutants arising from expanded energy consumption are emitted into the atmosphere, they affect radiant heat transfer to and from the earth. This is the so-called “greenhouse effect”. Also, although not often emphasized, there is direct heating of the air by the energy discharged by human activity.

Exponential Growth in Transportation:

The annual motor vehicle sales in USA were 4192 in 1910 but 11.1 million in 1965 (Stern *et al*, 1984). Worldwide, there were 600 million vehicles in 1999 and 3 billion are expected by 2020 (Fells, 1999). Emissions from traffic sector have a particular importance because of their rapid growth. Goods transport by road in Europe increased by 54% between 1980 and 2000. In the last 10 years, passenger transport by air and road increased by 67% and 46% respectively. The main traffic-derived emissions are NOx, hydrocarbons and CO, which amount respectively to 58%, 50% and 75% of such emissions. Motor vehicles accounted for 222Tg (i.e.,

60%) of the estimated total 371 Tg global anthropogenic carbon monoxide generation in 1970. Other mobile sources contributed yet another 25 Tg and solid waste disposal 23Tg (Yen, 1999). Clearly more than 50% of the global anthropogenic CO source is from automobile emissions. The frequency of occurrence of urban photochemical smogs has been correlated with high utilization of motor vehicles. Thus, other issues relating to motor vehicular use include the high emissions of principally NO_x , hydrocarbons and particulate matters, as well as the contribution to ambient

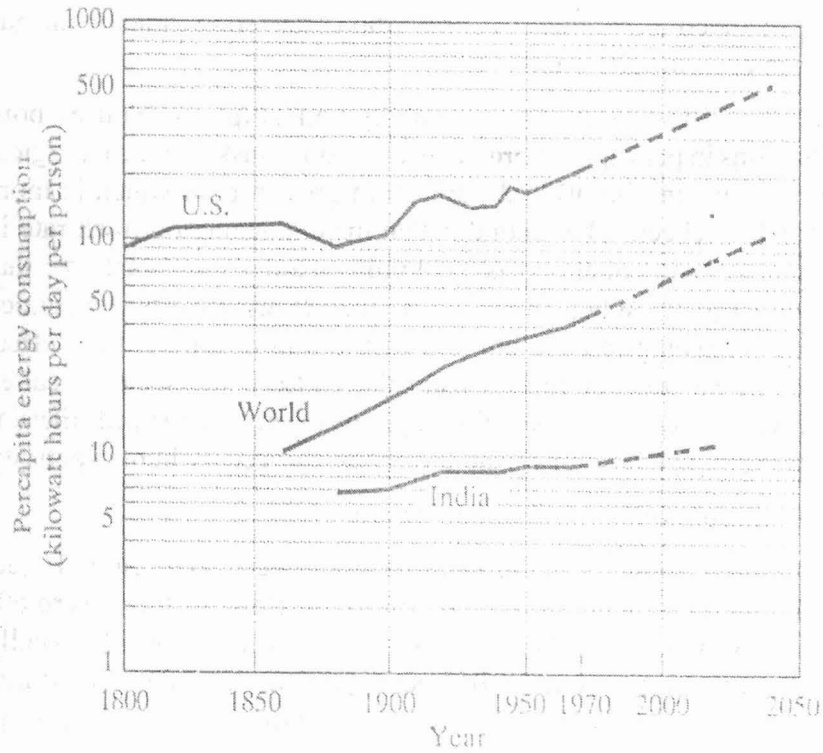


Fig. 2: Temporal Trend of Per capita Energy Consumption (Source: Heisohn and Kabel (1999))

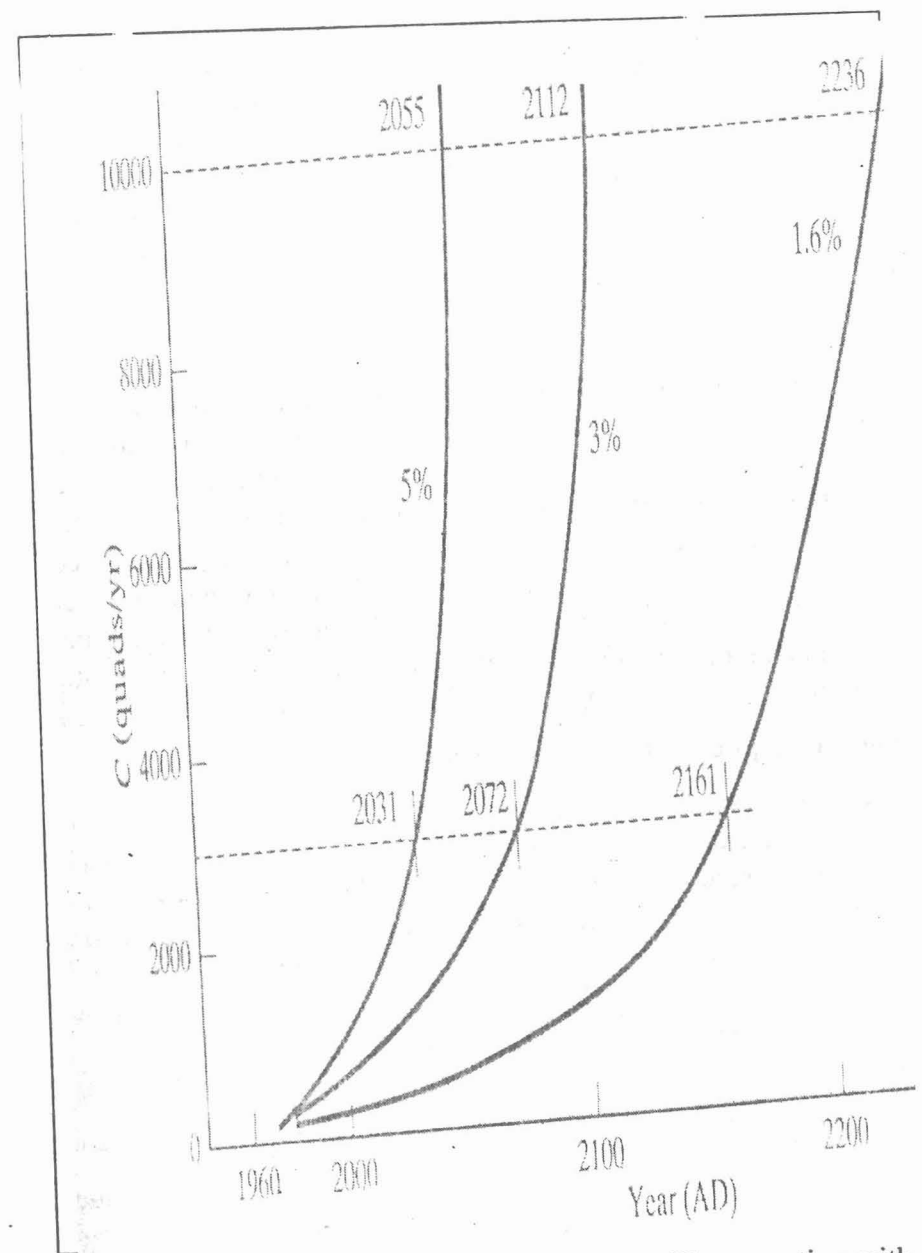


Fig. 2: Predicted Temporal Trend Total Energy (Consumption with Growth Rates as Parameter (Source: Heisohn and Kabel (1999))

hydrocarbons through volatilization of gasoline. While the three-way catalytic converter is a solution that eliminates pollutants from the exhaust gases, catalyst poisoning by lead additives must be prevented. Thus, there is a need for the elimination of tetraethyl lead additive used as antiknock agents. These issues demonstrate that the motor vehicular source cannot be left out of any meaningful national air pollution management strategy.

