OBAFEMI AWOLOWO UNIVERSITY, ILE-IFE, NIGERIA.

INAUGURAL LECTURE SERIES 271

CREATIVITY AND INNOVATION : THE APPLICATIONS OF THERMODYNAMICS AND SYNTHESIS TECHNIQUES IN IMPROVING AND CREATING PROCESS INDUSTRIES

By

AMBROSE NWORA ANOZIE
Professor of Chemical Engineering

OBAFEMI AWOLOWO UNIVERSITY PRESS, ILE-IFE, NIGERIA.

AMBROSE NWORA ANOZIE
Professor of Chemical Engineering

CREATIVITY AND INNOVATION: THE APPLICATIONS OF THERMODYNAMICS AND SYNTHESIS TECHNIQUES IN IMPROVING AND CREATING PROCESS INDUSTRIES

An Inaugural Lecture Delivered at Oduduwa Hall,
Obafemi Awolowo University, Ile-Ife, Nigeria
On Tuesday, 10th February, 2015

By

AMBROSE NWORA ANOZIE
Professor of Chemical Engineering

Inaugural Lecture Series 271

OBAFEMI AWOLOWO UNIVERSITY PRESS, 2015

ISSN 0189-7848

Printed by

Obafemi Awolowo University Press Limited
Ile-Ife, Nigeria.

1. PREAMBLE

The Vice Chancellor Sir, Principal Officers of the University, Members of the University Council, Members of Senate, Provosts, Deans, Directors, Heads of Department, Invited Guests, Members of the Press, Distinguished ladies and Gentlemen, it is a pleasure for me to stand before you today with a feeling of fulfillment in life to deliver the 271st Inaugural Lecture of Obafemi Awolowo University, Ile-Ife, and the 4th inaugural lecture from the Department of Chemical Engineering. I give the glory to Almighty God who made this day possible in my life.

The Vice Chancellor Sir, permit me to recount a brief history of what influenced my choice of Chemical Engineering as a course of study in the University of Ife (now Obafemi Awolowo University) and my choice of Process Design as an area of specialization. As a young boy, I was very inquisitive about how the things I use and the things around me were made. Secondly, the subject I liked most in secondary school was Chemistry. I desired to be an engineer (I was performing well in both the physical and biological science subjects) and when I heard about Chemical Engineering, I said it must have a lot to do with Chemistry, and Chemical Engineering became my choice of course of study in the University. My passion for Process Design was ignited like fire during my undergraduate Industrial Training at the old Port-Harcourt Petroleum Refining Company, Eleme, Port-Harcourt. When I saw the high rising columns, the pumps, the heat exchangers, the tanks and the pipes, all connected together in a complex network (Plate 1), the interest and the passion to become a process design engineer was planted in my heart. I graduated with a First Class Honours degree in Chemical Engineering in 1975 and I was the best student in the Process Design Project.

