University of Nigeria

37th INAUGURAL LECTURE

Engineering Systems Analysis and Optimization

An Inaugural Lecture of the University of Nigeria, delivered on August 26, 2008

Samuel Ogbonna Enibe
Professor of Mechanical Engineering
University of Nigeria, Nsukka

UNIVERSITY OF NIGERIA

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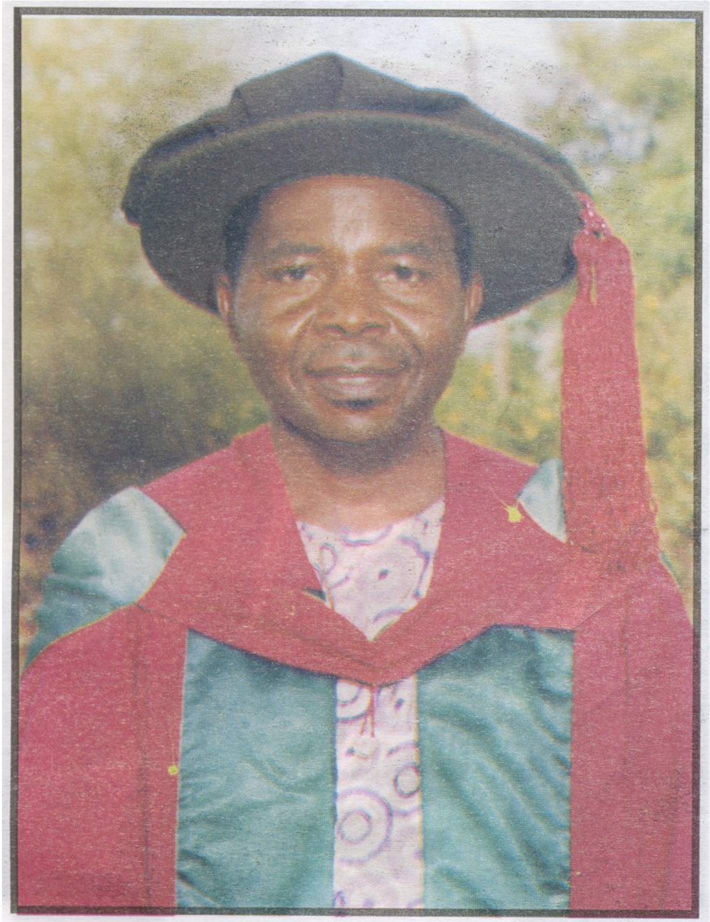

Samuel Ogbonna Enibe

Professor of Mechanical Engineering
University of Nigeria, Nsukka

Chapter 1

INTRODUCTION

1.1 Protocols

- The Vice-Chancellor, Venerable Engineer. Professor Chinedu Ositadinma Nebo

- The Deputy Vice-Chancellor (Academic), Elder Professor K. Mosto Onuoha

- The Deputy Vice-Chancellor (Administration), Engineer. Professor Francis I Idike

- The Deputy Vice-Chancellor (Enugu Campus), Professor (Mrs) Rich E Umeh

- The Dean, Faculty of Engineering, Engineer Professor Nkemakolnam Nwolisa Osadebe

- Deans of Faculties and Directors of Institutes/Centres here present

- All Past Inaugural Lecturers here present

- All Professors of the University of Nigeria here present

- The Registrar, Barister P C Dioka, Esq

- All Academic Staff here present

- Members of the University of Nigeria here present

- Staff and Students of the Faculty of Engineering here present

- Chaplain, Associate Chaplain, Council Members, Clergy and members of Christ Church Chapel here present

- Chaplain, Associate Chaplains, Council Members, Clergy and members of St Peters Catholic Chaplaincy here present

- Distinguished ladies and gentlemen
- Lions and Lionesses
- All other protocols duely observed!

1.2 Thanks

Thank you very much for giving me this singular opportunity to stand before this great assembly to deliver the 37^{th} Inaugural Lecture of the University of Nigeria.

1.3 In the begining

I praise the Lord God Almighty who made this day possible by keeping all of us alive and well. He saw each of us from cradle to where we are today and in Him we live and move and have our being (Acts of the Apostles 17:28). Indeed, we are fearfully and wonderfully made, Psalm 139:14.

Just after the Nigerian Civil War in 1970, I trod the streets and pathways of our quiet and serene Ndiagu Quarters of Amaenye Village of Abagana (a town of proverbial nine villages or clans) as a boy of 13 who survived the attrocities. I was then in Primary 5 at St. Peters CMS (now Central) School, Abagana. I noticed a deep longing for God within me that soon was caught in the wave of spiritual revival that spread from the South Eastern part of Nigeria at the time. That singular experience of conversion has shaped the rest of my life. I thank God for giving me that singular opportunity early in life, and pray that many young boys and girls, as well as the rest of us, shall enjoy a similar favour soon in Jesus name, amen.

The background for that experience had been prepared during my pre-War Primary School days at St Theresas Catholic School, Ogboja, Ogoja (Cross River State) and the refugee residency for some 18 months at the Catholic Primary School/Church at Ogboji, Orumba South LGA of Anambra State during the war.

1.4 Appreciation

Many people and institutions helped to shape my life. Some of them will be briefly mentioned here.

1.4.1 Wife and children

I met my wife Ojiugo for the first time in the Scripture Union fellowship at Central School, Odenigbo, Nsukka, sometime in 1984. On October 3 of that same year, I proposed to her for marriage. Sometime latter, she accepted, and we wedded on December 3, 1988. Ojiugo was a virgin until the night after our wedding ceremony! Up till today, that spirit of chastity, that charm of physical and inner beauty, that singleness of heart and deep commitment to the highest ideals, have not left her, but have rather been enhanced and strenghtened.

Our private vehicle at the time of our wedding was a third hand Honda MB 500 motorcycle, but she did not mind. She was convinced that we should not neglect the day of small beginings! She encouraged me as I struggled with my PhD and the publications that followed, and bore with me when we had to engage in several small scale enterprises to survive, including the production and sale of sachet water, soya milk/powder, baked products such as *chin chin*, etc. At a stage, we hired out our old motorcycle for *okada* business (commercial motorcycle taxi), yet our marriage remained strenghtened by God. We have had to take care of so many relations and others, and she has always lent her support. May the Lord bless you yet the more in Jesus name, amen!

Each of our six children have also been wonderfull and have contributed to the growth and joy of the family. Arinze, who was born a year and some fraction after our wedding, started a good example of being responsible and reasonable. Chimaluka and Ebube who maintained a two-year sequence, followed the same steps. The younger ones, Mmesoma, Chiagoziem and Amarachukwu have kept the tradition. We do apply various rods of correction as suggested by Proverbs 29:15, and they have learnt to accept them for our common good. I appreciate you all!

Miss Ijeoma Okoji joined the family within the first year or so of our wedding, and has stayed with us ever since. May the Lord continue to establish her and give her the very best in life, amen.

1.4.2 Parents and siblings

I begin in somewhat chronological order by thanking our late father, Elder David Nwoye Enibe who saw to it that we all went to school, and gave us an early christian upbringing. At the age of 63, he served as an apprentice in masonry trade and latter became proficient enough to scout for and secure his own building construction and maintenance jobs. Our mother, Mrs Cecilia Patricia

Egonyi Enibe supported our father with petty trading in *agidi* (a snack made from maize), *okpa* and the like. May the Lord continue to keep her for us.

I thank my elder brother, Mr Christian Chukwuemeka Enibe who chearfully supported our parents to bring up the rest of us. In 1973, he had to cut short his own education to work full time with our father so that the entire family will not perish in the post-war economic hardship in our part of the country at the time. Several years latter, he began a long struggle to recover part of that lost education. God has rewarded those efforts, and blessed him with a wife, Virginia and five wonderfull children. More blessings are yet in stock for him and the family!

I also thank my younger brother, David Okechukwu Enibe, his wife Ekene and children who have been very supportive. Similarly, I thank my sisters Ngozi and Gloria who have been very special people indeed.

1.4.3 Extended family members

These are so numerours that only a few will be acknowledged here. Principal among them is Mr. Edwin Enibe who wisely decided to whisk us off to Ogboji in February 1968 when Abagana was about to be overrun by Federal Troops. He has maintained the same level of vision and wisdom ever since. The same appreciations go to his siblings Patricia, Pius, Emma and Moses.

All the sisters of our mother deserve special mention. Starting from Nwaku and Elue down to Ojiugo and Mgbeke, they all showed us unusual kindness and always helped in times of need. Of particular note is the constant provision of food in those early post-war years of hunger. Similarly, we need to thank Mr. Benjamin Uzoh and his sister Mabel for their usual kindness.

The late Elder Reuben Onyedinma was very helpful to the entire family. He paid parts of my secondary school fees as well as the first term fees (worth fifty naira only (N50.00)) during my first year at the University in the 1977/1978 academic year.

The Osadebe family of Ogbunike in Anambra State deserve special mention. The relatioship between the two families dates back to over 150 years, yet the two families still share much in common. The courage and boldness of their late father, Nweke, was a constant source of encouragement, and this was transmitted to each of the children. I salute particularly Nkemakolan (and his dear wife Amaka), now Professor of Civil Engineering and Dean, Faculty of Engineering, for encouraging me in 1974 to study what is now known as Further Mathematics in the secondary school. Without this, I may not have studied engineering, or undertake some of the things I have done. I also salute his brother, Tochukwu (and his wife Ngozi), now an Engineer and current Director of Works, UNN.

1.4.4 In-laws

My in-laws have been very wonderful indeed! I am grateful to God for my late father in-law, Micahel Ejeagba Okeh, who gave his consent to my getting married to her daughter Ojiugo just a few months before his death in 1987. I also thank God for my late mother in-law, Enyidiya, who, as her name implies, was a true friend to her husband and a great mother indeed. I also thank the siblings of my wife, namely,

- Mr. Egbuta E Ejeagba, his wife Eunice and children Oluebube, Egbuta, Princewill
- Miss Ndubumma Mercy Ejeagba
- Mrs Uzochukwu Ogakwu, her husband Sylvester and children
- Mrs Oriaku Comfort Eti, her husband Ogbonna and son Awesome
- Dr Okezie Ejeagba

I am grateful to the step-brothers of my wife, namely

- Ekekwe Emmanuel Ejeagba, his wife Nkechi, and children
- Ifeanyi Ejeagba and his family
- Onwukwe Ejeagba and his family
- Ephraim Ejeagba and his family

I am grateful to Dr O U Okereke, brother to my late mother-in-law. He and his late wife brought Ojiugo to Nsukka in 1983, got a job for her, and encouraged her to aim at further studies.

1.4.5 Childhood friends

I thank my childhood friend, Chief Dennis Amobi who has remained as close as a brother for many years. Similarly, I appreciate my secondary school classmates Engr Emmanuel Ozobialu and Dr. Patrick Nze for their friendship.

1.4.6 Christian brethren

There is a very long list of christian brethren and associates that deserve some mention, but only a few can be accomodated within the available space and time.

Abagana/Ukpo

My early christian associates at Abagana were Mr Jeremiah Oyilagu, Mr James Aguegwu and Miss Veronica Anikobi (now Mrs Onyeyili). I derived a lot of spiritual nourishment from late Rev Prophet John Ezekwe of the Church of God of New Jerusalem, Abagana. He also bought me a pair of school uniforms and paid some secondary school fees. His successor, late Evangelist Benjamin Nwanonye provided much assistance as well. Dr Joe Okoye, whose foresight and vision encouraged me a lot, deserves special mention as well. He shared his beautiful residence with me between 1983 and 1987 before I could obtain my own residential flat.

Christian Union

Many brethren in the Christian Union, University of Nigeria, Nsukka during the period 1977–1982 have to be appreciated. Only the following will be listed:

- Iheanyi Uzoma (formerly Agbarakwe), my roommate at 320 Awolowo Hall for 4 years
- Barineme Beke Fakae (presently Vice Chancellor of Rivers State University of Science and Technology, Port Harcourt)

with whom we shared deep Christian friendship and companionship

- Uche John Rufus (formerly Okeke) presently Managing Director of Scripture Union Press & Books (SUPB), Ltd, Ibadan He has remained a close friend and associate for nearly 30 years. Now, together with the wife Rosaline and Children, we have become a very closely knit family
- The Enemuo brethren of Nibo in Anambra State, especially Nkiru, Robert, and Ifeoma
- Ashiwel Undie (now resident at USA) who was once our Bible Study Secretary
- Amarauche Chukwu (now Professor of Pharmaceutical Technology and 36^{th} Inaugural Lecturer) and his lovely wife Nomso.
- Adewale Sanda, one time Vice President, who gave me N20.00 in 1981 once when I was broke.
- Many thanks also to current and past generations of members of CU and NIFES (Nigeria Fellowship of Evangelical Students) with whom I we have associated.

Scripture Union

I have gained tremendously in Christian discipleship in this ministry over the years. They are just too many to mention for want of time. Only the following will be listed

- Evangelist Dr. Ikenna Ugochukwu, once our Group President and Zonal Representative
- Dr and Dr (Mrs) Willy & Vicky Onu. We shared a house of two flats at Amobi Street, Onuiyi between 1987 and 1993. the family bond that developed has remained ever strong.
- Many others include Prof & Mrs Ben Mbah, Mr & Mrs Walford Chukwu, Mr & Mrs Eugene & Nkechi Okpala, Mr & Mrs Sam Obeta, Mr & Mrs Sam Orji, Mr & Mrs Simon Omeke (our marriage counsellors), Mr & Mrs Nick/Uju Ugwu, Mr & Mrs Linus Okoro, Dr & Mrs S C Chuta, Dr & Mrs Emma Agomuo, etc, etc, etc.
- Many generations of members of the Scripture Union Campus Fellowship at UNN and UNEC with whom I have interacted closely. To represent them, I mention at least Bro Makua Ojide, Bro Ugochukwu and Bro Collins.

Christ Church Chapel

I salute the Chaplain of Christ Church Chapel, Ven Dr. Abraham C Okorie, his Associate, Rev Dr E A Ituma, other Clergy, past and present members of the Chapel Council and the entire congregation for providing a warm atmosphere to worship God. These include

- Prof & Dr (Mrs) Mosto/Ola Onuoha, immediate past Chairman of Chapel Council
- Prof & Dr (Mrs) Osondu & Pamela Eze-Uzomaka, past Chairman of Chapel Council

- Prof & Mrs Apia Okoroafor
- Prof & Mrs A R Ajayi, Mr & Mrs Femi & Ada Koledoye, Dr & Mrs D O Dike, Dr (Mrs) C I Oreh, Dr Victor Ogugua and all members of the current Chapel Council
- Members of the Christ Church Mens Association (CCMA) (presently led by Dr. Jacob O Onyechi)
- Members of the Christ Church Womens Association (CCWA) (presently led by Mrs. Chibuzo Ezekwe)
- Members of the Christ Church Youth Fellowship (CCYF)
- Sunday School teachers and the children

1.4.7 Academic Fathers and Associates

- Teachers in Primary School, especially Games Master and my class teacher in primary 5 & 6. He often paid for my *handiwork* to beef up my total marks to ensure that I do not loose the first position in class!
- Teachers in Secondary School, especially Mr Kalu Uduma (Chemistry Teacher). He drilled us so well in Chemistry that we not only understood it, but enjoyed it, joked about it and applied Deutronomy 8:6 to it.
- Dr Godwin Okoli (Geography teacher), later transferred to UNN and retired as Deputy Registrar. He was so thorough in teaching Geography that he nearly made me offer it in

WAEC. But I had already registered for the maximum allowable 9 subjects. When I came to UNN as a student, he was a constant source of encouragement.

- University teachers, especially
  - Late Prof G. Harding who taught us Engr 101 and made us go round the University Campus, identify all major Engineering facilities and show them in a map
  - Late Dr C. Chikwendu who made his lectures in Mechanics of Materials very easy to understand
  - Late Dr P. Anagbo who taught us Properties of Materials and later was my HOD at Federal Polytechnic Akure, Ondo State (now at Ado Ekiti) where I served as a Youth Corps member in 1982 to 1983.
  - Prof D. C. Onyejekwe (Uncle D) & Ir. Onyegbuchule (we used to call them *Jivers* because of their social & jovial attitudes)
  - Prof A. O. Odukwe, our teacher in Engineering Thermodynamics I (now ME 261). He so drilled and harassed us that each lecture day, we just had to prepare for any random question he may pose
  - Prof S. O. Onyegegbu whom we rated as a very respectable gentleman who was thorough in his teaching and also setting of questions
  - Late Prof C. C. O. Ezeilo. His stammer of the tongue and habitual smoking notwithstanding, he was a devoted teacher

  - Prof C. I. Ezekwe, who was well-organized and calm and my PhD co-supervisor
  - Prof O. C. Iloeje who was my supervisor at B Eng, M Eng (even though not completed) and co-supervisor at PhD levels. His lectures were always very interesting and exciting to me. It was rumoured among students that his exams were always very tough and difficult to pass, but I found I did very well in all his courses. After my PhD defence in 1995, he sponsored a party at the Senior Staff Club in my honour.
  - Prof C. E. Okeke and Prof A. O. E. Animalu of Physics Department. Even though they were not of my Department, I admired each of them separately at a distance. We latter came closer through programmes in Energy Centre and the Solar Energy Society of Nigeria.
  - Others include Dr A N Enetanya, Prof E A Onyeagoro, Dr Ogbonna Onuba, etc, etc

- Classmates at the University level, especially

  - Engr Dr. C. Ugochukwu Nwoji. He was often a spokesman for the class and always knew how to fix things.
  - Engr Prof Azikiwe Peter Onwualu, now Director-General of the Raw Materials Research & Development Council, Abuja. He was calm and calculated, and we latter worked together on some projects.