Explosive Growth in Fossil Fuel Utilization

The increasing combustion of fossil fuel has led to an increase in the atmospheric concentration of carbon dioxide levels, temperatures by 0.6°C and sea level rise by 18 cm over the 20th century. At the Kyoto meeting in 1997, parties committed themselves to make some small reductions in greenhouse gas emissions. The major energy sources viz: coal, tar sands, crude oil (and the refined petroleum products obtained from it), natural gas vary in their energy contents per unit mass and their pollution propensities. While cost may have favoured coal, there is a shift towards less polluting fuels such as natural gas.

The Atmosphere's Limits As A Sink For Pollutants

The atmosphere is not a limitless sink. The lower portion of the troposphere from ground level till the inversion layer is the depth available to receive anthropogenic inputs. When low vertical depth of the "mixing layer" coincides with low horizontal advection wind velocities and high generation rates of contaminants, pollution is said to arise. A quantitative indicator of the pollutant dispersion potential of the atmosphere is provided by the "ventilation coefficient", defined as the product of the meridional wind speed and the mixing depth.

Air pollution may be defined as

"The emission of substances into the atmosphere in such quantities (concentrations) and for such durations as to lead to deleterious effects on exposed humans, vegetation or materials"

Implicit in that definition is the time-concentration effect. Thus, a given concentration of pollutant exerts an undesirable effect on a subject exposed to it longer than a specific duration.

Air pollution may be local, urban, regional, continental or global in scale (Table 4).

Table 4: Air pollution scales and the organization required for their resolution

Category	Example	Vertical Scale	Temporal scale	Scale of organization required for resolution
Local	Motor vehicle emissions; Odour nuisance	Height of stacks	Hours	Municipal
Urban	Inversion episodes	Lowest 1.5km of the atmosphere	Days	Local Government Area
Regional	Forest fire emissions; Advection of urban pollution into non-urban locations	Troposphere	Months	State or National
Continental	Trans-boundary air pollution; (LRTAP); Acid rain	Stratosphere	Years	National or International
Global	CO ₂ induced global warming; Tropospheric Ozone depletion	Atmosphere	Decades	International

Sources of air pollution include industry, motor vehicles, energy production and domestic activity. In Nigerian urban cities, the burning of solid wastes also constitutes a serious air pollution source.

Air pollution episodes of note include the Meuse Valley (Belgium) episode of 1930, the Donora, Pennsylvania, episode (1948) and the London Smog (1952). The effects of air pollution on humans include bronchitis, emphysema, and exacerbation of respiratory ailments. Inhalation of carbon monoxide will lead progressively from disruption of human oxygen-transport system to decreased vigilance, headaches, coma and ultimately death. Several incidents of CO-induced fatality have been recorded in Nigeria through the use of standby electricity generators.

When hazardous air pollutants are concerned, the effect could be chronic or acute. After exposure, a latency period applies in some cases, as is the case with asbestos and cadmium, before manifestation of the effects. Now the mixed solid wastes burnt in our street corners include cadmium batteries and polyvinyl chloride materials. The acrid smells of such fumes suggest they may not be so healthy.

On vegetation, necrosis, chlorosis and growth abnormalities are among the effects of air pollutions. The deterioration of the black Forest in Germany is one of the most staggering illustrations of this effect. Preventing the negative economic impact of air pollution injury to plants informed the setting of secondary national ambient air quality standards in the United States to protect plants.

On the atmosphere, modifications of weather, acidification of rain and global warming are among the effects of air pollution. The stratospheric ozone concentration had been declining with the so-called Antarctic ozone hole. This has been attributed to reactions of chlorofluorocarbons (CFCs), nitrous oxide, methyl chloroform, carbon tetrachloride, methane and carbon dioxide. Stratospheric ozone normally shields humans from harmful UV- β radiation.

On materials, the adverse effects of air pollution include surface deterioration, weakening of leather, cracking of paints, corrosion of metals, blackening of stonework, ozone-attack on rubber and other elastomers as well as degradation of masonry mortar. Sulfurous fumes

react with red (lead oxide) paints to form black (lead sulfide) product over time. Ozone damage to rubber in tyres and wiper blades has been implicated in the finding that Los Angeles dwellers change these automobile parts more frequently than in other cities in the US.

On aesthetics, air pollution causes visibility degradation due to the light extinction characteristics of fine particles. The haze occurrences that have been observed in several cities such as Sydney (Australia), Denver (USA), New York and no doubt, Lagos (Nigeria) illustrate this.

Air pollution presents man with a "Catch 22" situation. To do nothing to control it leads to adverse effects with a cumulative social cost that is known to exceed the combined cost (capital and operating) of facilities required for controlling it.

IX. Recreation of Eden's Air

A. The Approaches

Practical measures to achieve clean air usually adopt a combination of legislative, administrative and technological instruments.

The legislative approach stipulates who pays for pollution control, to what extent should pollution be controlled, etc. Included in this approach are the following: Regulatory approach that involves the stipulation of mandatory limits for a stated number of air pollutants; the subsidization approach, in which tax rebates, grants-in-aid; pollution investment recovery tax moratorium are used; and the "Direct Charges approach" where the payment of pollution charges is intended to serve as disincentive to continued pollution of the environment.

In Nigeria, there are national air quality guidelines that stipulate limits for air pollutants. Direct charges also apply nationally to natural gas flaring. Some states specify pollution charges for industrial establishments. The fine for continued flaring (N10.00/scf) has been rendered meaningless by inflation (\$1 = N140).

The administrative approach utilizes administrative instruments to curb pollution generation e.g. introduction of parking fees or no-parking zones, vehicle movement restrictions on the basis of odd-even number plates, the introduction of fuel taxes, etc.

Granted that "zero-development option" cannot sustain the world's population in the long term, the technological options available for achieving clean air are: (a) the Cleaner technology approach, (b) the End-of-pipe treatment approach and (c) the Dilution (dispersion) approach.