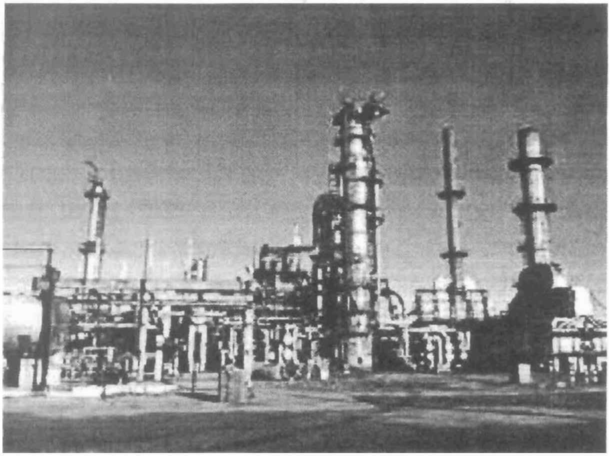


Plate 1: A typical crude oil distillation unit of a petroleum refinery

After graduation, one of my lecturers wanted to know what would be the area of my study for higher degrees. I told him that it was process design. My hope to specialize in process design was dimmed when he told me that process design was not a research subject. He went further to say that process design was more like an art where you use your own creativity and ingenuity to create a design. He spoke the truth because that was "the state of the art" in process design at that time in most parts of the world. But something happened in the world to make process design a research subject starting from the early 1970s. It was the Middle East war of 1967 that brought about the "energy crisis" of the early 1970s. The price of petroleum products shut up to the extent that the survival of process industries in Europe and America was threatened. It was then that the chemical and mechanical engineers in Industry and Academia in these nations began to ask the question "how can we design better processes to reduce the energy consumption in our process industries?" This sparked off research in process design in Industry and Academia in Europe and America. The research began in two directions, namely: thermodynamic or exergy analysis of processes and process synthesis or process integration. In my Master of Engineering studies at McGill University, Montreal, Canada, I acquired experience in mathematical modeling and computer simulation of chemical processes, which was very useful in my Doctor of Philosophy studies. My Doctor of Philosophy studies at University of Strathclyde, Glasgow, Scotland, was on thermodynamic analysis of chemical processes. I thank God who helped me realize my ambition in life.

Even though my Ph.D. research was on thermodynamic analysis of chemical processes, I had to acquire knowledge of process synthesis to enable me carry out research in process synthesis and thereby become a complete and modern process design engineer. The title of my inaugural lecture is: "Creativity and innovation: The applications of thermodynamics and synthesis techniques in improving and creating process industries." In this lecture, I will present the following: the components of process design, my contribution to knowledge in process design research, a novel method of integration of resources of a nation for the creation of manufacturing industries in Nigeria, highlights of my contribution, conclusions and recommendations, and finally my expression of gratitude and thanks.

2. INTRODUCTION

Various attempts have been made to define or explain the meaning of creativity and innovation. Creativity can be defined as the capability or act of conceiving a new idea and innovation as the implementation of the new idea. Creativity and innovation concern the process of creating and applying new knowledge (Gurteen, 1998). Creativity and innovation are necessary for bringing forth the change required to obtain the competitive advantage.

The design of process industries requires skills in process analysis and process synthesis or process integration. What is analysis? From Oxford Advanced Learner's Dictionary (Hornby, 2001) analysis is defined as "the detailed study or examination of something in order to understand more about it." Analysis deals with the understanding of how things are and how they work. What is integration? Again from Oxford Advanced Learner's Dictionary, integration is defined as "the act or process of combining two or more things so that they work together." Integration deals with the creation of artificial things that have desired properties. Civilized man relies ever increasingly on the artificial. Structures, clothing, tools, foods, medicines, methods of transportation and other artificial things are of man's creation. Raw materials intentionally are transformed to possess more useful or desirable properties to form the variety of things seen around us, such as: paper, rubber, petroleum products, glass, metals, paints, drinking water and electricity (Rudd *et al.*, 1973).

Historically and traditionally it has been the task of the science disciplines to teach about natural things, how they are and how they work. It has been the task of the engineering disciplines to teach about artificial things, how to make artificial things that have the desired properties and how to design. Of course, every person who devises courses of action aimed at changing existing situations into preferred ones can be said to be a designer. But the truth is that process network design in process engineering is so complex that it cannot be designed efficiently by someone who has not been trained to acquire the knowledge and the skills in process analysis and process integration.

Chemical Engineering education began with a strong leaning towards analysis or engineering science, with the development of courses dealing with individual process operations and phenomena. Transport phenomena, unit operations, process control, reaction engineering, thermodynamics and other engineering science courses greatly strengthened chemical engineering education by showing how things are and how they work. Unfortunately, there was not a parallel development of courses dealing with integration – the combining of diverse concepts into a coherent whole to form a process industry. At the early beginning, the design of process industries was dependent more on the creative ability and ingenuity of the designers, and most of these old designs have been found to be highly inefficient in energy and material usage.

It was in the early 1970s, as a result of the "energy crisis" that followed the Middle East war of 1967 that major advances in creativity and innovation came into process engineering design. Research and development of courses in process integration in chemical engineering education began at that time. The advances in process integration from that time have been rapid leading to new concepts in process integration such as pinch technology method in arriving at the final process network (Linnhoff and Turner, 1981). By means of these new concepts it is now possible to design more efficient process industries in terms of energy savings; capital and operating costs and emissions reduction; control, safety and reliability (Linnhoff, 1994). In the design of process industries, analysis and synthesis drive creativity leading to efficient designs (Kryssanov *et al.*, 2001). The best process design is arrived at by the application of integration method at the beginning of the design. However, process integration method can be used to re-design an existing process designed by the traditional design method to improve its performance.