- Pioneer research staff at the National Centre for Energy Research & Development, where I started my working carrear in 1983. Of these, I have to mention

  - Prof Ogbonna Ukachukwu Oparaku, present Director of the Centre.
  - Prof Onyemaechi Valentine Ekechukwu, now Director of Research & Development at the National Universities Commission.
  - Engr Olukayode Osaseri, who latter left for greener pastures in the oil industry.
  - Engr Theophilus Madu, who also latter left for the oil industry.
  - Dr. I R N Awachie, now in Canada
  - Dr (Mrs) Rose Osuji, now in the Physics Department

- Current staff of the Department of Mechanical Engineering with whom I have had good academic and social interactions.

  - Academic staff not already listed include Engr. S A Ugwu, Dr. S O Edelugo, Dr. Steve Nwanya, Engr. Ikenna Agwubilu, Engr. C. Mgbemene, Mr. Ikechukwu Ezema, Mr. Howard Njoku, Mr. Cornelius Agbo, Mr A O G Egonu
  - Technical and administrative staff not already listed include Mr Uchendu Obasi, Mr. Obasi Ota, Mr S. Eze, Mrs B I Oreh, Miss Irene Urama, and others

- Past and present staff and students of the Department of Mechanical Engineering not already listed.

- Past and present staff and students of other Departments in the Faculty of Engineering not already listed.

1.4.8 Sponsors

Many international and national agencies provided financial support for all my studies and research activities. These include

1. The United Africa Company (UAC) of Nigeria Plc, who granted me scholarship for undergraduate studies between 1977–1982

2. British Council for a Fellowship held for 12 months at the University of Reading, England, 1985–1986. This made the completion of my MSc possible.

3. The Association of Commonwealth Universities (ACU), London who granted me an Academic Exchange Fellowship for 3 months at the University of Zimbabwe, Harare, Zimbabwe, 1994

4. International Foundation For Science (IFS), Stockholm, Sweden who awarded me Grant No. G/1503-1 for a project entitled *Optimization of a solar powered solid absorption refrigeration system for rural agricultural applications* during the period 1989–1995. Total grant amounted to about US$ 13,850.00. Supervisor for the project was Prof. O. C. Iloeje. The IFS/King Baudouin Price was awarded the candidate in December 1995 for

    > *submitting reports indicating research of an exceptional quality in the area of solar refrigeration*

5. The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy who provided me with wonderful opportunities. Examples are

   (a) They provided me with travel grants that enabled me attend several international conferences/workshops/schools in their Campus at Trieste, Italy between 1987 and 2002.

   (b) Together with the Italian Agency for New Technologies, Energy and the Environment (ENEA), they awarded me a 12-month fellowship at the Casaccia Research Centre of ENEA in Rome, Italy, 1995–1996

   (c) I was also made a Regular Associate of ICTP which offered opportunity for 3 or more visits to the ICTP for a total of 270 days during the period 2000–2005

6. The African Network of Scientific & Technological Institutions (ANSTI) of the UNESCO Office in Nairobi, Kenya for an Academic Exchange Fellowship held for 3 months at the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, in year 2000

7. The Central Bank of Nigeria, Abuja for *Baseline Survey on Small and Medium Scale Industries in Nigeria – South-East Zone (covering Abia, Anambra, Ebonyi, Enugu and Imo States)*. The Research Team comprised several academic staff of the University headed by the former Vice-Chancellor, Prof. G. F. Mbanefo and Prof. N Ikpeze of the Department of Economics. The grant was worth twelve million naira.

8. The African Academy of Sciences, Nairobi, Kenya who sponsored our work on the theme *Agricultural Production, Nutritional and Engineering Development Project on Treculia Africana*, 2002 – 2004 (Phase 1). This was worth some seventy thousand US dollars for projects by eight academic staff in Nigeria, Ghana and Mali. They also provided me with a travel grant.

9. The Third World Academy of Sciences (TWAS), Trieste, Italy for Grant No. RG MP 88-19 for project entitled *Mathematical modelling and computer simulation of the thermal performance of buildings in tropical regions* during the period 1989–1994. Total grant amounted to US$ 2000.00

10. The National Mathematical Centre, Abuja, Nigeria, for Grant Ref. No. NMC/MP/R.9 of 06 October 1998 for a project entitled *Second law optimization of a solar heated poultry egg incubator with phase change material energy storage* during the period 1998–2000. Total grant amounted to about Nigerian N200,000.00 (about US$ 2000.00).

11. The Raw Materials Research & Development Council (RMRDC), Abuja. Their Research Grant Programme motivated me to develop a project on *Treculia africana* depulping machine which latter incorporated other related projects.

Chapter 2

ENGINEERING & DEVELOPMENT

Here, we provide a brief introduction to what engineering is, what the various members of the engineering team do, and how they operate. Various branches of engineering are listed, as well as some comments on interactions between them. Finally, some development indicators are provided, and energy is shown to be a key index of development.

2.1 What is Engineering?

2.1.1 Definition

The Oxford Advanced Learners Dictionary defines Engineering as *the practical application of scientific knowledge in the design, building, and control of machines, roads, bridges, electrical &*

electronic equipment, as well as chemical, material and agricultural facilities for the comfort of mankind. Engineering deals with the design of structures, processes, circuits, mechanisms, production environments, or systems of men and machines. Engineering appliers the knowledge of science and mathematics, creativity and judgement to utilize effectively and efficiently the natural resources for the benefit of mankind. Engineers create, synthesize, solve problems, and innovate. Through ingenuity and invention, new things are created and better ways of making old things are found. (Agunwamba and Enibe, 2008).

2.1.2 Science, technology & engineering

Agunwamba and Enibe (2008), provide a clear explanation of the terms *Science, technology* and *engineering* which are often confused. Science can be defined as the study of phenomena by scientific method which involves stating a hypothesis and testing it with controlled experiments. It is aimed at providing ideas and acquisition of knowledge. On the other hand, technology is the utilization of processes and products made via engineering. It is the methodology of making things, including all tools and procedures and their interrelationships. Engineering uses imagination, judgement and reasoning to apply science, technology, mathematics and practical experience in the design, production, and operation of useful objects or processes to solve human problems. While the scientist will ask *why does these phenomenom occur?*, the engineer *wants to know how it works*. The technologists, on the other hand, *will want to find out what it can be used for*.

They continue:

Engineering is not science. Science discovers the natural; engineering creates the artificial. Science discovers the world that exists; engineers create the world that never was.

2.1.3 Branches of engineering

Engineering initially had two main disciplines, namely military and civil engineering.

As the advancement of knowledge continued in line with Daniel 12:4, applications of engineering grew in complexity, making it expedient for professionals to restrict operations to narrower areas. For example, in the words of Agunwamba and Enibe (2008), *civil engineering came to be concerned primarily with static structures, such as dams, bridges, and buildings, whereas mechanical engineering concentrated more on dynamic structures, such as machinery and engines. Similarly, mining engineering became concerned with the discovery of, and removal from, geological structures of metalliferous ore bodies, whereas metallurgical engineering involved extraction and refinement of the metals from the ores. From the practical applications of electricity and chemistry, electrical and chemical engineering arose.*

At present, we can count at least 19 areas of specialization in engineering as listed in table 2.1.

Table 2.1: Disciplines in Engineering

Discipline	Description
Aerospace	The research, design and production of aircraft, spacecraft, aerospace equipment, satellites and missiles
Agricultural	The development of solutions to problems involving plants and animals and the natural environment
Biomechanical and Biomedical	Researching and designing equipment that assists in human movement, such as artificial limbs and organs
Chemical	The design and operation of industrial equipment and methods to manufacture chemical products
Civil	The design, construction and management of highways, railways, transit systems, airports, harbours, bridges, tunnels and buildings
Computer	The design, development and maintenance of computer systems
Electrical	The generation or production, transmission, distribution and application of electrical energy, as well as low power electricity that is the basis for telecommunication, television and technology
Environmental	The development of technically and economically feasible solutions to environmental problems

Table 2.1 continued: Disciplines in Engineering

Discipline	Description
Geological	Application of geological data, techniques and principles to the study of rock, soil and ground water
Geomatics (Surveying)	The collection and displaying of data about the Earths surface and its gravity fields for such uses as mapping, legal boundary delineation, navigation and monitoring environmental concerns
Industrial and Manufacturing	The combination of expertise in equipment, material, procedures, human resources and production methods to assist organizations to improve efficiency, effectiveness and productivity.
Mechanical	Applying the principles of mathematics, material science, physics and economics to the design, manufacture and maintenance of mechanical equipment
Materials	The study of non-metallic materials (semiconductors, synthetic organic polymers, ceramics and composites); taking scientific principles established in mathematics, physics and chemistry and applying them to various problems or needs in society.
Metallurgical	The study of properties and characteristics of metals and other materials.

Table 2.1 continued: Disciplines in Engineering

Discipline	Description
Mining	The discovery, extraction and preparation of minerals from the Earths crust to be used by manufacturing and energy industries; exploring, testing, mine design and construction, equipment, operations and management.
Naval Architectural and Ocean	The conception, design and construction of ships, offshore structures and other marine vehicles.
Nuclear	Research, development and application of nuclear technology to energy production, environmental protection, medical diagnosis and treatment, and the use of radioisotopes in construction, sterilization, and space systems.
Petroleum	The exploration, recovery, development and processing of oil and gas.
Software Engineering	The specification, design, development and maintenance of software systems and products.

2.1.4 Engineering team

Engineering professionals often work as a team consisting of engineers, technologists, technicians, craftsmen, labourers, etc. All the members complement each other, as shown in figure 2.1.

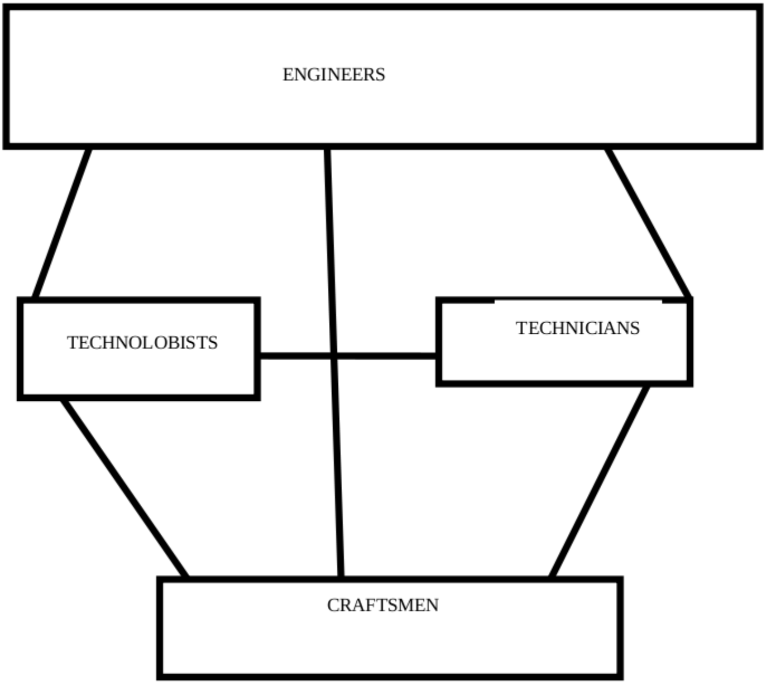

Figure 2.1: The engineering team

2.2 Creativity

Creativity is at the heart of engineering. When God said *let us make man in our own image, according to our likeness* (Genesis 1:36), he put a wonderful ability in us to create new things from what he has already made. Engineers are at the forefront of applying this biblical injunction.

In Genesis 1:3-26, God created the entire world and all that is in it by making proclamations. In the case of engineers, creation or engineering follows a complex set of processes, which result in the solution of problems. As observed in Enibe (2008),

2.3 Optimization

Optimization is the technique of making use of all the available resources to produce the best possible solution to a given problem having taken due consideration of all the factors, situations and constraints involved. In the past, optimization was achieved through trial and error, but there are now well-articulated scientific procedures of optimization.

Optimization is the key to sustainable engineering. In every area of engineering, once the basic ideas about the solution of a given problem have emerged, some optimization techniques are employed to ensure that the best possible solution is realized. Through optimization, better, faster, cheaper, safer and more elegant looking cars have emerged, leading to a more widespread utilization of the device.

2.4 Problem solution

It was observed in Enibe (2008) that the solution of problems is a key feature of engineering practice. Whether the problems are familiar or new, a number of general solution steps that may be applied over a wide variety of problems have emerged over the years. These include problem identification, analysis, subdivision into a set of simple problems, adaptation of existing solutions to each of the simple problems and/or development of new solutions, assembly of solution sets, application of solutions to the current problem (with appropriate feedback). Each of these steps is now discussed briefly.

2.4.1 Problem Identification

The first step in the proper solution of any significant problem is its proper identification. This involves proper *separation* of the problem from all other problems and its *description* in some detail in engineering terms. The relationship of the problem to be solved with its environment is *represented* in terms of input/output or causes and effects. Any engineering problem that is sufficiently *identified*, *described* and *represented* is likely to be effectively solved.

2.4.2 Subdivision into Simple Problems

Every problem can usually be subdivided into a set of simple sub-problems each of which can be solved quite independently. This approach has several advantages:

1. Many of the sub-problems may have existing solutions, which may be easily adapted, leading to a quicker solution of the main problem.

2. the sub-problems may be assigned to different persons or groups of persons, working simultaneously with suitable coordination and cooperation, the lead for the solution of the main problem may be significantly reduced.

3. the solution of each sub-problem may result in the development of a new process, technique or technology which may find application in several other fields.

2.4.3 Analysis

Analysis involves a detailed study of problem to understand its internal characteristics and how these characteristics affect its behaviour under external stimuli. The major characteristics often considered include:

- Deformations under various kinds of loading
- Input/output of energy of various types and their impact on the behaviour of the system.

A good analysis may often lead to a description of the characteristics using mathematical relationships. In such cases, prediction of the system behaviour under a made range of values of the external stimuli may be possible.

2.4.4 Assembly of Solutions

The solutions to the set of sub-problems are gathered to form a solution to the main problem. a thorough review is often recommended before application to the real problem. with suitable feedback, the solution can be continuously improved for greater effectiveness.

Chapter 3

ENERGY SYSTEMS

3.1 Energy & Development

As observed in Enibe (2008), energy is a basic necessity for survival and a critical factor affecting economic development. As shown in figure 3.1, countries with very little per capita energy consumption are among the poorest in the world. Per capita energy consumption has thus become a motive force behind the sustained technological growth of any nation.