B. Recognizing The Need - Sounding An Alert

The chemical industry produces about 100,000 chemicals currently, with only 5,000 of them being comprehensively documented⁷. Some of them are toxic. In terms of safety, the chemical industry has an enviable record. Its fatal accident frequency rate (FAFR)⁸ is 3.5 (Table 5).

Nonetheless, accidents do occur. Most often, the pollutant is a nuisance, but in some emergency

situations, the offending substance may become life threatening, demanding an emergency

response in order to mitigate its impact. The two plants operated by Union Carbide illustrate this

point. At Bhopal (India), the release of methyl isocyanate led to 2500 deaths overnight. At Institute (W. Virginia), the emission of methylene chloride and aldicarb oxime produced no human casualty. The difference in outcomes was attributable to emergency preparedness. In

Nigeria, most emergencies produce total loss. The ADC Flight 86 crash and the market fires in several Nigerian cities attest to this. With this in view, it is necessary to put a mechanism in place to have

⁷ Chemical Engineers (London), 11th March, 1999, p3.

⁸ FAFR is defined as the risk to life in 10⁸ exposed hours. This is equivalent to the number of fatalities occurring among 1000 men over their working life (assumed to be 33 years of working for 320 days per year and 10 hours per day).

a ready source of information (material safety data sheets) as well as operational dispersion models. My research has covered these very amply. However, it is regrettable that

Table 5: FAFR of typical activities/occupations³

Occupation	FAFR	Occupation	FAFR
Chemical industry	3.5	Air crew	250
British industry average	4	Professional boxers	7000
Steel industry	8	Staying at home	3
Fishing	35	Travelling by bus	3
Coal mining	40	Travelling by train	5
Railway shunters	45	Travelling by car	57
Construction workers	67	Pedal cycling	96
		Travelling by air	240

most models run for the Nigerian plants being designed along the coasts are based on Benin Republic data. The reason is that the full complement of Nigerian meteorological data needed to be preprocessed for use is missing. This requires to be addressed very urgently at the national level. We have here at OAU preprocessors to apply if the data were available.

The solution proffered for the air pollution problem must fit the types and characteristics of pollutants concerned, its composition and its effects.

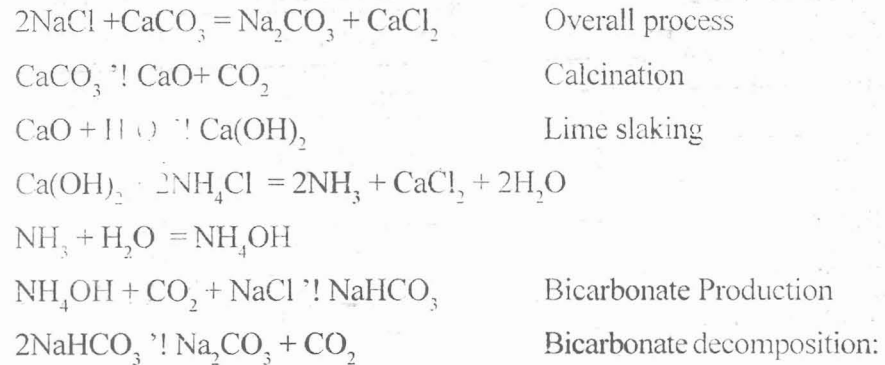
C. Identifying The Air Pollution Control Engineering Strategy to Adopt

1. *The Cleaner technology approach*: The idea here is to prevent the pollutant from getting formed in the first place. This may entail

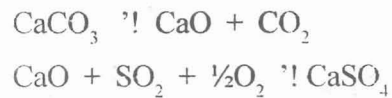
⁹ Kletz, T.A. "Hazard analysis—a quantitative approach to safety" *Institution of Chemical Engineers Symposium Series No 34*, London 1971

making a process change, raw material change or workplace environment change (improvements) in order to achieve this.

(i). *Process route change*: This involves knowing the chemistry of a process and changing the process route to match the required pollution control standard. For instance, the offensive LeBlanc process was replaced with the Solvay Process



(ii). *Raw material Change*: Here, the production of pollution in a process is envisaged and tactics are introduced to minimize or prevent it e.g by switching fuel from coal to natural gas or from a solid fuel to a liquid fuel. Alternatively, if high-sulfur coal is to be used as a fuel, it may be burned in a fluidized bed combustion chamber with the simultaneous injection of pulverized limestone.



The resulting quick lime reacts with the nascent sulfur dioxide thus preventing its escape. The sulfur removal efficiency is as high as 95%.

(iii). *Modification of Process Conditions*. High temperature combustion often leads to the emission of nitric oxide resulting from the oxidation of atmospheric nitrogen. From a consideration of the temperature variation of the equilibrium constants (Table 6), the control options can be deciphered.

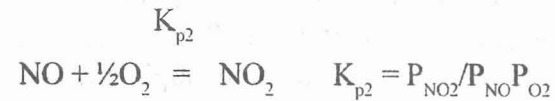


Table 6: Temperature dependence of the equilibrium constants of the reactions between nitrogen and oxygen

T (K)	K_{p1}	K_{p2}
300	10^{-15}	10^6
1000	8.7×10^{-5}	1.1×10^{-1}
1200	5.3×10^{-4}	
1500	3.3×10^{-3}	1×10^{-2}
2000	2.0×10^{-2}	3.5×10^{-3}
2500	5.9×10^{-2}	3.5×10^{-3}

Evidently, high temperature favours NO production from N_2 but high temperature disfavours NO_2 production from NO. For successful prevention of NO formation therefore, the strategy is to control the 3T's (temperature, turbulence and residence time) by reducing the maximum temperature and the residence time in the combustion chamber and adjusting the geometry of the burner/air and limit fuel Nitrogen. The practical steps that might be taken in this wise include:

- Dividing the combustion chamber into sub-chambers
- Introducing the required O_2 in stages - much of the O_2 in later stages
- Minimizing residence time of fuel in the high-temperature zones, else unwanted reactions take place and avoiding high heat release rates while ensuring high heat removal rates. These form the consideration of the low- NO_x technology that is the vogue with NO_x emission control in natural gas fired power plants.

2. *End-of-pipe treatment approach.* The idea here is to abate the pollutants formed prior to discharge. Where such pollution control devices were not incorporated at the design stage, they may have to be retrofitted. A particular factory merely rotated employees who showed signs of pollution impairment out of the "polluted zone". An example of this approach is flue gas desulfurization employing wet scrubbers.

3. *The dispersion approach.* This entails diluting the pollutants to acceptable ground level concentrations at the receptor site. Here, the goal is to use a sufficiently high stack to disperse the pollutants in a manner consistent with the prevailing meteorological conditions. The legislations in Nigeria have no stipulations on the minimum stack heights to be adopted. Tall enough stacks were made to disperse SO₂ from power plants in the UK. Although this solved the original problems, there was a resultant acidic deposition in the Netherlands (transboundary transport).