Material and energy balances have always been essential aspects of the traditional chemical engineering approach to process design, development and operations. However, the growing importance of the efficient use of energy led to the development of analytical techniques which can help engineers develop more energy-efficient designs and processes. One such class of analytical techniques which was developed is called exergy analysis or second-law analysis. The exergy function was considered in 1878 by Gibbs (Gibbs, 1928), and was further developed by Keenan (Keenan, 1941) and applied by Denbigh to a chemical process (Denbigh, 1956). Although the exergy concept has been known for some time, its application to chemical processes was not common in Europe and America until the beginning of the "energy crisis" of the 1970s. Even now in Nigeria, the application of exergy analysis to process improvement and design is not common both in academia and industry.

3. CONTRIBUTION TO KNOWLEDGE

3.1 Exergy analysis studies

The thermodynamic property exergy, *Ex*, is derived from a combination of the first and second laws of thermodynamics. The exergy of a system can be defined as the work associated with a completely reversible system in bringing the system to equilibrium at the temperature and pressure of the environment (Gaggioli, 1961). Sometimes definitions for exergy may include the chemical exergy of extraction of the pure materials from environmental precursors. Exergy has the same physical dimensions as energy. The change in exergy of a reversible system is defined as:

$$W_{s,rev} = \Delta Ex = \Delta H - T_o \Delta S \qquad (1)$$

where $W_{s,rev}$ is the reversible shaft work, ΔEx is the change in exergy of the system, ΔH is the change in enthalpy of the system, ΔS the change in entropy of the system and T_o is the temperature of the environment.

Gibbs free energy function is closely related to exergy but not identical with it. A change in Gibbs free energy function, ΔG, is defined as (Smith and van Ness, 1975):

$$\Delta G = \Delta H - \Delta(TS) \qquad (2)$$

Under the special circumstances of an isothermal (constant temperature) process we have:

$$\Delta G_T = \Delta H - T\Delta S \qquad (3)$$

If in addition, the condition is such that the isotherm is at T_o, then we have:

$$\Delta G_{T_o} = \Delta H - T_o \Delta S = \Delta Ex \qquad (4)$$

This means that the Gibbs free energy change is equal to the exergy change only for an isothermal process at T_o. The Gibbs free energy change is a measure of work extractable from an isothermal change of state. The exergy change by contrast is completely general; it measures the work extractable from any change of state (Sussman, 1980; Wilkie, 1973).

Real processes are not completely reversible, and they involve some degree of irreversibility. Exergy analysis provides a means of identifying and quantifying the thermodynamic irreversibilities in processes. For a work requiring process a simple exergy balance can be written as:

$$W_s = \Delta Ex + I \tag{5}$$

where W_s is the actual work requirement and I is the irreversibility of the process. Exergy is a potential, it drives processes and in so doing it is used up or consumed (Reistad, 1975; Gaggioli and Petit, 1977). It is useful to distinguish two types of irreversibility that occur in processes, namely: the inherent or unavoidable irreversibility and the non-inherent or avoidable irreversibility. The inherent irreversibility depends largely on the process route and the chemical efficiency of the reactions. The non-inherent irreversibility depends largely on the process design and can be reduced by improvements in process design and operation. From a thermodynamic viewpoint, it is desirable to design processes with as little non-inherent or avoidable irreversibility as possible (Denbigh, 1956). To achieve this it is necessary that exergy analysis methodology be readily available to the process design engineer in flow sheet simulation environment.

Exergy analysis gives insight into the nature and causes of irreversibilities in processes and how they can be minimized. The first-law energy balance does not account for the thermodynamic irreversibilities in processes and does not indicate how they can be reduced. Exergy analysis also provides a means of quantifying the second-law efficiency of processes. The second-law efficiency gives the true thermodynamic performance of the system and its maximum value is never greater than 100%. This is because it is defined with reference to the limitation imposed by the second-law of thermodynamics. On the other hand, the maximum value of the first-law efficiency is defined without reference to the limitation imposed by the second-law of thermodynamics and the value may be less than, greater than or equal to 100%. When the value of the first-law efficiency is greater than 100%, it is called the coefficient of performance (COP) as is done for the heat pump.