At present, the global energy economy is dominated by conventional energy resources, especially crude oil. The World Bank (1998) estimates that if an average growth rate of 3.0% per annum in global gross domestic product (GDP) were maintained during the period 1992–2005, world crude oil demand would have grown at an average rate of 1.4% per annum to reach 3849 million tonnes of oil equivalent (mtoe) by the year 2005. In industrialized countries, a lower growth rate (0.8%) is expected due to the moder-

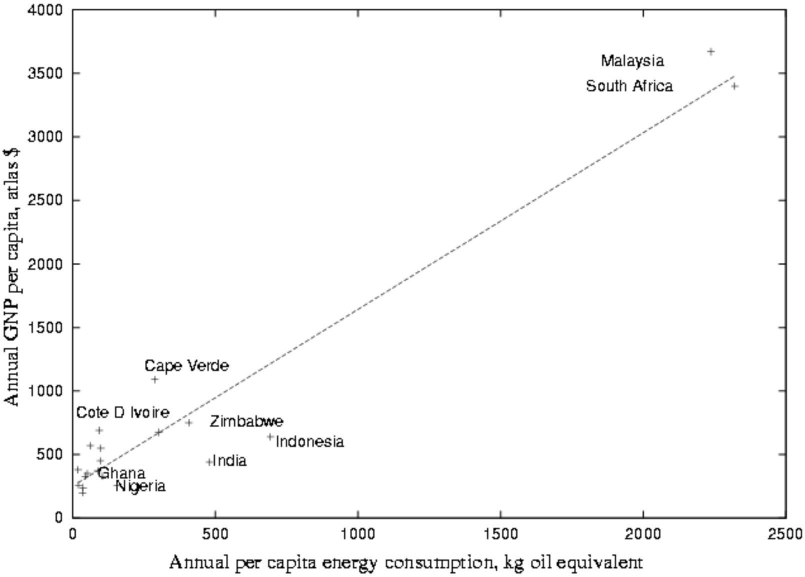

Figure 3.1: Gross national product as a function of energy consumption

Table 3.1: Development indicators in some African countries

Country	A	B	C	D	E	F	G	H	I	J
Benin	5.8	111	380	0.2	55	-	37	0.1	43.3	18.45
Burkina Faso	10.9	274	240	0.0	46		19	0.0	-	14.86
Cape Verde	0.4	4	1090	-9.7	66	-	72	-	-	287.50
Cote D'Ivoire	14.7	318	690	-1.6	54	18	40	0.8	159.3	92.65
Gambia	1.2	10	350	-2.0	53	-	39	0.2	-	50.83
Ghana	18.0	228	370	1.4	59	-	64	0.2	318.2	86.89
Guinea	6.9	246	570	1.6	46	26	36	0.1	-	61.16
Guinea Bissau	1.1	28	240	1.7	44	88	55	0.2	-	36.36
Liberia	2.9	96	-	-	49	-	38	0.1	-	37.59
Mali	10.3	1220	260	0.2	50	-	31	0.0	-	20.10
Mauritania	2.4	1025	450	0.9	53	38	1.4	231	96.25	96.25
Niger	9.7	1267	200	-2.1	47	62	14	0.1	-	34.02
Nigeria	117.9	911	260	1.6	53	31	57	0.8	-	156.01
Senegal	8.8	193	550	-0.3	50	54	33	0.4	84.8	98.41
Sierra Leone	4.7	72	-	-4.0	37	-	31	0.1	90.8	69.36
Togo	4.3	54	330	0.0	58	-	52	0.2	-	43.02
Kenya	28.0	569	330	0.0	58	50	78	0.3	122.8	103.82
South Africa	38.3	1221	3400	-0.4	65	24	82	7.4	3874.1	2320.68
Zimbabwe	11.5	387	750	0.0	56	41	85	0.9	738.1	406.35
Africa mean	745.5	29367	675	-0.5	55	-	56	1.1	518.0	301.29

Source: The World Bank(1998)

Key: A. Population, millions; B. Land area, thousand square kilometres; C. 1997 GNP per capita in atlas dollars; D. average annual percent growth rate in GNP per capita; E. Life expectancy at birth, years; F. percent of population living under US$1 daily; G. Literacy rate (percent of persons above 15 years old who are literate); H. 1995 per capita CO_2 emissions from industrial processes, metric tonnes; I. 1995 per capita electric power consumption, kWh; J. 1995 per capita commercial energy use, kilograms of oil equivalent per annum ating influence of energy taxes, efficiency improvements and the substitution of alternative fuels. In the developing countries outside the former Soviet Union, crude oil demand was expected to grow by 3.1% per annum to reach 1499mtoe in the year 2005, essentially due to anticipated robust economic growth, growing population and increasing transport needs. In view of this, developing countries were expected to account for about 75% of the total increase in global oil consumption over the forecast period, with their share of world oil demand expected to have risen to 39% by the year 2005, compared with the share of 32% in 1992.

Column 9 of table 3.1 shows the per capita electric power consumption for 1995 for selected countries. This varies from 43.3 kWh for Burkina Faso to 318.2 kWh for Ghana. In contrast, the 1995 per capita electricity consumption for Zimbabwe and South Africa were 738.1 and 3874.1 kWh respectively. A similar observation may be made from column 10 of the same table regarding the 1995 per capita commercial energy consumption. It may be observed that the Southern African countries utilised far more energy resources per capita than any of the ECOWAS states. This has both positive and negative implications.

On the negative side, it is clear that at least in the energy sector, West Africa is more underdeveloped than Southern Africa, implying that there is more drudgery and lower standard of living in the region. Could this have contributed to the lower life expectancy reported for the region (column 5 of table 3.1)?

On the positive side, environmental pollution resulting from energy use is still relatively low in West Africa. For example, column 8 of table 3.1 shows that the 1995 per capita CO_2 emmission from industrial processes lie between 0.0 and 1.4 metric tonnes, compared with the value of 7.4 metric tonnes for South Africa.

Countries of the ECOWAS subregion could take advantage of their low energy-related emissions and our improved understanding of the impacts of energy use on the environment to plan for a more sustainable and environmentally responsible energy use patterns for their economies.

There is increasing evidence that current global energy policies, which promote the inefficient use of fossil fuels and energy, are environmentally irresponsible and unsustainable, since they cause significant environmental degradation at the local, regional and global levels (The World Bank, 1997). It is estimated that the unabated emmisions of greenhouse gases (such as CO_2) will lead to a rise of 1 to 3.5^{o}C in global temperature and a 15 to 95cm rise in sea level by the year 2100 (Eskeland and Xie, 1998). This could result in the inundation of low-lying areas, loss of bio-diversity, changes in the frequency and intensity of tropical monsoons, and hence increase in deaths by flooding, etc. Several studies have shown that, by incorporating renewable energy resources into the overall energy mix of nations, many of these negative environmental impacts of energy use could be avaoided or minimised (The World Bank, 1997). Economic justifications of renewable energy use have also been ably demonstrated in the literature (Anderson, 1993).

3.2 Basic Laws

In general, every engineering system is an energy transformer. As shown in figure 3.2, it receives energy as input in various forms and at various rates, transforms the energy and rejects it to the environment in various output forms and rates. The number and types of energy input may differ substantially from the number and types of energy output; and some of the energy may be stored in the system. Over the years, two natural laws have been found to operate in every case of energy transformation. These are the first and second laws of thermodynamics.

3.2.1 Law number 1

The sum of all the energy input (I) plus storage (S) plus energy output (O) is constant. This may be written in a shorthand mathematical form as

$$\sum_{i=1}^{m} I_i + \sum_{j=1}^{n} S_j + \sum_{k=1}^{p} O_k = constant \qquad (3.1)$$

where m is the number of energy inputs, n is the number of storage items and p is the number of outputs. This law is often known as the *principle of energy conservation*. To use this law conveniently, all energy input or storage is treated as positive, and energy output as negative. A special application of this principle in situations involving heat flow (thermodynamics) is called the *first law of thermodynamics*

3.2.2 Law Number 2

A second principle has been articulated to summarise the following observations of natural processes over several centuries:

- All rivers flow down hill and the flow cannot be reversed without external energy input

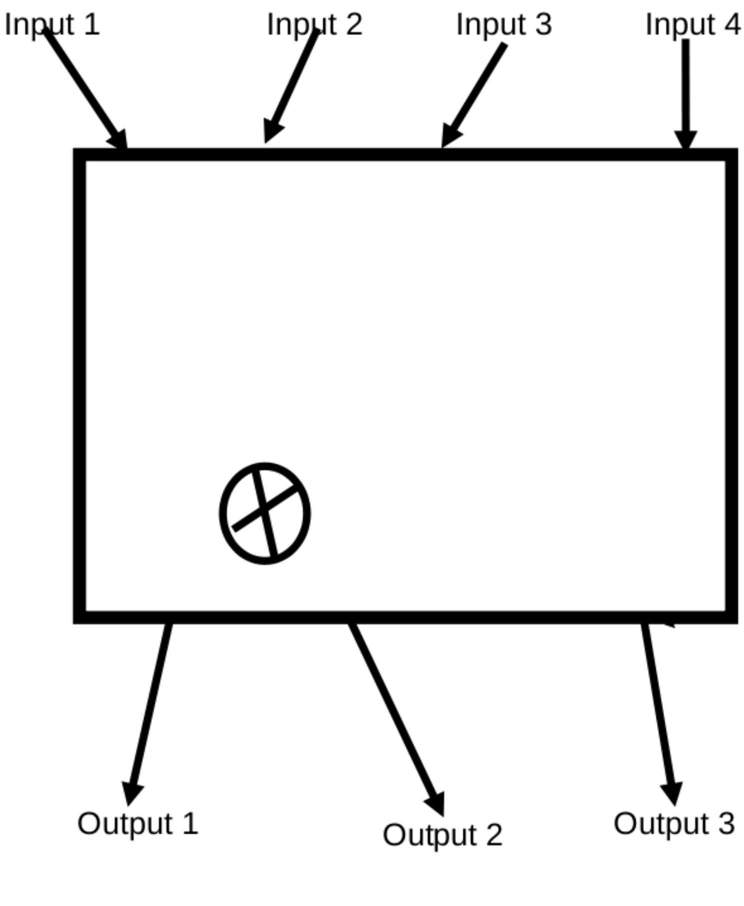

Figure 3.2: Illustration of an energy input/output system

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- All living systems are subject to aging, decay and death. The trend cannot be reversed.
- All objects cool down to the temperature of the environment. Even though all the heat lost in the process can be recovered, the overall quality has been degraded and cannot be up graded again to its former value without some external energy input.
- All machines operate at an efficiency of less than 100%. No machine with 100% efficiency has ever been built, and none can ever be built.

Observations of this kind have been summarized into what is now known as the *second law of thermodynamics*. We shall now look at a commonly used device and how it transforms energy to the benefit of mankind.

3.3 Examples

Many commonly used appliances are engineering systems which transform energy to our benefit. A typical example is the cooking stove or fireplace, of which many designs abound.

Here, energy is supplied to the system in the form of chemical energy stored in the fuel. As combustion takes place, this chemical energy is released as heat. The heat so released raises the temperature of the pot and its contents as well as that of the immediate surroundings. The resulting ash and the exhaust gases are products of the combustion process.

According to the first law of thermodynamics, the energy contained originally in the fuel was not destroyed, but was merely transformed into other energy types, as illustrated in figure 3.3

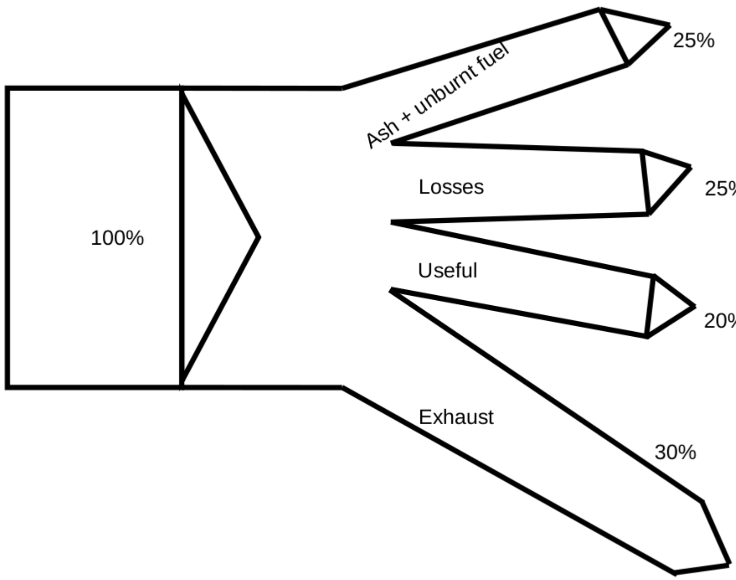

Figure 3.3: Illustration of an energy balance for a domestic fireplace

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The sum of the heat energy contained in the exhaust gasses, plus the heat energy stored in various parts of the system plus the energy in the unburnt fuel plus all the energy lost must be equal to the energy originally in the fuel. From the point of view of the user of the stove, the useful part of the energy may be part of the energy converted to storage. We may thus define a useful conversion efficiency, η, for this user as

$$\eta = \frac{\text{Useful energy output}}{\text{total energy input}} \tag{3.2}$$

Experience teaches us that once this combustion process takes place, it can not be reversed. Thus, even though the total energy output (including storage) is equal to the total energy input, the system has suffered some degradation because of the irreversible processes that have occurred,

The traditional 3-stone stove has a useful efficiency of the order of 10%. Through engineering analysis, design and optimization, wood and charcoal burning stoves with much higher efficiencies have been developed. In addition, cooking stoves employing other fuels in the solid, liquid and gaseous forms have been brought into common use. Typical examples are the kerosene stove, among others. Some of these have useful efficiencies of over 50%.

A similar approach is often adopted in several other areas, such as the development of automobiles, aircraft, machine tools, and the like.

Chapter 4

REFRIGERATION

Refrigeration is an area where many advances in technology has been achieved through a systematic application of diverse engineering sciences and system optimization. It basically involves transfer of heat out of a specified space so that its temperature could be maintained at a level lower than that of the immediate environment.

Naturally, heat would flow from a hotter to a colder environment. In refrigeration, we force heat to flow from a colder to a hotter environment. As a result, some external energy must be applied to maintain this reverse flow of heat (Remember: second law of Thermodynamics).

4.1 Vapour Compression Refrigeration

In most common refrigeration systems, the external energy is applied in a compressor to raise the pressure of a special vapour which is then condensed to the liquid form. The pressure of this liquid is then reduced in a special way so that the temperature is also lowered considerably. The resulting low-temperature liquid at low pressure then evaporates to produce a cooling effect. The major components required in such a system is a compressor, a condenser, an expander or throttle valve, and an evaporator, all arranged as shown in figure 4.1.

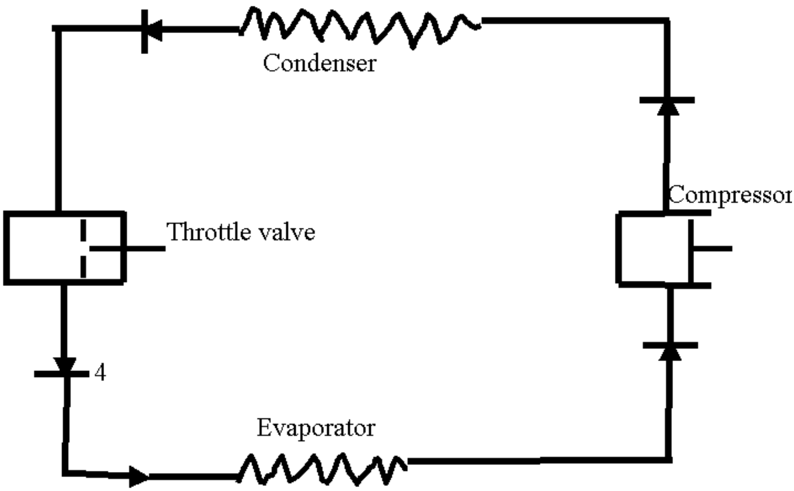

Figure 4.1: Schematic diagram of a common refrigeration system

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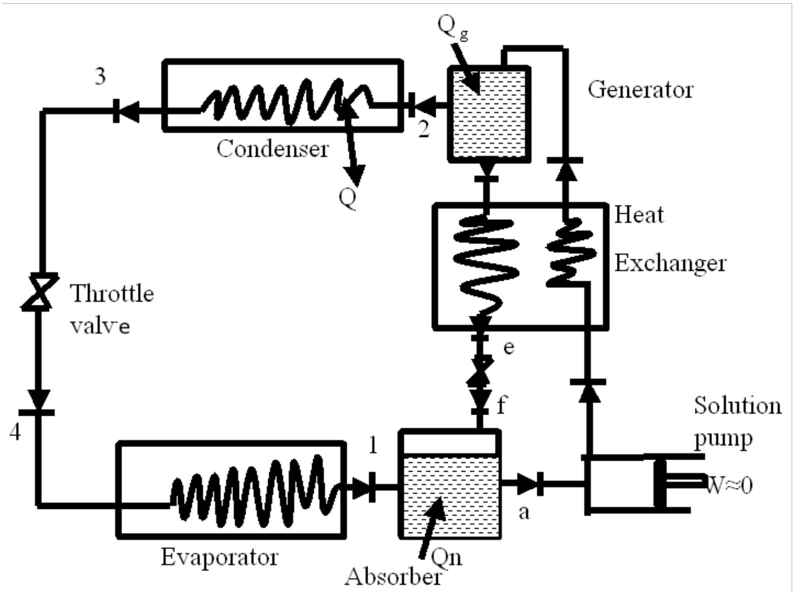
4.2 Vapour Absorption Refrigeration

The compressor in the above example is electrically powered. It is possible to eliminate the compressor entirely. One way of achieving this is to absorb the refrigerant vapour in a solid or liquid absorbent and regenerate the refrigerant at high pressure and temperature by heating it in a special way. The resulting system is called a vapour absorption refrigerator, and may be illustrated schematically as shown in figure 4.2



(a) Absorption mode (b) Generation mode

Figure 4.2: Schematic diagram of a vapour absorption refrigeration system

It may be observed that the major components remain the same., except that the compressor in the vapour-compression system has been replaced by a thermal compression arrangement. Since the compressor has now been eliminated, the resulting refrigerator could operate quietly without any moving parts; it could also use any heat source, including solar energy.

Iloeje (1985) built such a system which uses calcium chloride ($CaCl_2$) salt as absorbent and ammonia (NH_3) as refrigerant. The absorbent is treated as described in Iloeje (1986, 1989) to obtain hard porous granules which could withstand several cycles of operation. The basic components are arranged as shown in figure 4.3.