In the preceding hierarchy of options, the cleaner technology approach is the most favoured. However, none of them will be applied without the mandate provided by environmental legislation.

D. Ensuring Compliance with Applicable Environmental Legislations

Environmental legislations are to define who pays for pollution control (Polluter pays? User pays? Government?), the responsible enforcement agency (Federal/state/local), regulatory standards, applicable penalties/sanctions and the environmental monitoring/audits required as well as their frequencies.

Examples of such legislation are the Environmental Impact Assessment law, Federal Ministry of Environment regulations, etc. It is instructive to note that even though motor vehicles account for over half of urban air pollution, there is no legislation on mobile emission sources in Nigeria. This merits legislative attention right now!

E. Environmental Economics

In cleaning up the air, economic considerations readily come to the fore.

The cost of "doing something" is to be compared with the "cost of doing nothing about pollution". For correct pricing, also, environmental costs must be internalized. A balance is to be made between using "cost-effectiveness" (BATNEEC) as the decision criterion and best available technology (BAT).

F. Capacity Building Adequacy - Environmental Engineering as a Sub-discipline in Chemical Engineering

Without doubt, air pollution control requires capacity building for it to be achieved. Environmental Engineering focuses on this. It merits mention here that it has taken my colleagues a long time to recognize that Environmental Engineering was a valid part of Chemical Engineering. No doubt, other fields of specialization such as Civil Engineering and Air Conditioning /Ventilation Engineering pursue aspects of Environmental engineering different from those that interest the chemical engineer. The environmental engineer who is also a chemical engineer focuses on dealing with the environmental residuals of industrial processes. He is also to deal with the issues related to tackling the "environment as the *host* to the chemical process". In the latter regard, due cognizance must be taken of the fact of the NIMBY (Not In My Backyard) Syndrome. This is a reaction by communities to what is regarded to as environmental insensitivity. The environmental/chemical engineer thus needs to assess air quality; perform EIA's; get interested in Loss Prevention, etc., in order to demonstrate what has been legally coined as "Responsible Care".

X. The Adventurer's Discovery - My Contribution

A). Air pollution control

Prior to my research into air pollution control, the widely held view was that there the efficiency of a particle scrubbing equipment was mainly a function of the power consumption with little possibility of performance improvement through design (the so-called Contacting Power Concept).

Physically, pressure drop signifies the power consumed per unit volumetric flow rate of the gas through the pollution control equipment.

Mathematical model of particle capture by froth generated on a sieve plate and of sprays in a venturi scrubber were used to predict collection efficiency versus pressure drop relationships for a range of particle sizes and operating conditions (Muir and Akeredolu, 1982 and 1983). In order to check the theoretical predictions, experimental tests were carried out on pilot scales of these scrubbers under the same conditions as those used in the calculations. Contrary to the Contacting Power Concept, both theory and experimental tests showed that the multiple-stage column is capable of more energy-efficient particle collection than the single stage (See Figs. 4 and 5). The improvements in performance that can be achieved by using the appropriate three-stage venturi instead of the single-stage is very marked over most of the operating range and increases with increase in particle size and in pressure drop. These results on the design of air pollution control systems such as the *sieve plate* and *multistage venturi* particulate scrubbers have found direct application in designs implemented for dust control in secondary aluminium plants. How to apply them in the Nigerian situation was the subject of Akeredolu (1984).

B. Air Pollution monitoring

In 1983, my first invited paper, given at the request by the Lagos State Ministry of Works, Housing and Environment was titled "Is there air pollution in Lagos?" The answers to that question then were more postulative than affirmative. Now we know better. But that same question had propelled my air pollution investigations of other locations and settings.

Accordingly, several environmental phenomena had been researched including:

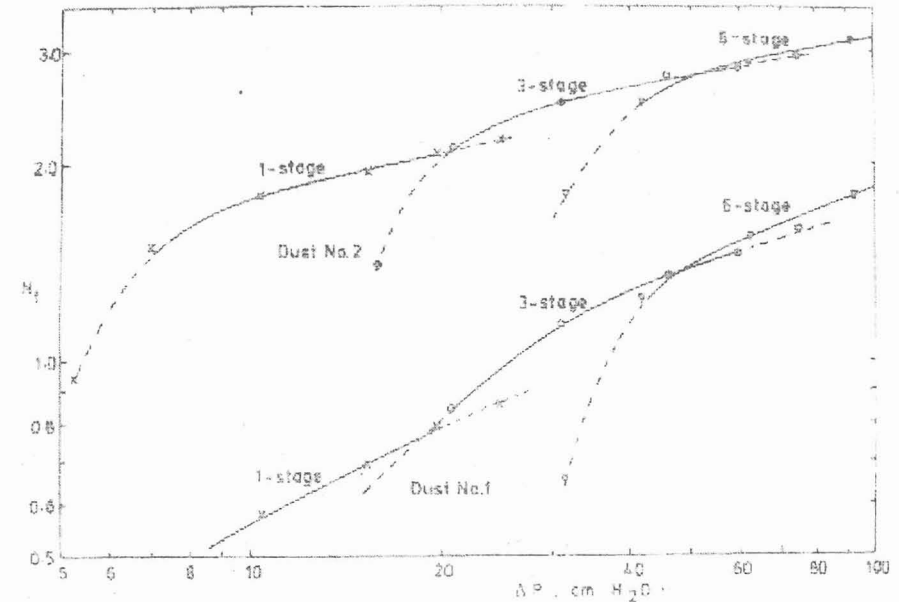


Fig 8. Theoretical relationships of N_1 vs ΔP for polydisperse test dusts

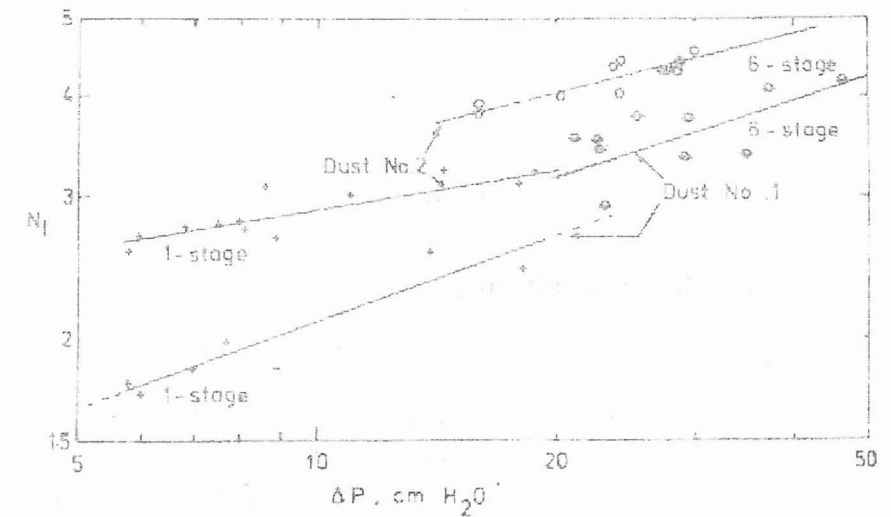


Figure 4: Theoretical and Experimental Performances of Multiple Stage Sieve Plate Column