3.1.1 Definition of overall second-law efficiency of chemical processes

Various definitions have been put forward in the literature for the evaluation of overall second-law efficiency of chemical processes. Some of the well known definitions are those given by Riekert (1974), Reistad (1975) and Denbigh (1956). Anozie and Grant (1993) developed a new definition of the overall second-law efficiency of chemical processes from the exergy balance and the concept of net primary exergy. The actual work required or produced by a process is equivalent to the net primary exergy required or produced by the process. The general overall second-law efficiency of a work requiring process was derived as:

$$\Psi = \Delta Ex_{process} / \Delta Ex_{primary} \quad (6)$$

and the general overall second law efficiency of a work producing process was derived as:

$$\Psi = \Delta Ex_{primary} / \Delta Ex_{process} \quad (7)$$

The primary exergy is usually in the form of work (electrical, mechanical) and heat exergy (steam) and the process exergy is in the form of material exergy and chemical reaction exergy.

The overall second-law efficiency of a nitric acid plant, a work producing process, was evaluated at two plant throughputs using the efficiency definitions of Riekert (1974), Gaggioli and Petit (1977), Reistad (1975), Denbigh (1956), and Anozie and Grant (1993) and the results are summarized in Table 1.

Table 1: Overall second-law efficiency results for the nitric acid plant

Definition	*Overall second-law efficiency, %*	
	105% design capacity	*70% design capacity*
Riekert (1974)	41.88	43.58
Gaggioli and Petit (1977)	30.08	32.16
Reistad (1975)	17.15	6.51
Denbigh (1956)	17.15	6.51
Anozie and Grant (1993)	17.15	6.51

The values of the overall second-law efficiency obtained using the definitions of Riekert (1974), and Gaggioli and Petit (1977), show that the plant is more efficient at the lower throughput than at the higher throughput. This is in disagreement with real world practice and suggests that these definitions are not meaningful. The values of the overall second-law efficiency obtained using the definitions of Reistad (1975), Denbigh (1956), and Anozie and Grant (1993), are the same and the values at the higher throughput are greater than the values at the lower throughput which is in agreement with real world practice.

3.1.2 Development of thermodynamic diagram called stage-exergy rate diagram

Exergy analysis of distillation processes has been reported by several workers using different thermodynamic diagrams. The Carnot factor-specific enthalpy diagram was used by Le Goff *et al.* (1996) to show the heat and mass transfer effects in distillation of ammonia-water mixture. Column grand composite curves and stage-exergy loss profiles have been used in exergy analysis of distillation systems in design and retrofit studies (Dhole and Linnhoff, 1993; Demirel, 2006). The stage-exergy rate diagram for determining feasible distillation column operation was developed in our research group. It was applied in the analysis of binary distillation process of benzene-toluene and methanol-water mixtures (Anozie *et al.*, 2009A). The stage-exergy rate diagram for the base case of distillation of benzene-toluene mixture is shown in Figure 1.

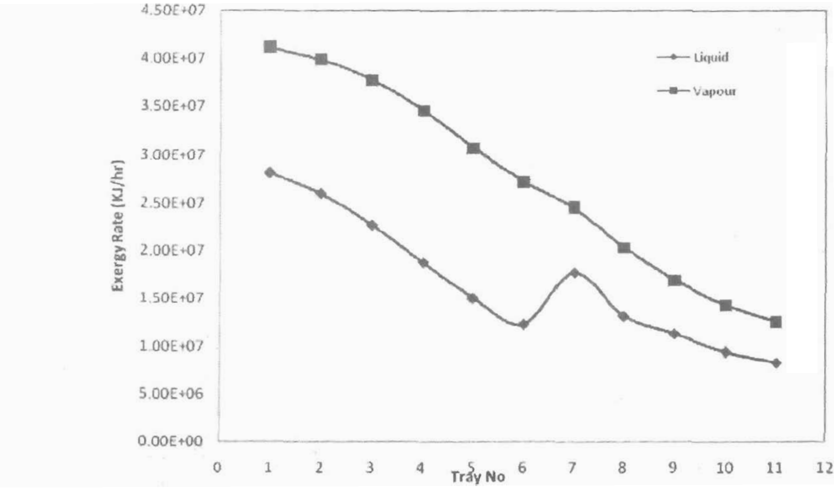


Figure 1: Stage-exergy rate diagram (base case) for benzene-toluene mixture (feed at 95°C, 350 kmol/hr; column pressure at 1 atmosphere)

The difference in exergy rates between the vapour and liquid profiles indicate the exergetic driving forces between the vapour and liquid phases from the top to the bottom of the distillation column. It is required that the profiles do not cross each other, as that would amount to reversal of driving forces. It is also required that driving forces are fairly well distributed in process equipment and are not constricted at some points or sections in the equipment. The stage-exergy rate profiles were used to distinguish feasible, infeasible and undesirable process operating conditions in the distillation column. The base case in Figure 1 shows a feasible operation. Another set of operating conditions were used to generate the profiles in Figure 2. Figure 2 shows that the profiles are crossing each other indicating infeasible operating conditions in the column. The summary of the sensitivity analysis for benzene-toluene distillation operations is shown in Table 2.