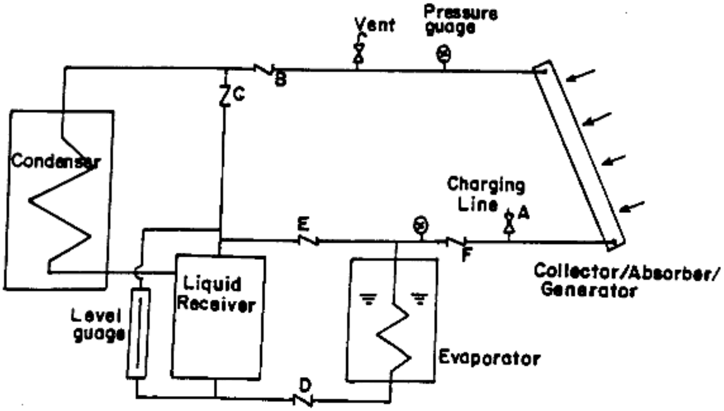


Figure 4.3: Schematic diagram of a calcium chloride - ammonia refrigerator

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The refrigerator operates intermittently in a daily cycle made up three modes, namely the generation, cooldown and absorption modes. This is illustrated schematically in figure 4.4. Further details appear in Enibe (1997).

During the absorption mode, the vessel A acts as the absorber and absorbs the refrigerant released from the evaporator, B. Heat

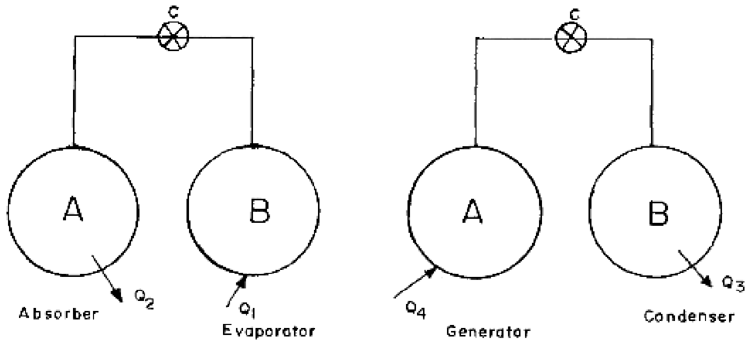

Figure 4.4: Schematic diagram of an absorption refrigerator

Q_1 is absorbed in the evaporator and heat Q_2 is released at the vessel A. During the generation mode, vessel A now acts as the generator, while vessel B acts as the condenser. Heat Q_4 is supplied to the generator from a suitable heat source, while heat Q_3 is rejected at the condenser. The valve C is used to control the direction of flow of the refrigerant. Thus, vessel A doubles as the absorber/generator.

4.3 Coefficient of Performance

The performance of an absorption refrigerator is indicated by the coefficient of performance (COP) which is given by the expression

$$COP = \frac{\text{Energy extracted at the evaporator}}{\text{Energy supplied at the generator}} \tag{4.1}$$

Detailed experimental performance data on the $CaCl_2$/ammonia refrigerator were compiled between 1983 and 1984 (Iloeje, 1984).

With the daily incident radiation varying between 6.68 and 16.77 MJ/m^2 and ambient temperature between 22 and 31^{o}C, the COP was found to vary between 0.01 and 0.09.

4.4 Modeling/Simulation

In order to optimize the system, we must first determine the performance of the refrigerator over a wide range of operating conditions and for various design parameters. This could be done experimentally or through modeling and simulation. The experimental approach would require building several physical prototypes of the system and testing them at different locations over a period of at least one year. Obviously, this would require the expenditure of enormous human and material resources to accomplish. We therefore chose to under take the mathematical modeling and computer simulation of the system as a more cost effective and better solution. The modeling was accomplished as follows:

1. First, the actual refrigerator was considered to consist of six (6) physical components whose response can be handled quite independently. For completeness, three virtual components are concieved, namely *DIALOG*, *CLIMATE* and *OUTPUT*. All components (whether real or virtual) interact following a natural sequence, as shown in figure 4.5.

2. The relevant physical laws are applied to each component under suitable initial and boundary conditions to determine the governing equations. Full details are presented in Iloeje, Ndili and Enibe (1995) and Enibe and Iloeje (1997a)

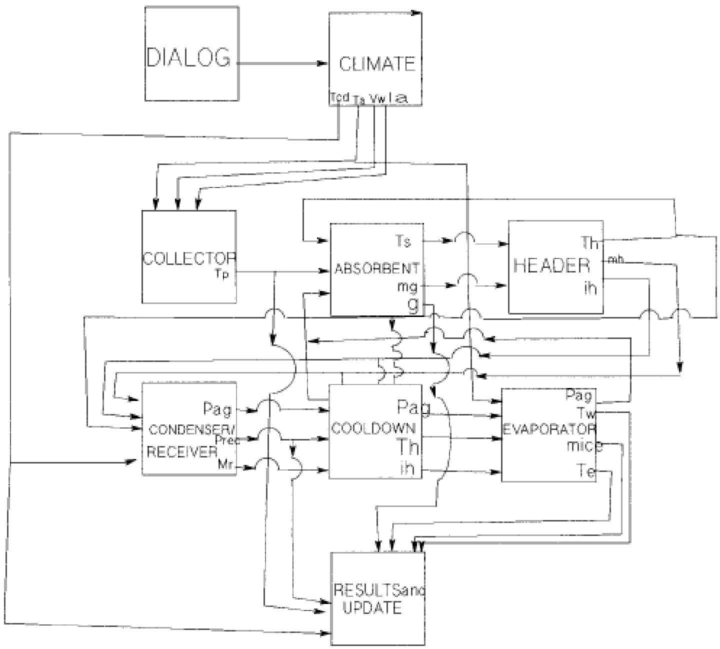

Figure 4.5: Information flow diagram for selected variables in a solar refrigerator

3. The governing equations are converted to sets of algebraic equations using discretization procedures described in Enibe (1995).

4. The algebraic equations together with the initial conditions and climatic input data are solved numerically using a computer software, COSSOR (Computer Simulation of a Solar Refrigerator), developed for the purpose. The computational flow chart for COSSOR is shown in figure 4.6, while other details are presented in Enibe and Iloeje (2000).

5. The predicted results obtained with COSSOR are compared with the experimented data of Iloeje (1984) for all the 21 runs which contained sufficient input data. The data covered all seasons of the year for Nsukka.

6. Improvements in the analysis and the COSSOR software as outlined in steps 1 to 5 above were undertaken until at least each of the eight key parameters shown in table 4.1 compared well experimental data over a wide range of operating conditions.

7. Using the COSSOR software, the performance of the refrigerator was determined for all seasons of the year at Nsukka and ten other Nigerian cities (see Iloeje, Ndili and Enibe, 1990; Iloeje and Enibe, 1991). Similarly, the monthly mean performance in some African cities was predicted (see Enibe and Iloeje, 2000). The summary of the predicted data is shown in figure 4.14.

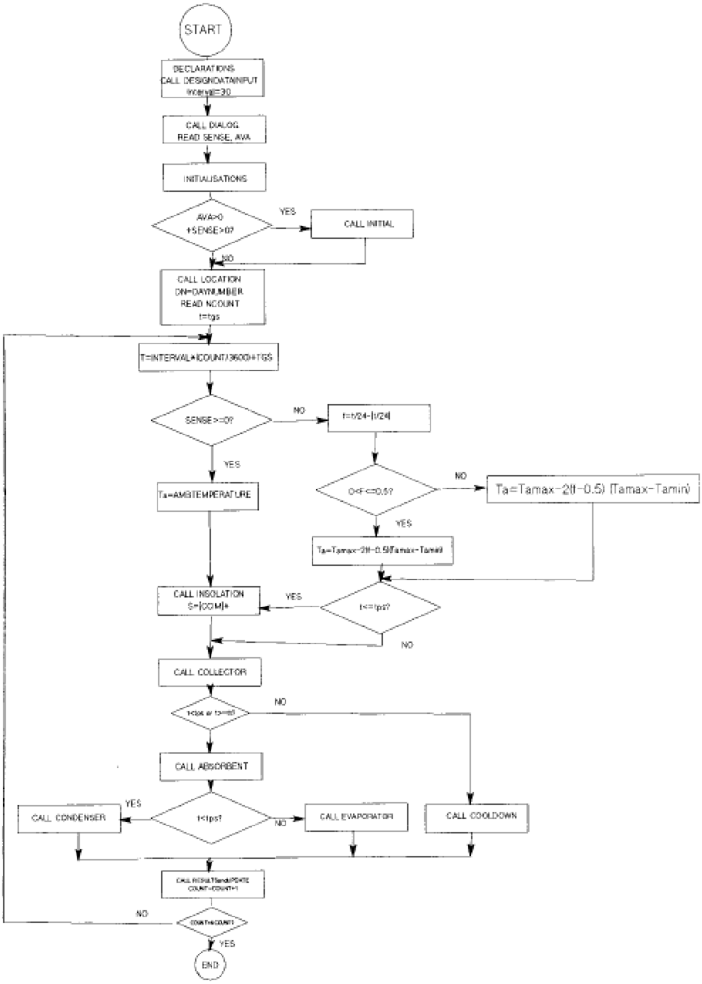

Figure 4.6: Computational flow chart for COSSOR Programme

Table 4.1: Comparison of COSSOR prediction with experiment

(a) The onset and termination of generation and absorption was very closely predicted.

(b) The collector plate temperature trends and time of peak tube surface temperature are well predicted. Generally, the predicted results agreed with experiment to between 2 and 5^{o}C (see figure 4.7)

(c) The system pressure for the generation and cool down modes is very well predicted. For the evaporation mode, a computational logic was employed to keep the pressure within 5% of the experimental values. (see figure 4.8)

(d) Mass of refrigerant condensed was predicted to within 8% for days with high insolation. (see figure 4.9)

(e) Evaporator water temperature was generally well predicted, usually to within 3% of the experimental values. (see figure 4.10)

(f) Mass of ice produced for all runs whose condensate masses were predicted to within 7 to 31%. (see figure 4.11).

(g) Collector efficiency was predicted to within 5%. (see figure 4.12).

(h) Refrigerator coefficient of performance was predicted to within 13% (see figure 4.13).

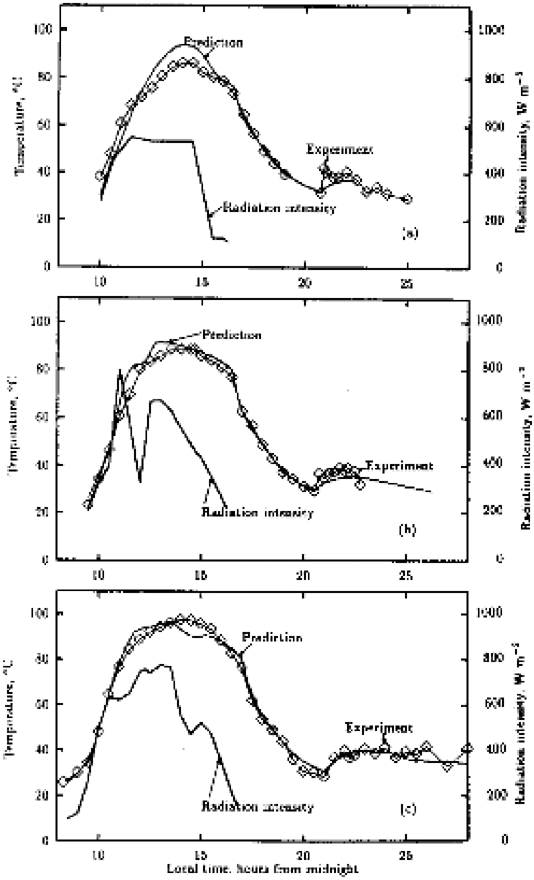

Figure 4.7: Collector tube surface temperature in the solar refrigerator for different radiation levels
(a) low insolation $Q_{rad} = 10.4MJ/m^2$, (b) medium insolation $Q_{rad} = 11.8MJ/m^2$, (c) high insolation $Q_{rad} = 15.1MJ/m^2$

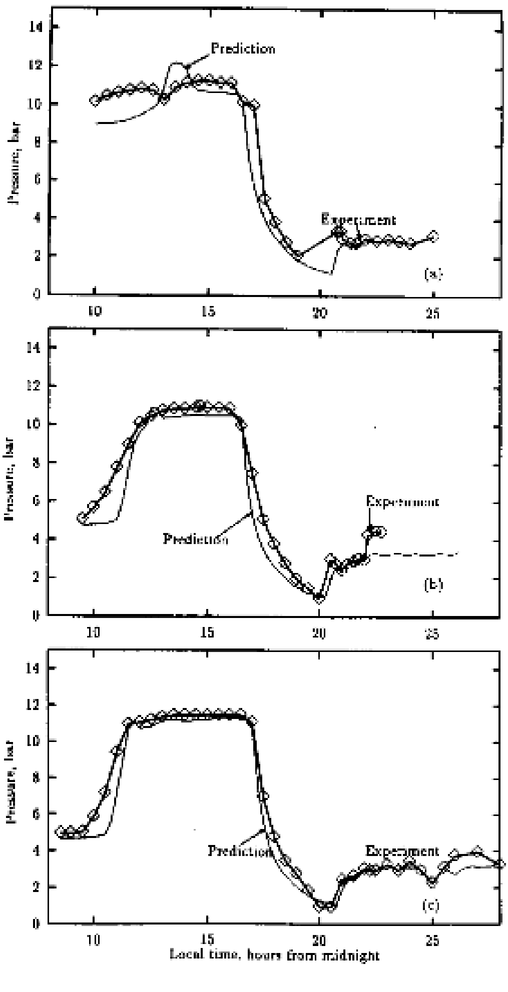

Figure 4.8: Absorber/generator pressure in the solar refrigerator for different radiation levels
(a) low insolation $Q_{rad} = 10.4MJ/m^2$, (b) medium insolation $Q_{rad} = 11.8MJ/m^2$, (c) high insolation $Q_{rad} = 15.1MJ/m^2$

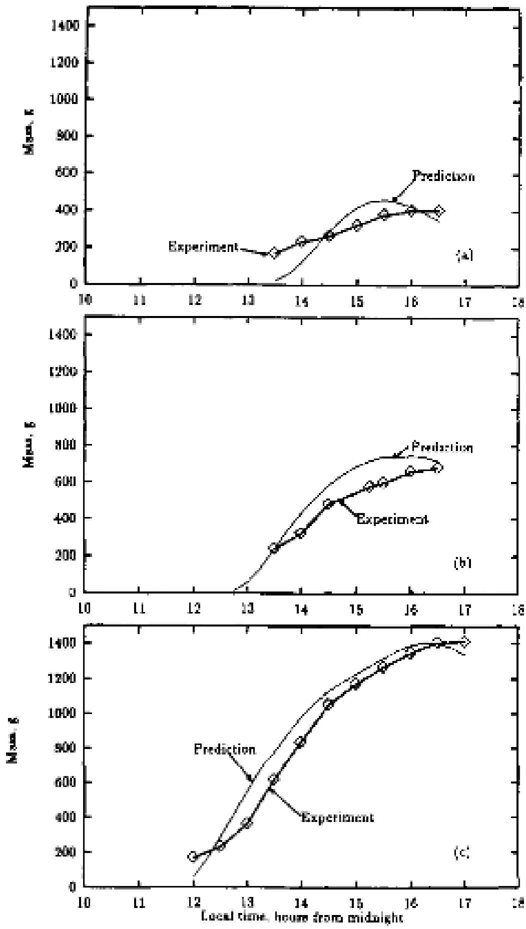

Figure 4.9: Mass of refrigerant condensed in the solar refrigerator for different radiation levels
(a) low insolation $Q_{rad} = 10.4MJ/m^2$, (b) medium insolation $Q_{rad} = 11.71MJ/m^2$, (c) high insolation $Q_{rad} = 15.1MJ/m^2$

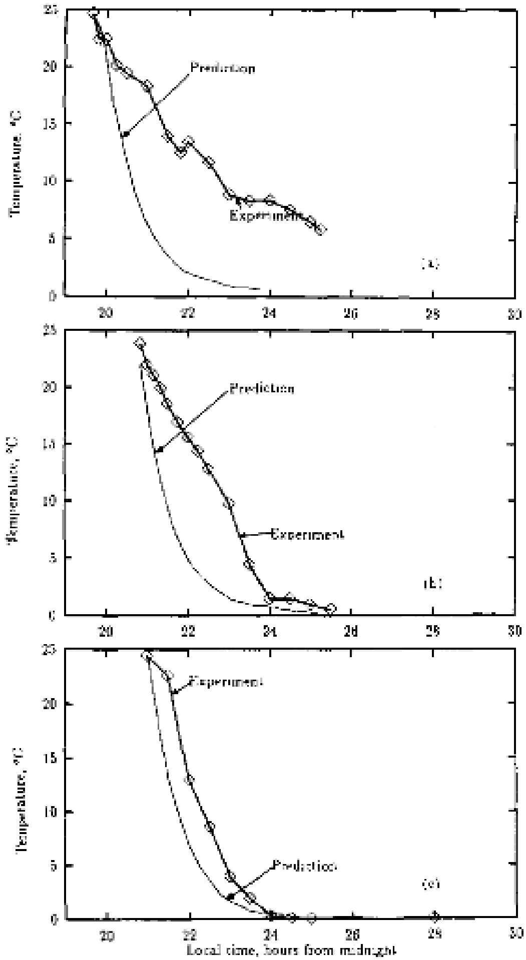

Figure 4.10: Mean evaporator water temperature in the solar refrigerator for different radiation levels
(a) medium insolation $Q_{rad} = 11.7MJ/m^2$, (b) medium insolation $Q_{rad} = 11.4MJ/m^2$, (c) high insolation $Q_{rad} = 15.1MJ/m^2$