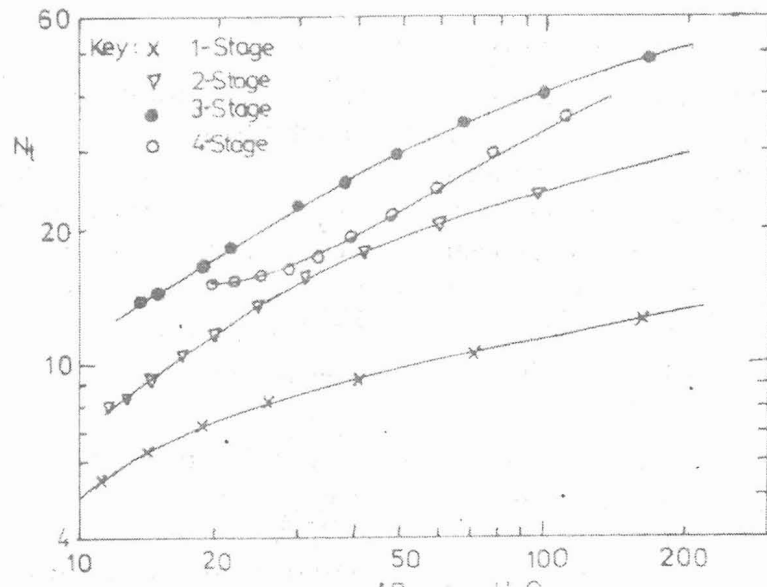


Figure 5a: Theoretical Performance of Multiple Stage Venturi Scrubber

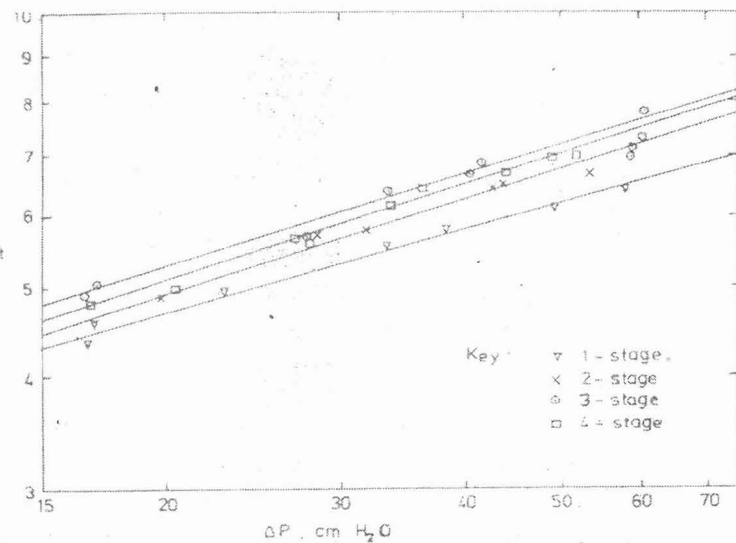


Figure 5b: Experimental Performance of Multiple Stage Venturi Scrubber

1. Industrial Sources/Environments

The manufacturing industry in Nigeria had grown astronomically from just a few in 1920s. In parallel with this trend is the increase in the capacity to generate air pollution. Furthermore, establishment of several plants pre-dated strict industrial zoning regulations and thus their proximity to residential areas cause landuse conflicts and serious environmental disamenity (Akeredolu 1989). Citizen protests and even legal actions have been instituted against some factory managements. Our team conducted air pollution monitoring in several of such factories.

- (a) *Cement* – Akeredolu *et al* (1994) reported their measured concentrations and elemental composition of suspended dust particulates from cement industries in Nigeria. The dust concentrations ranged from 500 to 1300 $\mu\text{g}/\text{m}^3$ within the factory and 100-370 $\mu\text{g}/\text{m}^3$ outside the factory. The inhalable dust concentrations ($D_p < 2\mu\text{m}$) are about 1-2 orders of magnitude above WHO prescribed limits. Lead was among the highly enriched elements whilst chromium was moderately enriched. Adejumo *et al* (1994) found the dust deposition rates to be 1-1681 tons/ km^2 /month within the works and 0.5-266 tons/ km^2 /month within the neighbourhood, tailing off exponentially with the distance from the factory. Toxic metals like Pb, As, Ni, Co and Cr were among the highly enriched elements found in the deposits around three cement factories. The need for maintaining a greenbelt zone around major factories was highlighted.
- (b) *Oil and Gas* – Field measurements were made on flues of flare systems of various designs (Obioh *et al*, 1994). The combustion efficiency determined for a newly modified flaring system with enhanced air supply and liquid aspiration system for the atomization of the condensates associated with the flared gas was found higher than the conventional flare types in vogue by 20 percent or more. Theoretical predictions were

also carried out on flares. (Sonibare and Akeredolu (2004). The air quality in the vicinity of a Nigerian refinery was studied (Akeredolu and Sonibare (1997)).

- (c) *Iron and Steel* – The cost price per ton on steel would be halved if no environmental protection measures were incorporated into its production. But the life expectancy would be decreased by years in the vicinity of such plants. Major air pollution campaigns have been conducted elsewhere to characterize the nature of pollution emanating from steel and non-ferrous smelter. In Nigeria, Ndiokwere and Ezihe (1990) reported the occurrence of heavy metals in the vicinity of industrial establishments but my team produced the first set of data on the total suspended matter and the trace and heavy elemental composition of air particulates within and outside an iron and steel factory in Nigeria (Akeredolu and Latinwo (1997) and Latinwo and Akeredolu (2005)).

My investigation of air quality covered other industrial sectors such as Food and Beverages, Small-scale industries (Ikamaise *et al*, 2001).

2. **Transportation sources:** When cars are discarded in Europe for failing emission tests, they find their way, *en masse*, into the Nigerian market. No emission tests are demanded. Our work had shown that there is a significant contribution to air quality degradation by motor vehicles in Nigeria. Emission measurement results for some Nigerian vehicles were reported. (Ogunsola *et al* (1993), Ogunsola *et al* (1994) and Baumbach *et al*, (1995)).