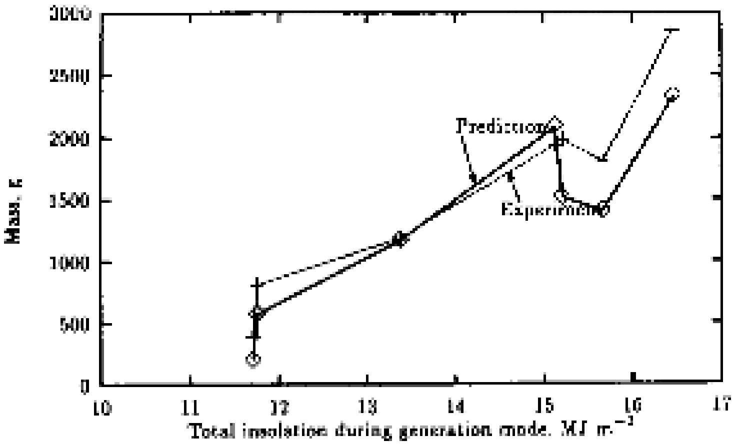

Figure 4.11: Mass of ice produced in the solar refrigerator for different radiation levels

4.5 Optimization

Optimization of the solar refrigerator was achieved through parametric analysis followed by design optimization. Brief descriptions are given here, while further details are available in Enibe and Iloeje (1997b)

4.5.1 Parametric analysis

The parametric analysis was carried out in the following manner:

1. Nine key design parameters which affect the performance of the refrigerator and could easily be varied at the design

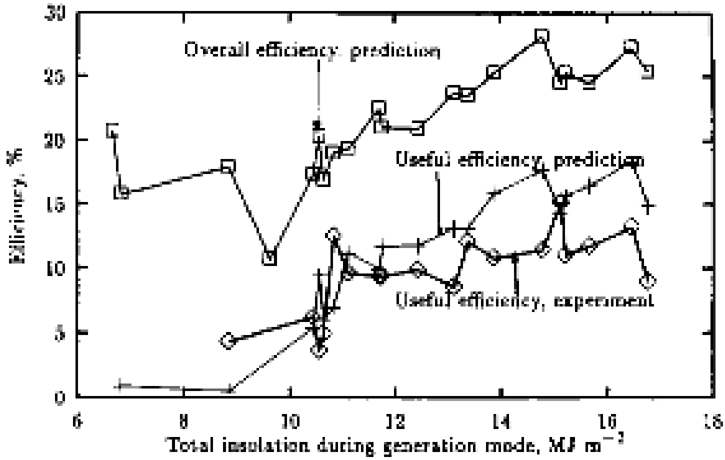

Figure 4.12: Variation of collector efficiency in the solar refrigerator for different radiation levels

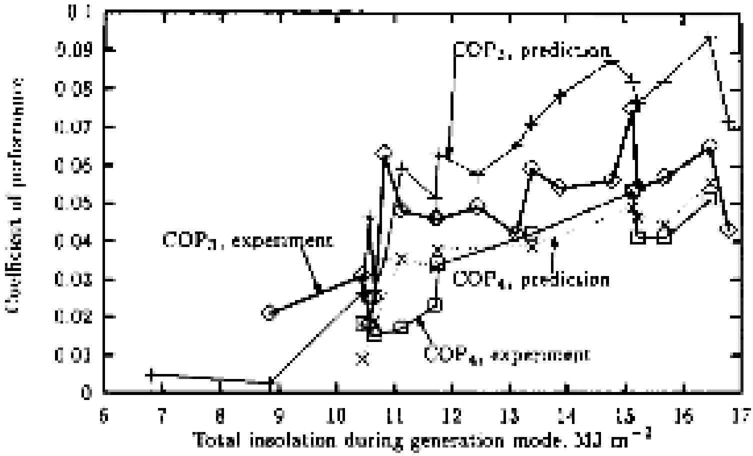

Figure 4.13: Variation of coefficienct of performance (COP) with insolation in the solar refrigerator

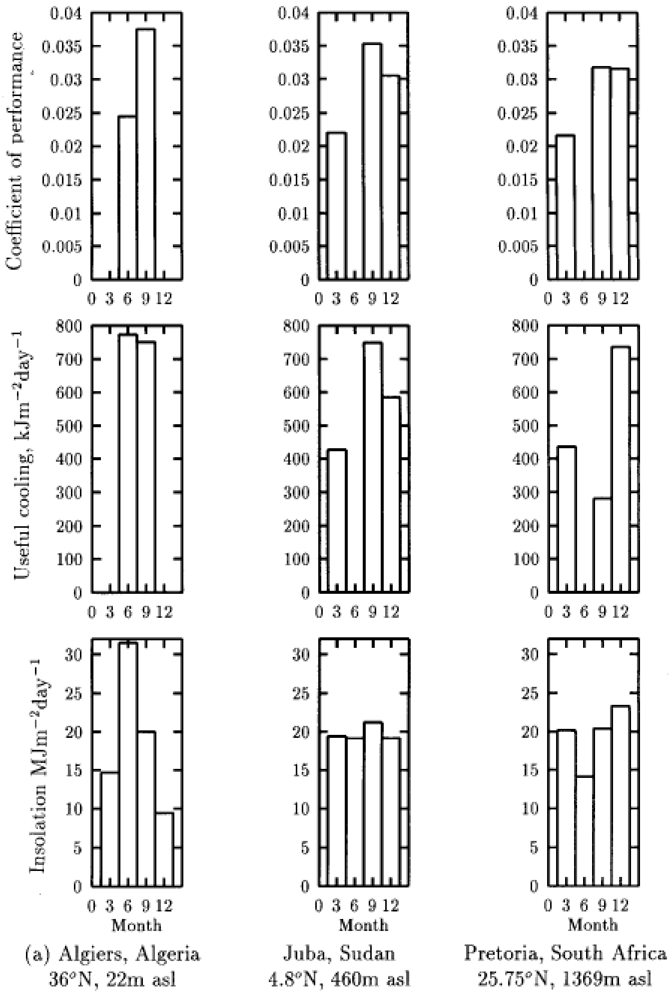

Figure 4.14: Typical predicted monthly mean performance of the solar refrigerator in some African cities

stage were selected. These are the material of construction (steel or aluminium), absorber plate emissively, and collector tube spacing, collector tube diameter, ammonia distribution tube diameter, absorbent packing density, pellet thermal conductivity, pellet mean diameter, and number of glass covers.

2. Each of these parameters is varied in stages between the minimum and maximum values of the parameter shown in table 4.2.

Table 4.2: Range of values of collector parameters

Parameter	Reference value	Minimum value	Maximum value
Absorber plate emissivity	0.9	0.1	0.9
Collector tube spacing, m	0.152	0.06	0.210
Collector tube OD, m	0.059	0.034	0.098
Ammonia distribution tube OD, m	0.021	0.015	0.041
Absorbent packing density, kg m^{-3}	483	360	700
Pellet thermal conductivity, W m^{-1} K^{-1}	0.23	0.05	1.00
Absorbent pellet mean diameter, m	0.0075	0.003	0.020
Number of glazing	2	1	8

3. For each set of parameters, the refrigerator performance is determined for a given climatic condition using the COSSOR software. In this way, performance data for over 100 numerical experiments are generated. This is equivalent to over 100 physical prototypes of the system. Optimal values of the collector specifications for single parameter variation is shown in table 4.3, while the effect of changing the collector tube spacing is shown in figure 4.15.

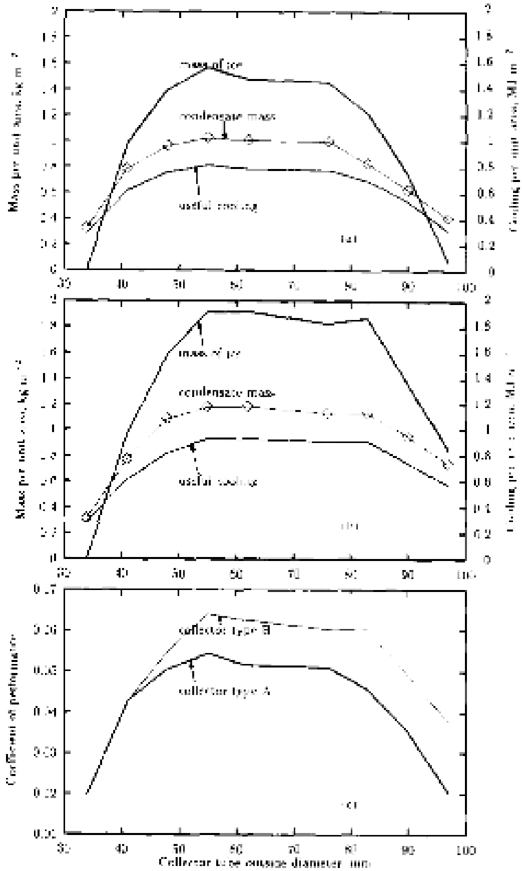

Figure 4.15: Effect of collector tube spacing on solar refrigerator performance for different types of collectors
(a) Collector type A (steel tube and steel plate), (b) collector type B (aluminium tube and aluminium plate), (c) collector type A and B

Table 4.3: Optimal values of the collector specification for single parameter variation

		Refrigerator performance at optimal value			
Single parameter varied	Optimal value	Condensate mass, kg m^{-2}	Mass of ice, kg m^{-2}	Useful cooling, MJ m^{-2}	*COP*
(a) Collector with steel tubes and steel absorber plate					
Plate emissivity[a]	0.3	1.4435	2.5008	1.250	0.0746
Tube spacing, m	0.08	1.223	1.408	1.0257	0.0679
Collector tube OD, m	0.055	1.0228	1.5665	0.8134	0.0545
NH_3 distribution tube OD, m	0.033	1.0735	1.7178	0.6669	0.0613
(b) Collector with aluminium tubes and aluminium absorber plate					
Plate emissivity[a]	0.26	1.8435	2.7928	1.25	0.08478
Tube spacing, m	0.09	1.5196	2.0836	1.2532	0.08431
Collector tube OD, m	0.055	1.1779	1.9147	0.9291	0.06403
NH_3 distribution tube OD, m	0.033	1.369	2.2888	1.0570	0.07169

[a]This is the minimum plate emissivity with a reabsorption time ≤ 11 h.

4.5.2 Solar Refrigerator Optimization

The optimization of the solar refrigerator was carried out in five stages as follows:

1. The design parameters are normalized to obtain dimensionless parameters in the range 0.0 to 1.0

2. Each of the most important performance criteria is correlated with the dimensionless design parameters using the linear multiple regression algorithm described by Kuester and Mize (1973).

3. An objective function which combines all the performance criteria using suitable weighting factors is defined, the weighting factors being assigned based on pragmatic considerations.

4. Using the constrained Rosenbrock sequential search optimization procedure adapted from Kuester and Mize (1973),

the dimensionless parameters which optimize the performance of the refrigerator are determined.

5. The best values of the design parameters so determined are now utilized in COSSOR to recomfirm the performance of the optimal refrigerator.

The optimization studies showed that a performance improvement of about 30% was possible through an optimal choice of the design parameters.

Chapter 5

AIR HEATER

Air heaters are important in many industrial and agricultural applications, including the drying of crops and medicinal/aromatic plants, timber, natural rubber, tea and coffee products, and fodder for animals. They could also be used for poultry egg incubation.

5.1 Experiment

We first undertook experimental studies on the performance of a natural circulation air heater with phase change material energy storage. The heater is powered by solar energy. As shown in figure 5.1, it has an in-built solar energy-collector unit marked A in the photograph, while the working material is placed in the chamber marked B. During the day, the collector-storage unit is heated by solar energy.

Part of the heat is stored in the phase change material mainly as latent heat, while the remainder heats air which flows by natural

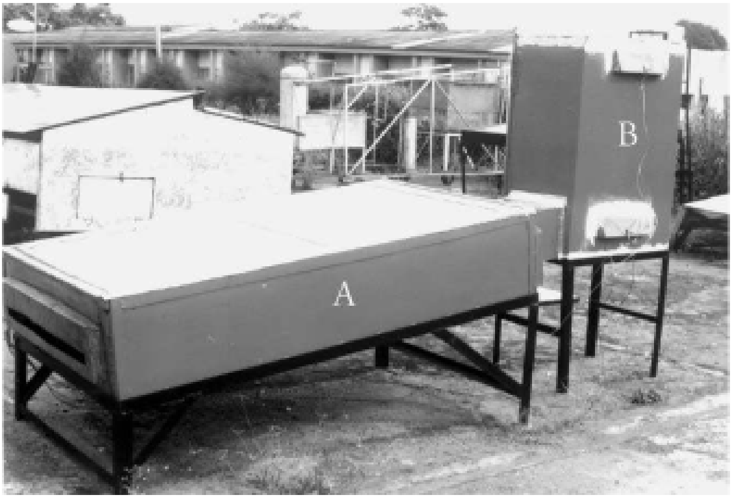

Figure 5.1: Photograph of the air heating system
. A = collector assemble with energy storage and solar- heating subsystem B = heated space

convection through the heated space, B. A key feature of the system is that it would supply hot air within a regulated temperature range for several hours. As a result, it is suitable for applications requiring air supply within a regulated temperature range. The system was first instrumented with thermocouples for digital temperature measurement, as well as devices for solar radiation recording. Tests were then conducted for several days with a global daily radiation of between 4.9 and 19.1 MJ/m^2-day. Typical temperature profile of the heated space for three different days is shown in figure 5.2.

Further performance details are presented in Enibe (2002).

5.2 Modeling/Simulation

In order to gain a deeper insight into the determinants of the system performance, energy balance equations are developed for each major component of the heater and linked with heat and mass transfer models of the air flowing through the system. For example, figure 5.3 shows the heat fluxes on a differential element of the absorber plate, while figure 5.4 shows the heat fluxes on a differential element of the fluid in the heating chamber. Further details are presented in Enibe (2003)

Having completed the modeling of all components of the system, all the partial differential equations resulting from the model are discretized for simultaneous solution using an iterative scheme. Convergence was assumed when two consecutive iterations agres within 5% at all nodes. A computer simulation programme, EGGINS, was developed to implement the numerical solution of the equations. To verify the accuracy of the analysis the predicted perfor-

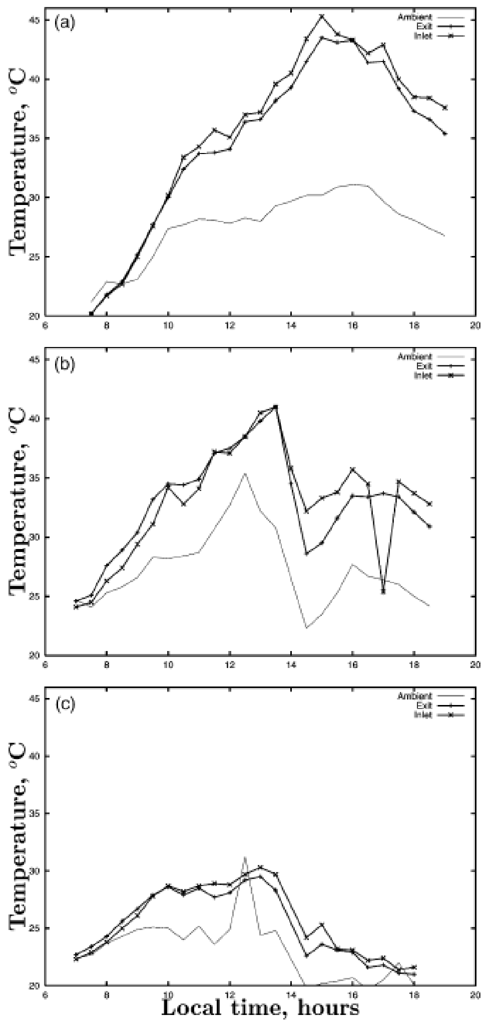

Figure 5.2: Variation of heated air temperature with time in the working chamber of a solar air heater
(a), (b) and (c) are for days with total insolation of 19.87, 15.14

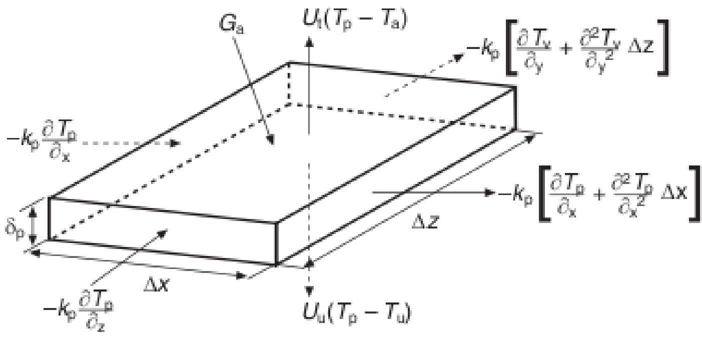

Figure 5.3: Heat fluxes on a differential element of the absorber plate

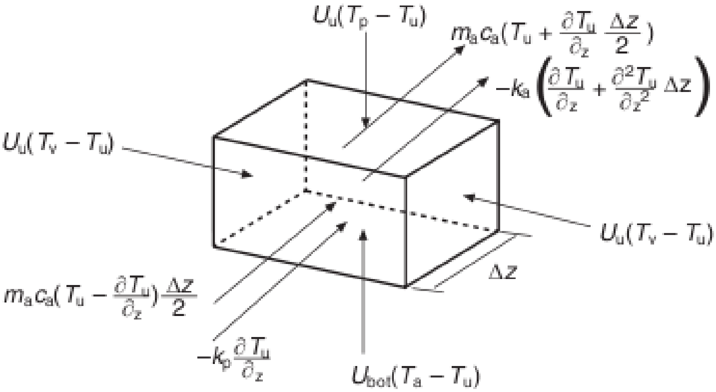

Figure 5.4: Heat fluxes at a differential element of fluid in the heating chamber

mance of the air heater is compared with experimental data for daily global irradiation of 4.9 to 19.9 MJ/(m^2-day). A comparison of the measured and predicted absorber plate temperature is shown in figure 5.5, while further details are presented in Enibe (2003).

The results show that the time of peak temperature and overall temperature profiles for the absorber and heat exchanger plates, the heated air and glazing surface are predicted to within 10^oC.

The predicted useful and overall instantaneous efficiencies from the study are shown in figure in figure 5.6

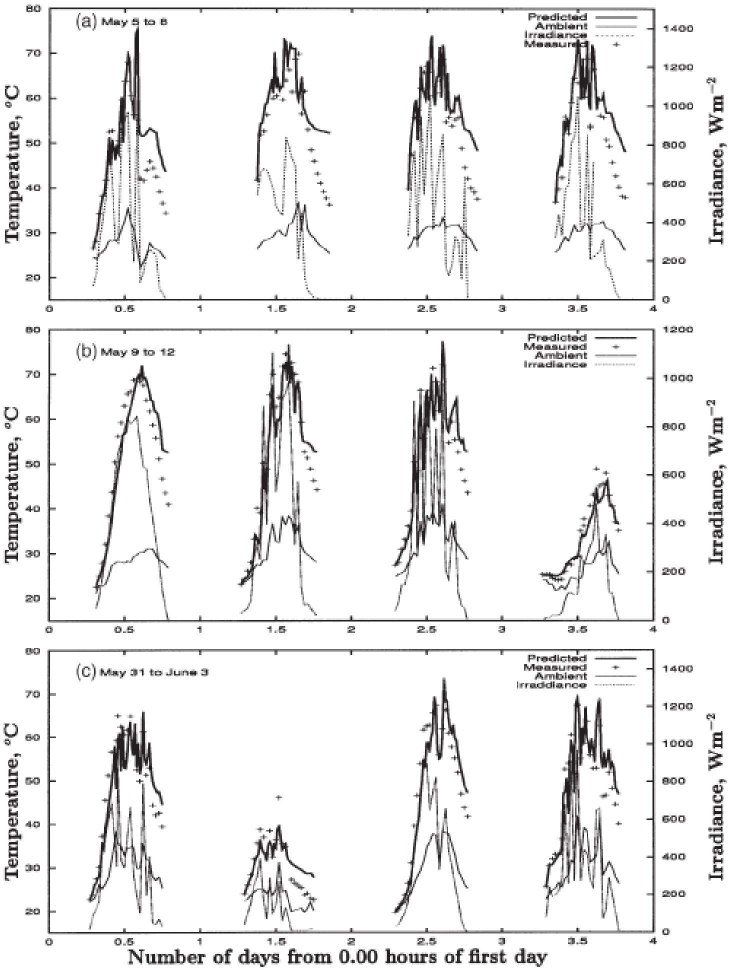

Figure 5.5: Measured and predicted absorber plate temperature for air heater

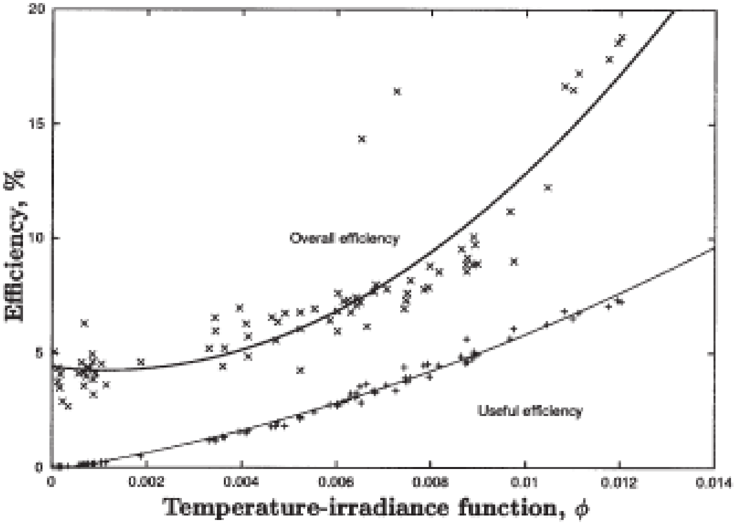

Figure 5.6: Predicted instantaneous efficiency for air heater

Chapter 6

OTHER CONTRIBUTIONS

In this chapter, we give a summary of the other major contributions of the author and his associates. in a number of other areas.

6.1 Renewable & Sustainable Energy

In Enibe (1994), we considered various renewable energy options for electricity generation, such as solar thermal power plants, solar photovoltic system, and wind energy systems. Major constraints towards their utilization are highlighted, as well as strategies for overcoming them. We also presented a method of assessing the wind energy potential of any location in Enibe (1987), and gave a detailed review of recent developments in renewable energy applications in Nigeria in Enibe(2000). A technical report on the environmental benefits of using renewable energy commissioned by UNESCO is presented Onyegegbu *et al*, 1997. Other conributions in this area are presented in Okoroigwe et al (2006), Agbo *et al*, 2005, Enibe (2002) and Enibe (1997). Some contributions in the area of sustainable energy are presented in Enibe and Enibe (2002), Ugwu *et al* (2005), Eke and Enibe (2007)and Odukwe and Enibe (1988).

6.2 Breadfruit depulping

In Enibe (2001), the design, construction and testing of a machine for the depulping of fermented fruits of *Treculia Africana* Decne (African bread fruit or *UKWA*) is presented. Further improvements in the machine performance, as well as the development of a continuous flow depulping process, have been carried out (see Enibe, Asiegbu and Njoku, 2006).

6.3 Thermophysical properties determination

We also worked on the determination of the thermophysical properties of materials which are important in solar energy research and development (see Enibe and Iloeje, 1989). The paper contains a comprehensive review of several methods of determination of such properties, including transient and steady state methods.

6.4 Heat Pumps

The design and testing of absorption heat pumps and their compenents is presented in Enibe (1996). First, an overview of the ammonia-water gas fired heat pump is presented, followed by a detailed analytical design of the distillation column. The design is based on detailed heat and mass balances of the vapour and liquid phases in the rectifying and striping sections of the column. The tower dimensions are determined for both winter (heating mode) and summer (cooling mode) operations of the device.

6.5 Software Development

All the efforts of the author in software development are need based. For example, COSSOR and EGGINC programmes were developed at various times for simulation of solar thermal systems because no suitable software were readily available at the time. Encouraged by this, when confronted with frequent requests by scholarship awarding bodies and sometimes the University authorities to send the umulative grade point averages of students of Mechanical Ecngineering, he was compelled to begin the development of the ACADEMIA software in year 2000. Unlike the previous programmes which were all written in Quick BASIC, ACADEMIA is written in C++. Presently, compiled versions are available for LINUX operating systems, but was designed for compilation into other operating systems, such as WINDOWS. A few highlights of the software will be presented here.

6.5.1 Examination Results

The ACADEMIA software provides a systematic way of processing examination results of all students in all approved courses in a convenient manner. For each course in a given academic year, the following data can be generated:

1. Total and grade of each student with various forms of input data.
2. Detailed results for each candidate arranged in order of Departments. Within each Department, names of candidates are arranged in alphabetical order.
3. Automatic summaries of results for each page, giving number of candidates with a particular grade on each page. Usual details in a standard grade sheet are also preserved.
4. Overall summary of results for the entire course, with number and percentage of candidates who obtained a given grade in the entire course.

Figure 6.1 shows the last page of a typical examination results processed by ACADEMIA.

Having processed the examination results for any number of courses in a semester for a given level of study, a convenient summary giving vital statistics can be compiled as a report. For example, figure 6.2 shows the summary of results for 2006/2007 academic year for 500-level courses in the Department of Mechanical Engineering.

6.5.2 Student Course Registration

The software also provides a systematic way of compiling the details of courses registered by a student. Input data may be from

UNIVERSITY OF NIGERIA Registrar's copy
OFFICIAL GRADE REPORT & CLASS ROSTER
(Effective from 1996/97 Session)

Title of Course: The Use of English
Examination Date: 29/03/06
Department: GS Course No: GS 101 Section: Units: 2
Faculty: GS Semester: FIRST Academic Year: 2005/2006
Name of Lecturer: INOMA B. U. (MRS)

S/N	Name of Student (Surname First)	Reg. No	Dept	Year of Study	Cont. Ass. Mark	Exam. Mark	Total	Letter Grade
1	UGWUANYI L. U.	2005/128077	ME	1/5	14.0	33.0	47.0	D
2	UGWUANYI O. O.	2005/128087	ME	1/5	14.0	38.0	52.0	C
3	UGWUMMADU I. P.	2005/128153	ME	1/5	14.0	37.0	51.0	C
4	UMEOKWUIBE O. C.	2005/128009	ME	1/5	14.0	39.0	53.0	C
5	UNAEGBU D. C.	2004/127669	ME	1/5	14.0	46.0	60.0	B
6	UNAEGBUNAM O. V.	2005/127949	ME	1/5	14.0	36.0	50.0	C
7	UNAH I.	2005/128069	ME	1/5	12.0	30.0	42.0	E
8	UNAMBA K. C.	2005/128037	ME	1/5	15.0	45.0	60.0	B
9	UWANDI O. D.	2005/127905	ME	1/5	14.0	37.0	51.0	C
10	UZODIMMA C. E.	2001/111853	ME	5/5	14.0	46.0	60.0	B
11	UZOR C. C.	2005/128160	ME	1/5	13.0	33.0	46.0	D
12	YOUPELE P. B.	2005/128006	ME	1/5	13.0	29.0	42.0	E

Summary

Minimum	Maximum	Mean	Standard deviation
0.0	70.0	50.9	7.3

Grade	A	B	C	D	E	F	Total
Number	1	17	47	18	16	2	101
Percent	1.0	16.8	46.5	17.8	15.8	2.0	100.0

Score	Letter Grade	
70–100	A	= Excellent
60–69	B	= Very Good
50–59	C	= Good
45–49	D	= Fair
40–45	E	= Pass
0–39	F	= Fail

Lecturer's Sign: ____________ Date 4/10/2006
Head of Dept's Sign: ____________ Date 11/10/2006
Name of Head of Dept. MR. E. O. OKWOR

SUMMARY OF GRADES: **Page 4 of 4**
A's 0 B's 3 C's 5 D's 2 E's 2 F's 0

Figure 6.1: ACADEMIA output for last page of a typical examination result

UNIVERSITY OF NIGERIA

REGISTRAR'S DEPARTMENT (EXAMINATIONS)

FACULTY: **Engineering** FINAL YEAR EXAMINATION RESULTS, **2006/2007** SESSION DEPARTMENT: **Mechanical Engineering**

Table 1: Summary of Results

Course	Course Title	Units	Lecturer	Exam Date	No of Candidates	Mean %	A %	B %	C %	D %	E %	F %	Inc %
ME 511	Applied Design	4	Dr. A N Enetanya	April 2007	175	50.4	13.7	42.3	21.1	5.1	0	0	17.7
ME 512	Manufacturing & Tools Engineering	3	Dr. D O N Obikwelu	03/03/05	180	44.5	20	20	11.7	11.7	5.6	13.9	17.2
ME 521	B.Eng Project	6	All Academic Staff	October 2007	119	67.3	47.9	26.9	17.6	5	2.5	0	0.0
ME 523	Engineering Materials Selection & Economics	3	Prof B A Okorie	Sep 2007	184	45.7	13.6	12.5	22.8	11.4	20.7	6.5	12.5
ME 541	Vibrations & Control	3	Dr S O Edelugo	28/09/2007	104	47.5	10.6	12.5	20.2	6.7	26	24	0.0
ME 551	Mechanics of Fluids II	3	Prof S O Onyegegbu	2007	218	31.4	8.3	5	6	0.9	44	23.9	11.9
ME 561	Thermodynamics III	3	Prof A O Odukwe	19/3/2007	189	34.9	6.3	6.9	14.8	5.3	37	15.3	14.3
ME 568	Power Plant Engineering	3	Prof O C Iloeje	24/9/2007	39	41.1	15.4	20.5	7.7	2.6	23.1	30.8	0.0
ME 573	Refrigeration & Airconditioning	3	Prof S O Enibe	12/09/07	145	58.4	41.4	12.4	9.7	3.4	9	24.1	0.0
ME 581	Engineering Law & Management	3	Dr D O N Obikwelu	APRIL 2007	176	52.4	36.9	18.8	9.1	7.4	2.8	9.7	15.3
ME 591	Engineering Metallurgy	3	Dr D O N Obikwelu	04/10/07	152	49.5	12.5	14.5	7.2	9.9	51.3	4.6	0.0
Average					144	46.9	19.7	17	13.7	6.8	20.9	12.4	9.5

	(1) External Examiner	(2) External Examiner	Head of Department	Dean of Faculty
Name:	Prof C O Nwajagu	Prof E E Anyanwu	Prof S O Enibe	Prof C C Osuagwu
Sign:				
Date:				

Page 1 of 1

Figure 6.2: ACADEMIA output for summary page of sessional results for 500-level courses in a Department

on-line course registration spreadsheet files, or the older paper versions of the student course registration forms. In each case, all the usual data in the paper formats captured, and can easily be extended to include new information fields. From these, list of students registered for a particular course can easily be compiled for output or use by other components of the software.

6.5.3 CGPA Computation

Once the database of results and student course registration are built, ACADEMIA can easily compute the cumulative grade point average of any number of students. The courses are arranged in alphabetical order for each semester, and problems such as incomplete results are reported at the end. The details can be presented in a compact for as *statement of results* (useful for data cross-checking), or as a final *transcript of results*. A sample of the lastpage of a typical transcript is shown in figure 6.3.

If the CGPA is compiled for a group of students, it automatically arranges them according to the level of study and then categorizes each level according to class of degree (eg *first class*, *second class upper, etc*).

6.5.4 Prospects

ACADEMIA is a robust tool for managing data of students in higher institutions. It is expected that a user manual and a graphical user interface (GUI) will be prepared in due course to facilitate its wider use.

UNIVERSITY OF NIGERIA

NSUKKA, NIGERIA

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Our Ref: UN/ ME /S /1998/12345

TRANSCRIPT OF ACADEMIC RECORDS

Name	Reg. No	Department	Date of Birth	Sex
OKORO BAMIDELE YESUFU	1998/12345	Mechanical Engineering	30/8/1981	MALE

2002/2003 Session, First Semester

Course No	Course Title	Credit Load	Cont Asses.	Exam Mark	Total	Grade	Point
ME 511	Applied Design	4	16.0	62.0	78.0	A	20.0
ME 523	Engineering Materials Selection and Economics	3	—	71.0	71.0	A	15.0
ME 551	Mechanics of Fluids II	3	—	91.0	91.0	A	15.0
ME 581	Engineering Law and Management	4	—	77.0	77.0	A	20.0
Total		85	GPA = 374/85 = 4.400				374

2002/2003 Session, Second Semester

Course No	Course Title	Credit Load	Cont Asses.	Exam Mark	Total	Grade	Point
ME 521	B.Eng. Project	6	—	82.0	82.0	A	30.0
ME 541	Vibrations and Control	3	20.0	46.5	66.5	B	12.0
ME 568	Power Plant Engineering	3	25.5	59.5	85.0	A	15.0
ME 573	Refrigeration and Air-Conditioning	3	16.5	61.0	77.5	A	15.0
ME 591	Engineering Metallurgy	3	—	77.0	77.0	A	15.0
Total		103	GPA = 461/103 = 4.476				461

incomplete

1998/1999; 1 PHY 107, PHY 192
1998/1999; 2 , CHM 111, CHM 121, GS 102, PHY 105, PHY 109
1999/2000; 1 , CE 211, CE 212, EE 211, ENGR 201, GS 207
1999/2000; 2 , CE 221, EE 251
2000/2001; 1 , ME 315, STA 203
2000/2001; 2 , ENGR 301, ME 316
2001/2002; 1 , ENGR 401, ME 418, ME 441, ME 442
2001/2002; 2 , ENGR 402, ME 419, ME 431
2002/2003; 1 , ME 561
Note: Courses with incomplete results were not utilised in the computation of final cumulative grade point avaerage, CGPA Final Cumulative Grade Point Average = 4.476

Name	Signature	Date	Position

3 of 3

Figure 6.3: ACADEMIA output for last page of full transcript for a student

Chapter 7

CONCLUSION

From the experiences gained in the foregoing studies, the following conclusions may be drawn

1. The development of a wide range of engineering systems in the Nigerian environment is possible and should be encouraged.