3. **Urban air quality:**

Akeredolu (1989a) reported the contribution from unpaved roads to air quality and indoor/outdoor dust deposition. The prediction of the carrying capacity of the urban air in Nigeria through the computation of ventilation coefficients has taken my research attention. The results were the first to be published on that subject for the country. (Akeredolu *et al* (2002) and Akeredolu and Sonibare (2002)). I served on the committee

that the Federal Ministry of Environment Guidelines. Our air quality data moderated the standards that were ultimately set for particulate matter. Figures 6 and 7 show the typical continuous air monitoring data for Lagos. (Baumbach *et al*. (1995).

4. Regional Air Quality Issues

- a) *Bush burning and air pollution* – The contributions of C, N and S from bush burning were predicted and presented to American Geophysical Union conference in 1990 as the only African input to the conference discussing such a pertinent issue (Akeredolu and Isichei, 1990); The contribution of biomass burning in Nigeria to the African Greenhouse Gases Inventory was predicted (Isichei *et al* 1995)
- b) *Acidification* – The Scientific Committee on Problems of the Environment (SCOPE) requested for a presentation of the Nigerian position paper to the book on Acidification in Tropical Countries (SCOPE 36), Prof. Isichei and I took up the

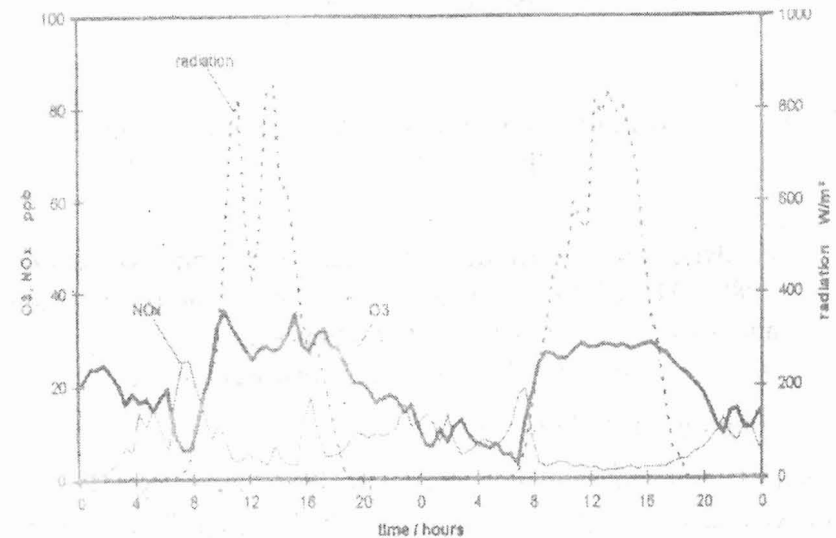


Figure 6: Typical Data for Continuous Measurement of NO_x , O_3 , and Radiation in Lagos

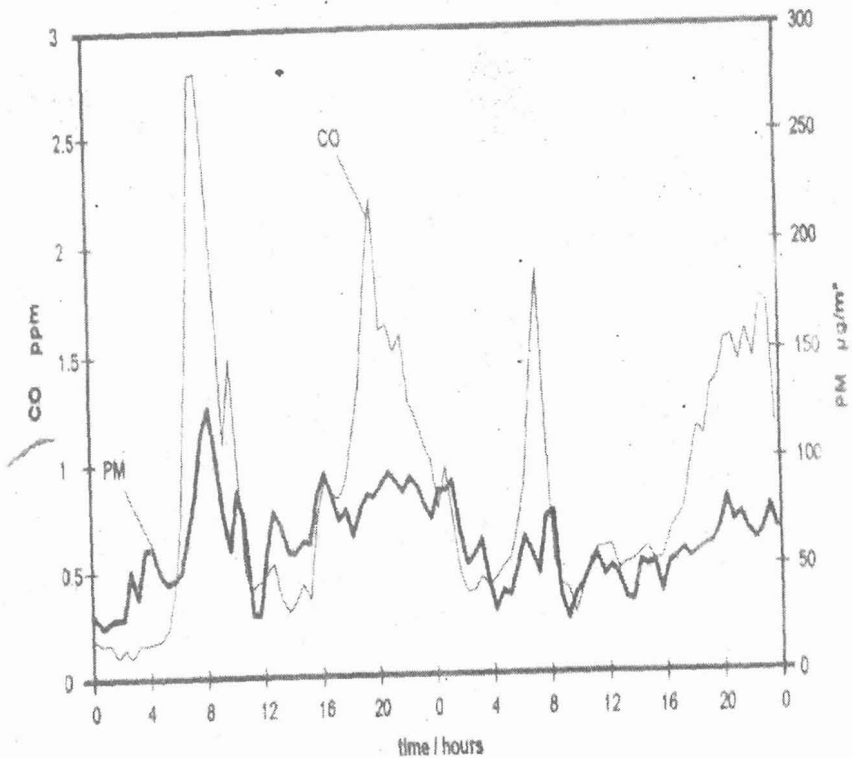


Figure 7: Typical Data for Continuous Measurement of CO and PM n in Lagos

challenge and contributed a chapter (Isichei and Akeredolu, 1988). Akeredolu *et al* (1995) summarized the precipitation and aerosol chemistry measurements in Nigeria in support of the IGAC/DEBIT AFRICA (IDAF) research initiative.

5. Air pollution modeling

When the Chernobyl accident occurred in USSR, I was spending my sabbatical leave at the Air Quality Research Branch of Environment Canada. Naturally, the Canadian scientists ran global circulation models to depict the possible footprints of the nuclear radiation fallout.

The output was a colour-coded map of the world. "Red" was used to depict the high-risk zones, "orange" the medium risk zones, etc. The models colour-coded Nigeria orange, to my uttermost surprise. The question that arose in my mind was then: "would my compatriots believe that Chernobyl had anything to do with them? Would any precautionary measures be issued out as was the case in Europe and North America?"

(a) Dispersion modeling

Dispersion models seek to answer the question "To where does emit pollutant spread and what are the downwind concentrations to be experienced by receptors?"

Receptor models, on the hand, answer the question: "From where did the contaminant in the air sampled at a given location originate and what is the percentage contribution by each of the identified sources to the overall sample?"

Dispersion models provide the link between emission standards and ambient air quality (i.e. immission) standards set for regulatory purposes. They also find use in environmental impact prediction. The wind data that serve as input to dispersion models are "forward trajectories" whilst "backward trajectories" apply more to receptor models. Akeredolu *et al.* (2004) modeled the spread of and dispersion of LNG spilled on a tropical waters. The predicted ambient air footprint fell partly within the radius at which there were some residential settlements.