2. The performance of many such systems can be greatly enhanced through detailed analysis of the physical laws governing their behaviour, modeling and simulation of such behaviour using available mathematical procedures with the aid of the digital computer, and optimization of such behaviour within the context of the available resources. Usually, this has to be accompanied with careful experimentation on laboratory or full scale prototypes of the system.

3. Nigerian engineers and other professionals should be given opportunites to apply their skills to the solution of technical

problems facing the nation. Many of the technical problems being sent to other countries for solution can benefit from the expertise of local professionals.

4. Opportunities should be made available to young engineers and other professionals to enhance their training and skills through the award of research grants, fellowships and conference support.

Thank you very much for your kind attention. May God bless you all richly!

SAMUEL OGBONNA ENIBE

last revised 14 August 2008, updated 17 September 2008

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INAUGURAL LECTURES OF THE UNIVERSITY OF NIGERIA, NSUKKA

1. **Prof. K. Nzimiro - 1976**
   Title: The Crisis in the Social Sciences: The Nigerian Situation.

2. **Prof. Chika Okonjo - 1976**
   Title: Economic Science, Imperialism and Nigerian Development.

3. **Prof. K.S. Hedge, Vet. Medicine - 1977**
   Title:

4. **Prof. D.I. Nwoga - 1977**
   Title: Visions Alternatives: Literary Studies in a Transitional Culture.

5. **Prof. J.A. Umeh - 1977**
   Title: Land Policies and Compulsory Acquisition of Private Land for Public Purposes in Nigeria.

6. **Prof. D. C. Nwafo - 1984**
   Title: The Surgeon as an Academic.

7. **Prof. G.E.K. Oformata - 1985**
   Title: Soil Erosion in Nigeria: The View of a Geomorphologist.

8. **Prof. E.U. Odigbo - 1985**
   Title: Mechanization of Cassava Production and Processing: A Decade of Design and Development.

9. **Prof. R.O. Ohuche - 1986**
   Title: Discovering what Learners have attained in Mathematics.

10. **Prof. S.C. Ohaegbulam - 1986**
    Title: Brain Surgery: A Luxury in a Developing Country like Nigeria.

11. **Prof. I.C. Ononogbu - 1998**
    Title: Lipids: Your Friend and Foe.

12. **Prof. V.F. Harbor-Peters - 2001**
    Title: Unmasking Some Aversive Aspects of Schools Mathematics and Strategies for Averting Them.

13. **Prof. P.O. Esedebe — 2003**
    Title: Reflections on History, Nation Building and the University of Nigeria.

14. **Prof. E.P. Nwabueze - 2005**
    Title: In the Spirit of Thespis: The Theatre Arts and National Integration.

15. **Prof. I.U. Obi - 2006**
    Title: What have I done as an Agricultural Scientist? (achievements, Problems and Solution Proposals).

16. **Prof. P.A. Nwachukwu - 2006**
    Title: A Journey through the Uncharted Terrain of Igbo Linguistics.

17. **Rev. Fr. Prof. A.N. Akwanya - 2007**
    Title: English Language Learning in Nigeria: In Search of an Enabling Principle.

18. **Prof. T. Uzodinma Nwala - 2007**
    Title: The Otonti Nduka Mandate: From Tradition to Modernity.

19. **Prof. J.A. Ibemesi — June 2007**
    Title: From Studies in Polymers and Vegetable Oils to Sanitization of the Academic System.

20. **Prof. Obi U. Njoku — June 2007**
    Title: Lipid Biochemistry: Providing New Insights in our Environment.

21. **Prof. Humphrey Assisi Asobie — July 2007**
    Title: Re-inventing the Study of International Relations: From State and State Power to Man and Social Forces.

22. **Prof. Aloy Emeka Agbaji — July 2007**
    Title: Prostrate Cancer: Coping with the Monster in a Third World Setting.

23. **Prof. Eunice A.C. Okeke — August 2007**
Title: Making Science Education Accessible to All.

24. **Prof. Chibuike U. Uche - August 2007**
Title: The Future of the Past in Banking.

25. **Prof. Ossie O. Enekwe — September 2007**
Title: Beyond Entertainment: A Reflection on Drama and Theatre.

26. **Prof. Onyechi Obidoa — September 2007**
Title: Life Does Not Depend On The Liver: Some Retrospectives, Perspectives, Reflections and Relevance in Xenobiosis, Chemoprevention and Capacity Building.

27. **Prof. Okechukwu Ibeanu - 2008**
Title: Affluence and Affliction: The Niger Delta as a Critique of Political Science in Nigeria.

28. **Prof. Damian Ugwuntikiri Opata - 2008**
Title: Delay and Justice in the Lore and Literature of Igbo Extraction.

29. **Rev. Fr. Elobuike Malachy Nwabuisi - 2008**
Title: Education for What?

30. **Prof. Michael C. Madukwe - 2008**
Title: Practice Without Policy: The Nigerian Agricultural Extension Service.

31. **Prof. Anthony N. Eke - 2008**
Title: Delay and Control in Differential Equations: Apogee of Development.

32. **Prof. Joe Sonne Chinyere Mbagwu - 2008**
    Title: From Paradox to Reality: Unfolding the Discipline of Soil Physics in Soil Science.

33. **Prof. Inno Uzoma Nwadike - 2008**
    Title: Igbo Studies: From the Plantation of West Indies to the Forest Lands of West Africa, 1766-2008.

34. **Prof. Benjamin Chukwuma Ozumba - 2008**
    Title: Improving Maternal Health in Developing Countries: The Nigerian Experience.

35. **Prof. Henrietta Nkechi Ene-Obong - 2008**
    Title: Nutrition Science and Practice: Emerging Issues and Problems in Food Consumption, Diet Quality and Health.

36. **Prof. Amarauche Chukwu - 2008**
    Title: Using Neglected Local Raw Materials in Developing High Level International Health Manpower.

INTRODUCTORY NOTES ON THE 37TH INAUGURAL LECTURE, 2008

UNIVERSITY OF NIGERIA
(Senate Ceremonials Committee)

To: The University Community and Guests at the Lecture	From: Public Relations Office
	Date: August 26, 2008

INTRODUCTORY NOTES ON THE 37TH INAUGURAL LECTURE, 2008

Title **Engineering Systems Analysis and Optimization**

Lecturer **Professor Samuel Ogbonna Enibe**

1. **Appreciation and Felicitations**

During my State of the University Address to the National Executive Council (NEC) of the University of Nigeria Alumni Association (UNAA) in Kano last Saturday, August 23, 2008, I told them that the primary mission of getting the wounded lion to roar again is like a mission accomplished.

The lion is on its feet rejuvenated, roaring and confidently focused for leaping forward for competitive national and world class positioning. The focus has shifted to getting the rejuvenated lion to soar to regain leadership and keep abreast of developments in the world. The strategies that brought the University to the stage before the lion was knocked out, are no longer relevant. We need to re-engineer and re-tool to provide the needed momentum to soar forward.

One aspect of this Administrations performance that illustrates this is the progress in the delivery of inaugural lectures. After today, it would be a rich harvest of 24 lectures since 2005, in steadily increasing speed: 1 in 2005, 2 in 2006, 10 in 2007 and 11 in 8 months of 2008. Some 4 more are planned before the end of the year. Compare this with 13 lectures in 14 years. What a rejuvenation! The lion is roaring and soaring indeed.

On behalf of the Senate Ceremonials Committee and the Information and Public Relations Office, I formally welcome you to the 37th Inaugural Lecture. Thank you for honouring the invitation to be present and to participate in the proceedings.

Todays outing is the second by the Faculty of Engineering since the first by Engr. Professor E.U. Odigboh of the Department of Agricultural Engineering in 1985. We felicitate with the Department of Mechanical Engineering for giving the Faculty a showing as we celebrate the oasis of delightful green and sturdy growth in the inaugural lectures.

2. **Brief Profile of Professor S.O. Enibe**

When we think of engineers, we usually associate them with physical structures and construction work. We fail to realize that they do use their expertise to work on our minds. Unknown to us, they do a sort of engineering of good image for their profession. Take two examples. When the former Head of State, Chief Olusegun Obasanjo, delivered an address during one of the Herbert Macaulay Memorial Lectures in our Faculty of Engineering, he did this openly, raising a controversy in the process.

He pointed out that Herbert Macaulay, Nigeria‘s first engineer, was also the nation‘s foremost political leader. After more illustrations of prominent engineers in prominent political leadership positions, he concluded that Nigerians would have to accept that engineering was a better training for political office than political science. As if smarting from the hangover of this assertion is not enough, we now have a Vice-Chancellor who is an engineer. He has not told us that engineering is the best preparation for the post of Vice-Chancellor. No. He hasn‘t. But his rating among others appears to give an obvious impression. This has been strengthened by his relation of a joke showing that engineers are the most honest professionals. Here, read the details.

A number of professionals were lined up for summary trial

 INTRODUCTORY NOTES

and execution by guillotine. Fortunately, the guillotine did not release to behead any one of them, because of a fault. So each of them was pronounced not guilty and set free. When it was the turn of the engineer, it was the same thing. But in his honesty, he discovered a fault is the catch of the guillotine that impeded its release. He pointed it out, rose from his position, and got it repaired. Then he lay down again. When the order was given, the guillotine went to work and accomplished its mission. Judge for yourself.

Fortunately, Professor Enibe is featuring in an inaugural lecture, not in a summary trial and execution. No faulty catch to repair in the process. But he is required to make an honest appearance.

In an ICT age when the University is straining towards a world class ranking, it is welcome development that an academic involved in the development of computer programmes and software for special applications is featuring as an inaugural lecturer. It is a welcome appearance as we speak and act digitalization of staff and students‘ records, academic publications and the like. He is an available source to tap from. Here are more pictures of him in regular headings:

(a) . **Academic Qualifications**

- B. Eng., Mechanical Engineering, 1982
- M.Sc., Alternative Energy, 1986
- PhD, Mechanical Enginering, 1995.

(b) **Academic Awards and Distinctions**

- Scholarship of the United Africa Company (UAC) of Nigeria Plc, 1977-1982

- British Council Fellowship at the University of reading, England, 1985-1986
- Academic Exchange Fellowship, Association of Commonwealth Universities, (ACU), London, 1994
- International Foundation for Science (IFS)/King Baudouin Award, 1995
- Joint Fellowship, Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, Italian Agency for New Technologies, Energy and the Environment (ENEA), Rome, Italy, 1995-1996.
- Academic Exchange Fellowship, African Network of Scientific & Technological Institutions (ANSTI) of the UNESCO, 2000.
- Regular Associate, Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, 2000-2005.

(c) Membership of Professional Associations/Bodies

- Member, International Solar Energy Society, 1993
- Member, Solar Energy Society of Nigeria, 1989
- Member, Nigerian Society of Engineers (NSE), 1998
- Member, African Technology Policy Studies Network (ATPS), 1998
- Member of the International Advisory Committee of the International Energy Foundation, Saskatchewan, Canada, 1998.

(d) Service Within the University

- First appointed, Graduate Assistant, 1983

- Promoted Professor, 2003
- Head, Department of Mechanical Engineering, 200(
  2003, 2006-2008
- Postgraduate Coordinator, Mechanical Engineering, 2003-2006
- Hall Master, Kwame Nkrumah and Mbanefo Halls, 2005
- Director, Service and Training Centre, 2008
- Chairman, Faculty of Engineering Committee on Monitoring of Examination Results, 2004
- Senate Representative on Joint Council/Senate Com
  mittee on Appointment of the University Librarian, 2007
- Service in various other University Committees between 1990-2008

(e) Service Outside the University

- NYSC Lecturer, Federal Polytechnic, Akure, 1982-1983
- External Examiner, Nnamdi Azikiwe University, Awka, 2006
- External Examiner, University of Science and Technology, Kumasi, Ghana, 2000

(f) Research and Academic Publications

- Editor-in-Chief, The Nigerian Journal of Solar Energy, 2000-2006
- Editor, Nigerian Journal of Technology and Reviewer, Nigerian Journal of Solar Energy, Nige-

rian Journal of Renewable Energy and Global Journal of Technology.

- Has published a total of 38 articles in national and international journals.
- Has attended and read papers at 15 national and international conferences.

Conclusion

Once again, thank you for being present for this lecture. Thank you for reading through these introductory notes. It is our hope that they have put you in the mood to benefit most from Professor Enibe as he presents his lecture. It has been a special delight for me serving you in this regard.

Happy Inaugural Lecture. Happy Listening.

/sgd./
Gozie Arazu
Alumni Relations Officer
For: Public Relations Officer

Cc: Vice-Chancellor
Deputy Vice-Chancellor (Academic)
Deputy Vice-Chancellor (Administration)
Deputy Vice-Chancellor (Enugu Campus)
Registrar
Bursar
University Librarian

UNIVERSITY OF NIGERIA
(Senate Ceremonials Committee

37TH INAUGURAL LECTURE

PROGRAMME

1.00 p.m.	- Group Photograph
1.30 p.m.	- Procession begins in front of Administration Building
1.40 p.m.	- Entry into the Princess Alexandra Unity Hall and Theatre
1.45 p.m.	- National Anthem Opening Prayers The University of Nigeria Song Introduction of the Chairman, Principal Officers of the University and Special Guests
2.15 p.m.	- Chairman's Opening Remarks Citation on the Inaugural Lecturer by Prof. N.N. Osadebe The Lecture: **Engineering Systems Analysis and Optimization** By Professor **Samuel Ogbonna Enibe**
3.30 p.m.	- Vote of Thanks by **Dr. C.O.T. Ugwu** Chairman's Closing Remarks Closing Prayers National Anthem

Recession

4.00 p.m. - Cocktail at the Centre for Entrepreneurial and Development Research.

Appendix A

CITATION

UNIVERSITY OF NIGERIA, NSUKKA, NIGERIA

CITATION ON SAMUEL OGBONNA ENIBE

PROFESSOR OF MECHANICAL ENGINEERING

read by

Engr. Prof. N. N. Osadebe, Dean, Faculty of Engineering

A.1 A Child is Born

Mrs. Egonyi Cecilia Patricia Enibe had been sick for several months. Her husband, now late Elder David Nwoye Enibe, therefore had to take her to what were considered to be the best available medical centers — usually manned by herbalists and other trained physicians.

When she became well, no one was sure she would be able to have other children. Hence everyone concerned had to pray! When therefore she became pregnant and gave birth, the plumpy fine boy was named Samuel — born in answer to many prayers! Though the exact date was not ascertained, it was estimated to be around the 4th of May 1957.

As the news of his birth filtered into the serene and wooded Umu Enibe Settlements in the Ndiagu Quarters of Amaenye Village, Abagana, there was joy in the air! *This one looks like the father*, said one of the women as she carried the young baby on her palms. *Yes*, agreed the other, as she waited for her turn to carry the baby. With time, a second name OGBONNA (like his father) emerged. A plethora of other names were given, but most have faded from the memory due to lack of use.

Like all young mothers, Samuels mother, Egonyi, was confronted with the task of taking care of this young boy, together with his older siblings (one of whom later died). Strapped at her back, she would take the young Samuel to the farm, to the market, to the stream — virtually everywhere she went! Often there were willing helping hands — relations, neighbours and friends — but this was not always guaranteed. Further, the boy was increasing in weight, and she was expecting another baby! (This baby turned out to be a girl, Ngozi).

A.2 Education

Let Sam join the other children to school, Egonyi suggested to her husband, David, one day. *This will give me at least two or three hours every school day to devote to other matters*, she continued. The idea was soon accepted, and Samuel joined his elder brother, Christian, for nursery/kindergarten-level of education at the Epupe Preparatory School, Adagbe, Abagana, at a tender age of 3 or 4. In 1964, the family moved to Ogboja, Ogoja, in the present Cross River State where he was admitted into class one at the St. Theresas Catholic Primary School, Abakpa, Ogoja. When he was halfway through Primary 4, the rumbles of the Nigerian Civil War forced the family to return to Abagana in 1967.