(b). Long range transport

If answering the question "Is there air pollution in Lagos?" propelled me into monitoring various aspects of the Nigerian environment, a similar question, "Why is there air pollution in the High Arctic?" propelled my modeling of the transport of heavy metals from the mid-lattitudes into the High Arctic during my sabbatical leave spent at the Air quality Research Branch of Environment Canada (1988-1999). The results (Akeredolu *et al* 1994c) yielded new quantitative

insights into human influence on the Polar Regions. The model showed that apart from the winter maximum input into the Arctic, a peak was also shown in October. For lead, there was a nearly equal Arctic input from each of the three source regions investigated (namely western Europe, Eastern Europe and the former Soviet Union). But for As, Cd, Sb, V and Zn, the highest Arctic input originated from Eastern Europe. In contrast, the highest input of sulfur to the Arctic originated from the former Soviet Union. These findings contradicted those reported by Lowenthal and Rahn (1985) who for the same time period attributed 75-90% of these trace elements in aerosols at Barrow, Alaska to sources in the former Soviet Union. We also concluded that not all trace elements enter into the Arctic at the same longitude.

(c). *Regional-scale models*

Akeredolu *et al.* (1999) demonstrated the fact that air masses from urban areas can affect the air quality in relatively clean areas. Aerosol black carbon was monitored at Egbert, Ontario at a remote regional air quality measurement station using an aethalometer. Using 5-day back trajectories, it was shown that pollution episodes corresponded with periods when the air parcels passed over polluted regions and vice versa.

(d). *Issue related models*

Modeling of carbon monoxide (CO) at signalized road intersections (i.e. with traffic lights) in Lagos was carried out (Akeredolu *et al.* (2004d)). The CO concentrations range between 9.5 and 29.9 ppm. By comparison, the Nigerian national ambient standard for CO is 10 ppm.

6. Emission measurements:

In the course of my career, I have carried out emission measurements on several industrial stacks for diesel-fired electricity generators, gas power plants, gas flares (stationary sources) as well as on motor vehicle exhaust (mobile source).

7. Emission Modeling/Predictions

Emission models answer the question: "How much pollution is being generated and from where?" When a national policy on the environment is to be formulated, the rational basis should be an inventory. Air pollutant inventorization usually includes emission predictions and emission modelling. Emission factors, defined as the quantity of an air pollutant emitted per unit of production, computed from measured air pollution emission data are used as basis. Thus:

$$\text{Pollutant Emission} = \text{Source activity descriptor} * \text{Emission factor.}$$

In 1989, this author published the first national summary on atmospheric pollutants in Nigeria (Akeredolu (1989b)). The EU-funded Environmental Monitoring and Impact Assessment project group, to which I belonged, published a more comprehensive, detailed national inventory on air pollutants for Nigeria in 1988 (Obioh *et al.* (1994)). The results were presented as Nigeria's working paper to the Intergovernmental Panel on Climate Change (IPCC) at several workshops. Finer grid emission modeling has been attempted at the city-scale for Lagos and at the Industrial Estate Scale for Ikeja and Agbara Estates (Olaniyan *et al.* 2003). The results of the stack emissions carried out by us were used to predict emission factors for Nigerian upstream oil and gas facilities and the cement industry.

8. Receptor Modeling

The *Chemical Mass Balance* (CMB) model was applied to evaluate the source contributions to the ambient levels of benzene, toluene and xylene measured in Warri by the local Refinery (Akeredolu and Sonibare 2001). Using multivariate statistical tools such as Factor Analysis and CMB, the sources of air particulate pollutants monitored at urban (Minna study) and industrial (cement) sources have been successfully established. In a certain case legal, I prepared the expert witness document to help resolve the dust nuisance complaint between a luxury car refurbishing shop (plaintive) and her cement bagging plant neighbour (defendant). The scientific evidence adduced showed

the nature and most probable source of the offending dust. Nevertheless, the ruling was in favour of the defendant, a man of influence.

9. Natural Gas Utilization:

The utilization options for natural gas have been my focus lately (Akeredolu and Sonibare (2003 and 2004). The use options include channeling the gas towards power generation and household cooking. The engineering problems to be solved were addressed.

10. Environmental Impact Assessment (EIA)

EIAs were first developed formally in the United States in the late 1960s. As a management tool, their purpose was to identify and assess possible impacts on the environment due to a planned action. My involvement in the use of this tool is twofold. I have been privileged to prepare as an air quality specialist at several developmental projects. I have also been privileged to be in the Technical Review Panels, appointed by the Federal Minister of Environment, where EIA reports of other major projects are critically reviewed. Apart from such, the environmental audits involving issues on noise have attracted some of my research attention (Sonibare *et al*, 2003, and Sonibare *et al*. 2004)

C. Environmental Engineering Education

I have taught Environmental Engineering in this University for over two decades. At the onset, it was an elective. The students nursed fears that the course had no relevance to Nigeria's needs. Such fears had since long disappeared. The Institution of Chemical Engineers (UK) requires that the graduate demonstrate competence in Process Design as well as Industrial Pollution Control prior to registration. The departmental curriculum has aligned with this position to make the course compulsory. Recently, too, the Department introduced a course on "Loss Prevention in the Process Plant". Its link with Environmental Engineering is apparent. Both courses should prepare our graduates for designing plants that are "people-friendly" as well

as environment-friendly". In terms of lecture delivery, it would be most wonderful if a greater portion of it could be available via the electronic medium. Fired by this belief, about a fifth of my Final Year Project students in the last five years had been given IT-related topics!

D. The Multidisciplinary Nature of Environmental Research

The in-depth study of the environment requires multi-disciplinary participation. No wonder that I have collaborated with Geographers, Soil scientists, Chemists, Physicists, Botanists, Zoologists, etc., in my career. The facilities and analytical tools I have used were state-of-the-art and very expensive. They were made accessible only because our team's proposal to the European Union (Under the Lome IV Agreement) provided the funds.

E. International Linkages

I have benefited from the following international linkages, for which I am grateful. Environment Canada hosted me for a Visiting Fellowship for two years. I was given the opportunity to serve in the scientific steering Committee of the International Global Atmospheric Chemistry Project (Deposition of Biogeochemical Trace Species Subdivision) - IGAC/DEBITS. I was also privileged to serve on the committee of IGAC/DEBITS-AFRICA (IDAF), with the headquarters in Toulouse, France. I also participated in the Environmental Monitoring and Impact Assessment Project which benefited from the EEC/FGN Linkage with Universities of Stuttgart (FRG) and Surrey (UK).

XI. Policy Issues And Mechanisms For Cleaning The Air

In the course of this lecture, the following issues have emanated that require being addressed through mechanisms for cleaning the air: The need for hard data on Nigeria's air quality, climate change issues such as global warming and ozone depletion, bush burning, vehicular emissions and the concerns of host communities about the risk to

their lives due to the presence of industrial facilities. Also identified, were the needs to check population growth (a social policy issue) as well as to check the per capita energy consumption growth rate through appropriate technological innovation and energy policy. In this regard, a maxim of Environmental Management applies: "Think globally, Act locally".

There had been a National conference on water pollution sponsored by the Ministry of Water Resources as far back as 1982. There is yet to be a national conference at which data on the air quality of Nigeria will be critically assessed. It would be most useful if the Department of Petroleum Resources will spearhead an initiative to assess the air quality data that had been submitted to her for the Niger Delta over the past decade.

Nigeria is a main financial contributor to UNEP but her participation in terms of UNEP scientific projects had been nearly minimal. The nation's representation to that organization will need to be broadened to include not mainly bureaucrats, but more researchers from Nigerian institutions.

The local responses on the conventions and protocols to which Nigeria is a signatory should be given better attention. Prominent among these are the Montreal protocol on ozone-depleting substances and the Kyoto protocol. The facilities available for changing over to ozone-friendly production systems should be better publicized. Research into alternative refrigerants applicable to the tropics should be considered. Also implied may be the need to look at our energy consumption patterns to identify wastages. Our major refineries and petrochemical industries should be compelled to carry out environmental as well as energy audits. The flare-down date set by the Federal government should be made firm, quite unlike the earlier deadlines on flares. The natural gas utilization projects penciled down for Nigeria should be kept on course. Government's commitment to the clean development mechanism should be strengthened. The implementation of the Kyoto Protocol should be better concretized

f. Nigeria. Nigerian engineers should be involved in the required facility/machinery conversions. Gas is the fuel of the future. The nation's reserves of gas will outlive that of crude oil. The government should promote gas engineering research right from now.

The growth in the use of private cars for commuting should be stemmed through the introduction of conducive *mass transit* vehicles. The nation has moved away from the operation of mass transit systems for our major cities preferring the use of small buses under their "mass transit" scheme. The latter is regrettably "a misnomer". However, government should be considering legislating that all mass transit systems should use Compressed Natural Gas rather than gasoline. There will be cost implications of the switch, but in the longer term, it is a more environmentally sound decision. The nation should be considering the introduction of new and less-polluting specifications for fuels (oxygenates and biofuels inclusive). The abatement of vehicular pollution through the introduction of the three-way catalyst should be considered. But most importantly, emission standards should be set for mobile emission sources. Systems for measuring vehicular emissions should be acquired. Capacity building should also be set in motion for running an efficient national motor vehicle emission-testing programme. Despite the reluctance of government to regulate the age of the vehicles they import, there is a clear correlation between vehicular age and emissions.

The industrial estates in the country should be surveyed in order to ascertain the extent of encroachment into their green belts zones. Other countries that ignored this have stories of woes to tell.

XII Here Was An Eden

Permit me, Mr. Vice Chancellor, Sir, to go allegorical. Unife was an Eden. The "air" of it was splendid. The master plan was visionary and the energy for implementing it was effusive. Into this garden came cuttings of rare species from the best gardens the world over. The rains came in season. The bloom was colourful. Laurels were won. The keepers were very contented. Many Keepers down the road,

exotic species stopped coming. Droughts replaced rains. The soil became parched and flowers began to wilt. In their place resistant weeds flourished. May I submit, Mr. Vice Chancellor, Sir, that the "air" of Ife needs to be recreated? My humble suggestions include getting the alumni to come and identify how to restore parts of this garden. The "Unife Chem Eng Class of '74" deserves a special commendation in that regard. The Class of '76 to which I belong is aspiring to follow in their footsteps. Recently, the class donated a Computer Aided Process Engineering (CAPE) facility – comprising a fully multimedia computer system loaded with operational Hysis® Software - to the Department. To all of you my buddies goes my special appreciation for heeding that clarion call. However, an endowment would go a longer way to help the University than occasional gifts!

XIII. A New Eden?

In the Biblical Eden, man was kept out of the garden by the angel after the fall. Several attempts to build a new Eden in which God is kept out have been conceived and experimented. In 1825, one of such experiments to create an atheistic Utopia was performed by Robert Owen in New Hampton. The dream was short-lived, ending in 1826. My standpoint sharply contrasts with that of Owen!

XIV Conclusions

Is there air pollution in Nigeria? It can be safely said that from the results of my research presented in this lecture, the air in Nigeria is not pristine (like the air of Eden!) in many regards. The exponential growths in population, energy consumption and vehicular traffic predispose our environment to rapid deterioration of air quality unless adequate corrective measures are put in place. The nation has, to date, regrettably ignored the traffic source of emissions. Several mechanisms have been proposed for redressing the situation.

Stemming the growth rates of per capita energy consumption and per capita air pollution requires research and development for which Nigerian institutions should be strengthened

XV Recommendations

- a. A national air quality monitoring programme should be commenced
- b. National emergency planning must be put in place – a national chemical emergency response center should be a component of the plan.
- c. In my several factory air quality measurements, I have come to see how many pollution control devices were installed but dysfunctional. There is a need for revisiting the environmental audit process that the Federal Ministry of Environment has in place in order to ensure that the process leads to real and remarkable environmental improvements.
- d. Several Emission stacks observed in Nigerian industries do not meet international standards. There should be national guidelines on emission stacks.
- e. There is an urgent need to enact national mobile emission source regulations with enforceable limits. In pursuance of this, the appropriate agencies should be strengthened and trained in anticipation.
- f. The failure of central electricity generation and the use of so many pollution-prone standby generators should be redressed. It has increased the per capita pollution emission for the same energy consumption.
- g. Public enlightenment about the hazards of using standby electricity generators in enclosed spaces should be carried out.

- h. Atmospheric inversions occur with moderately high frequency in our major industrial conurbations. On the basis of my work, the percentage considered to be capable of producing air pollution episode is also high. It is therefore necessary for the Federal Department of Aviation to revive the regular acquisition of meteorological upper air sounding data for those atmospheres as well as the other site-specific data that can facilitate the running of dispersion models.
- i. The use of alternative, less polluting, energy sources should be considered. Gas easily suggests itself. Adoption of environmentally-friendly options of gas-utilization should be encouraged through fiscal incentives.
- j. Prominent attention should be given to capacity building on gas engineering, as gas is the fuel of the future.

It is important that we, as a nation, set mechanisms in place to make our air like the air of Eden. We must however note that:

"It is a long, hard road from a successful experiment to a successful mechanism, a road on which ninety-nine percent of inventions break their necks" – Ernst Werner von Siemens, Engineer and inventor (1816-1892)

So the LORD God banished him from the Garden of Eden to work the ground from which he had been taken. After he drove the man out, he placed on the east side of the Garden of Eden cherubim and a flaming sword flashing back and forth to guard the way to the tree of life.

(Genesis 3:23-24)

But did man learn the secret of the air of Eden? Who can learn the secret of recreating a utopia from which the Almighty is excluded? Can we contemporary citizens of the world get our acts together to recreate that air of Eden where we live today? The answer, my friends, is blown in the winds!

Mr. Vice Chancellor, Sir, here I rest my case.

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