Samuel completed his primary education at St. Peters CMS (now Central) School, Abagana, in 1971, and obtained the First School Leaving Certificate with Distinction. Between 1972 and 1976, he was educated at the St. Marys High School, Ifitedunu, Dunukofia Local Government Area of Anambra State and obtained the West African School Certificate with Distinction (A1 in Additional Mathematics, Physics and Chemistry; A2 in Mathematics and English, and A3 in French, a total of Aggregate 10).

In 1977, Samuel Ogbonna Enibe was admitted into the Department of Mechanical Engineering, University of Nigeria, Nsukka and graduated in 1982 with a Second Class Honours (Lower Division). In 1986, he obtained the Master of Science degree from the University of Reading, Reading, England; and bagged the University of Nigeria Doctor of Philosophy Degree in Mechanical Engineering in 1995.

A.3 A Harvest of Firsts

Professor Samuel Ogbonna Enibe has had the special privilege of being the first in a number of areas.

- He is the first member of the Enibe Family to obtain a University degree.
- He is the first indigene of Amaenye Village, Abagana, to be a University lecturer and a Professor.
- He is the first person to obtain the degree of Doctor of Philosophy (PhD) from the Department of Mechanical Engineering, UNN.
- He is the first lion to be promoted to the rank of Professor in the Department of Mechanical Engineering, UNN.

A.4 More Than Conquerors

Like all mortals, Samuel Ogbonna Enibe had his own fair share of setbacks. But he always believed, like Paul in Romans 8:28, that in all these things *we are more than conquerors*. Two such examples are worth considering.

In 1977, he applied for admission into the University of Nigeria and sat the required entrance examination. (This was the last entrance examination conducted by the University before JAMB took over admission matters). In May of that same year, he received a letter from the Admissions Office of the University indicating that his performance in the examination was below the cut-off mark! The boy Samuel, who just triumphed in the WAEC School Certificate Examination with an aggregate 10 Distinction, could not believe it.

Could it have been a mistake, he wondered! How could his dream University make such a mistake!

While in the penultimate years in the secondary school, he had read so much about the University of Nigeria, its programmes, available scholarships, etc. and had looked forward to joining such an institution where the *nations potentials do brood in the nest*. He had no godfather to fight for him, and knew no one at the Nsukka citadel of learning. But he knew God the author of knowledge, and believed that with God, *nothing shall be impossible* ... . Few months later, he received another letter from the University congratulating him on his performance, and offering him admission!

A second instance happened five years later. Samuel had always desired to be a University Professor, and was indeed nicknamed *Professor* by his peers, church members and admirers while in secondary school. As an undergraduate student, he determined to make a first class to ensure that his career dreams came through. Unfortunately, when the degree results were released in July or August 1982, he did not make a first class or even a second class upper, but a mere second class lower! While one of his friends and classmate who made a third class was rejoicing for becoming a University graduate, Samuel was disappointed and felt that his dreams were shattered.

He wondered what the future held for him! But he also knew that God holds the future for all mortals! Later that year, he read an advertisement in a national daily newspaper calling for applications for academic staff employment at the National Centre for Energy Research and Development (NCERD), University of Nigeria, Nsukka, for the post of Graduate Assistant. The advert stated that the minimum qualification was a Second Class Honours (Upper Division), but that in exceptional circumstances candidates with second class honours (lower division) could be considered! Samuel turned out to be that exceptional case, and was employed after a rigorous interview.

A.5 Employment Record

Samuel Ogbonna Enibe has had almost three decades of experience in teaching at the secondary school, polytechnic and university levels. The details are as follows:

1. Auxiliary teacher, Adazi Boys High School, Adazi, Anambra State, Nigeria, 1976–1977. Subjects taught were English Language and Mathematics

2. NYSC Lecturer, Department of Mechanical/Production Engineering, Federal Polytechnic, Akure (now Ado-Ekiti), Ondo State, Nigeria, 1982–1983. Subject taught was thermodynamics.

3. Research Fellow at the National Centre for Energy Research and Development (with parallel appointment as Lecturer in the Department of Mechanical Engineering), University of Nigeria, Nsukka, Nigeria, in the following positions

    (a) Graduate Assistant, 1983–1986

   (b) Assistant Research Fellow/Assistant Lecturer, 1986-1987
   (c) Research Fellow II/Lecturer II, 1987–1990
   (d) Research Fellow I/Lecturer I, 1990–1993
   (e) Senior Research Fellow/Senior Lecturer, 1993–1997

4. Senior Lecturer, Department of Mechanical Engineering, University of Nigeria, Nsukka, Nigeria, since 1993.

   The courses which have been taught at undergraduate and/or postgraduate levels include applied mechanics, mechanics of machines, thermodynamics, heat and mass transfer, and solar energy conversion.

5. Professor of Mechanical Engineering, since 2003

A.6 Professional experience

Apart from teaching, SAMUEL OGBONNA ENIBE has accumulated professional experience in the areas of research and development, administration, computer programming/software development, electronic documentation/computer typesetting, journal editorship, etc. These are described below:-

A.6.1 Research and development

This has centred on the following research problems

1. Design, construction, performance evaluation and optimization of solar energy thermal applications devices, including

a solid absorption refrigerator, thermosyphon water heater, passive air heating collector and poultry egg incubator

2. Development of some non-conventional energy conversion devices, such as ammonia-water gas fired heat pump and energy-efficient wood burning stove

3. Design, construction and test performance of a machine for processing the fruit of African Breadfruit (*Treculia africana*), which is a tropical tree crop

4. Energy policy analysis, including energy conservation and policy options evaluations

Many of these research efforts have resulted in academic publications.

A.6.2 Administrative experience

Administrative experience has been accumulated over the years through the membership or headship of a number of University Committees or panels covering a wide range of activities.

1. Director, National Centre for Equipment Maintenance & Developmnet (formerly Service & Training Centre, STC), since 2008

2. Head, Department of Mechanical Engineering, 2000–2003, 2006–2008

3. Hall Master, Kwameh Nkrumah and Mbanefo Halls, since 2005

4. Appointed Hall Warden, Ziks Flats Hostel Block D, since 2004.
5. External Examiner, Department of Mechanical Engineering, Nnamdi Azikiwe University, Awka, Nigeria, since 2006
6. Between 2003 and 2006, served as Postgraduate Coordinator, Department of Mechanical Engineering, University of Nigeria, Nsukka
7. Between February 2000 and September 2003, served as Head, Department of Mechanical Engineeering, University of Nigeria, Nsukka, Nigeria and member of the University Senate.
8. In 2000, served as External Examiner for MSc research projects at the University of Science & Technology, Kumasi, Ghana.
9. External Asessor for a number of Universities in Nigeria and one University in Ghana

A.6.3 Project Supervision

Has supervised well over 200 undergraduate final year projects encompasing many areas of Mechanical Engineering. In addition, has supervised/co-supervised or currently supervising/co-supervising a number of Postgraduate Research projects. Some of the successful ones are listed in table A.1.

Table A.1: Supervision of Postgraduate Students Research Projects

Date	Project topic or theme	Name of candidate
2001 – 2004	Development of commercial scale biogas digesters	Mr. E. C. Okoroigwe
2000 – 2004	Structure of energy consumption in manufacturing industries	Mr. H. U. Ugwu
1998 – 2001	*Optimal scheduling of petroleum products distribution in Nigeria*	Mr. M. Eke

A.6.4 Service in University Committees

SAMUEL OGBONNA ENIBE has served in a number of Departmental, Faculty and University Committees.

Departmental/Faculty Committees

COMMITTEE	POST HELD	DATE
Counselling Services	Member	1999/2000
HMML Programme/Invitation	Member	1999/2000
CCC Project Implementation	Member	1998/1999
Mech Engr Exams Committee	Chairman	1997/1998
EDPC Refresher Course	Member	1997/1998
Library Board	Chairman	1997/1998
Fac. Engr. Seminar/Conf.	Member	1991/1992
NCERD Tenders Board	Member	1990/1991 – 199[illegible]/1993
NCERD Library Committee	Chairman	1994/1995

University Committees

COMMITTEE	POST HELD	DATE
Exam Malpractice	Member	1993/1994
Exam Malpractice	Member	1994/1995
Library Board	Member	1997/1998
Exam Malpractice	Member	1999/2000
Senate	Member	1999/2000 – 2000/2001
Works Eval. Committee	Member	2000/2001

1. Further, since 2004, has served as Chairman of Faculty of Engineering Committee on Monitoring of Examination Results and Member of the University Committee.

2. In 2007, Represented Senate in the Joint Council/Senate Committee on the appointment of the University Librarian

3. In this year 2008, he was appointed a member of the Senate Committee on Nuclear Science & Engineering and Chairman of the Local Organising Committee for the National Symposium on Nuclear Science and Engineering to be hosted by the University from 31 August to 3 September 2008

A.6.5 Computer Programming & Software Development

This has involved the development of computer programmes and software for special applications. The most notable of these are as follows:

1. COSSOR. (Computer Simulation of a Solar Refrigerator). Written between 1988 and 1996 in Microsoft QuickBasic programming language, this computer programme was developed and used by the author for the performance prediction and optimization of a solid absorption solar refrigerator.

2. EGGINC. This programme, developed between July 1999 and July 2001, was used for the thermal analysis and performance simulation of a natural circulation solar air heater. It consists of over 3600 lines of code in Microsoft QuickBasic programming language.

3. ACADEMIA. This software has been under development by the author since year 2002. It is designed for use in the processing of examination results and academic transcripts of students in Universities and other tertiary institutions. It is presently undergoing comprehensive testing at the Department of Mechanical Engineering, University of Nigeria, Nsukka. Written in ANSI Standard C++ programming language, the software employs key principles of object-oriented programming and is designed for use in many different computer operating systems, especially LINUX and Microsoft Windows. The programme, which currently traverses over eleven thousand eight hundred (11,800) lines of code, employs many **classes**, **structs**, stand-alone functions and other kinds of objects.

4. BASELINE This programme was developed in C++ as part of the final phase of our multidisciplinary work on *Baseline Survey on Small and Medium Scale Industries in Nigeria –*

South-East Zone (covering Abia, Anambra, Ebonyi, Enugu and Imo States), sponsored by the Central Bank of Nigeria, Abuja

A.6.6 Electronic Documentation and Computer Typesetting

Since 1986, the author has developed a large number of electronic documents for teaching/learning/panel discussions or publication in hard copy. Most of these are available in the latest version of Portable Document Format (PDF) or PostScript, and were largely prepared using the latest version of the LaTeX software as the typesetting engine. In this way, versions of the documents in HTML and other formats can be generated automatically if required. Documents prepared in this way include lecture notes, articles for journal publication, books, learning/teaching materials, etc. Materials containing complex mathematical structures, complex tables and graphics have been handled.

A.6.7 Editorship of Journals

1. Between 2003 and 2006, served as Editor-in-Chief of the *Nigerian Journal of Solar Energy*

2. Currently, an Editor of the *Nigerian Journal of Technology*

3. Currently serving as reviewer for a number of journals, especially *Nijerian Journal of Solar Energy*, *Nigerian Journal of Renewable Energy*, and *Global Journal of Technology*

A.6.8 Industrial work experience

This was undertaken at the tractor and heavy equipment maintenance workshops of the Tractor and Equipment Division of the United Africa Company (UAC) of Nigeria Plc. This was for about three months each in 1978 (at Port Harcourt), 1979 (at Kaduna), 1980 (at Port Harcourt) and 1981 (at Kaduna). It involved the breakdown and preventive maintenance of various tractor components for the company's clients.

A.7 Academic awards

SAMUEL OGBONNA ENIBE has received a number of scholarships and other academic awards. Some of the most notable are:

1. Scholarship of the United Africa Company (UAC) of Nigeria Plc, 1977–1982

2. British Council Fellowship held for 12 months at the University of Reading, England, 1985–1986

3. Academic Exchange Fellowship of the Association of Commonwealth Universities (ACU), London held for 3 months at the University of Zimbabwe, Harare, Zimbabwe, 1994

4. International Foundation For Science (IFS)/King Baudouin Award for

    submitting reports indicating research of an exceptional quality in the area of solar refrigeration

International Foundation For Science, Stockholm, Sweden, December 1995. This award had a cash value of US$ 1000.00

5. Joint Fellowship of the Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy and the Italian Agency for New Technologies, Energy and the Environment (ENEA), held for 12 months at the Casaccia Research Centre of ENEA in Rome, Italy, 1995–1996

6. Academic Exchange Fellowship of the African Network of Scientific & Technological Institutions (ANSTI) of the UNESCO Office in Nairobi, Kenya held for 3 months at the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, in year 2000

7. Regular Associate, Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy to cover 3 or more visits to the ICTP for a total of 270 days during the period 2000–2005

A.8 Research Grants

Many of the research works of SAMUEL OGBONNA ENIBE were supported with grants from local and overseas institutions. Some of these are:

1. Co-Investigator, *Baseline Survey on Small and Medium Scale Industries in Nigeria – South-East Zone (covering Abia, Anambra, Ebonyi, Enugu and Imo States)*, sponsored by the Central Bank of Nigeria, Abuja

2. Chief Investigator, Grant from the African Academy of Sciences, Nairobi, Kenya on the theme *Agricultural Production, Nutritional and Engineering Development Project on Treculia Africana*, 2002 – 2004 (Phase 1)

3. Chief Investigator, Grant No. G/1503-1 of the International Foundation for Science, Stockholm, Sweden for a project entitled *Optimization of a solar powered solid absorption refrigeration system for rural agricultural applications* during the period 1989–1995. Total grant amounted to about US$ 13,850.00. Supervisor for the project was Prof. O. C. Iloeje. The IFS/King Baudouin Price was awarded the candidate based on the excellent research reports submitted.

4. Principal Investigator (with Prof A. O. Odukwe), Grant No. RG MP 88-19 of the Third World Academy of Sciences (TWAS), Trieste, Italy for project entitled *Mathematical modelling and computer simulation of the thermal performance of buildings in tropical regions* during the period 1989–1994. Total grant amounted to US$ 2000.00

5. Principal Investigator, Grant Ref. No. NMC/MP/R.9 of 06 October 1998 of the National Mathematical Centre, Abuja, Nigeria, for a project entitled *Second law optimization of a solar heated poultry egg incubator with phase change material energy storage* during the period 1998–2000. Total grant amounted to about Nigerian N200,000.00 (about US$ 2000.00).

A.9 Professional societies

SAMUEL OGBONNA ENIBE is or has been a member of at least five professional societies. These are:

1. Member, International Solar Energy Society, since 1993
2. Member, Solar Energy Society of Nigeria, since 1989
3. Member, Nigerian Society of Engineers (NSE), since 1998
4. Member, African Technology Policy Studies Network (ATPS) since 1998
5. Member of the International Advisory Committee of the International Energy Foundation, Saskatchewan, Canada, since 1998

A.10 Publications

SAMUEL OGBONNA ENIBE has authored or co-authored at least 35 publications in various areas of Engineering. A good number of them have been published in international journals with high impact factors.

A.11 Conferences

SAMUEL OGBONNA ENIBE has attended several local and international conferences whre he presented scientific papers.

A.12 Christian Service

Prof. Samuel Ogbonna Enibe gave his life to Christ in the 1970s, and ever since then has remained a committed Christian. He would wish, like Paul in Acts of the Apostles , *that you become as I am*.

He has been privileged to serve the Christian Community in many different positions. Examples include:

1. Leader, Bulletin Group and Editor-in-Chief of Conqueror, the Christian Union, University of Nigeria, Nsukka, 1980-1981.

2. Coordinator, Nigerian Christian Corpers Fellowship (NCCF), Ondo State Chapter, 1982-1983.

3. .Scripture Union (Nigeria), Nsukka Area in many different positions. Some of these are

    (a) Bible Study Secretary, Odenigbo Group, 1984-1985.
    (b) Bible Study Secretary, Ugwuoye Group, 1987-1995.
    (c) Zonal Secretary, Nsukka Zones, 1995.
    (d) Zonal Secretary, Onuiyi Zone, 1997-2001.
    (e) Area Secretary, Nsukka Area, 2002-2008.
    (f) Church Relations Officer, Nsukka Area, since 2008.
    (g) Staff Adviser, Scripture Union Campus Fellowship (SUCF), UNN, since 2000.

4. Christ Church Chapel, University of Nigeria, Nsukka. Some of the capacities he has served include:

(a) Secretary, Couples Table, 2002-2007

(b) President, Christ Church Mens Association (CCMA), 2006-2008.

(c) Chairman, Chapel Council, since 2007.

A.13 Invitation

- The Vice-Chancellor and Chairman of the Occasion
- Deputy Vice-Chancellors
- Lions and Lionesses
- Distinguished Ladies and Gentlemen.
- With all due respect and honour, may I invite to serve as our 37th Inaugural Lecturer;
- This distinguished Mechanical Engineer;
- This devoted Lecturer;
- This Servant of God

PROFESSOR SAMUEL OGBONNA ENIBE