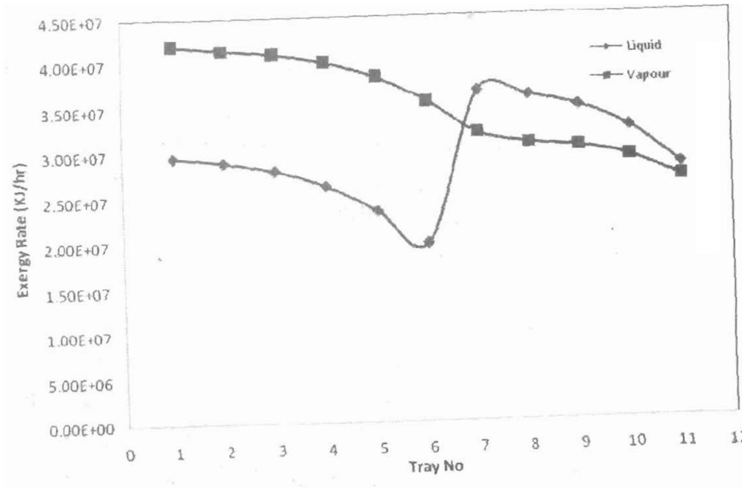


Figure 2: Profiles of exergy rate versus tray number in benzene-toluene distillation column (feed flow rate: 650 kmol/hr)

Table 2: Summary of sensitivity analysis for benzene-toluene distillation column

System conditions	*Profiles of stage-exergy rate diagram*	*Exergy efficiency (%)*	*Energy efficiency (%)*
Base case	Feasible	66.86	100.0
Pressure = 1.5 atm	Feasible	68.95	100.0
Pressure = 2.0 atm	Feasible	69.37	100.0
Temperature = 86°C	Feasible	67.11	100.0
Temperature = 102°C	Constricted	74.89	100.0
Temperature = 105°C	Constricted	74.95	100.0
Feed flowrate = 650 kmol/hr	Not feasible	80.04	100.0
Feed flowrate = 260 kmol/hr	Feasible	62.63	100.0

It is observed from Table 2 that the exergy efficiency values obtained for all the operating conditions investigated appeared meaningful, but the stage-exergy rate diagrams indicated some operating conditions that are not feasible or constricted. It shows that the second-law efficiency calculations in distillation operations must be complemented with the stage-exergy rate diagrams during process analysis.

The stage-exergy rate diagram has also been applied to multi-component distillation of crude distillation unit (CDU) of Warri refinery (Osuolale, 2010) as shown in Figure 3. In Figure 3, a crossing of the profiles was noticed. A marked difference was noticed on the 6th stage which is the feed stage of the column. This is indicating that the feed condition is not adequate enough. Exergy rate profiles make it easy to see a feed which is excessively heated or sub-cooled so that condenser or reboiler heat loads can be minimized. This is in line with the work of Dhole and Linnhoff (1993) in the use of column grand composite curve for column modifications. Attempts were made to remove the crossing of the profiles by altering the feed conditions and the stripping steam and the result is shown in Figure 4.

3.1.3 Development of methods in carrying out exergy analysis of processes

The method of exergy analysis of processes began with the method of lost work which involves calculating the entropy of streams and the lost work (irreversibilities) of the units in the process (Smith and Van Ness, 1975). The method of exergy of streams involves calculating the exergy of all the streams in a process. The method of evaluating the exergy of streams has an advantage over the method of lost work in that the exergy of material streams can be combined with other types of process exergies like heat, work, electricity and chemical reaction (Grant and, Anozie, 1985). Therefore, process networks can be analyzed and compared in a consistent way. Moreover, the method of lost work gives only the overall second-law efficiency of the process whereas the method of exergy of streams gives both the overall second-law efficiency of the process and the second-law efficiencies of units.

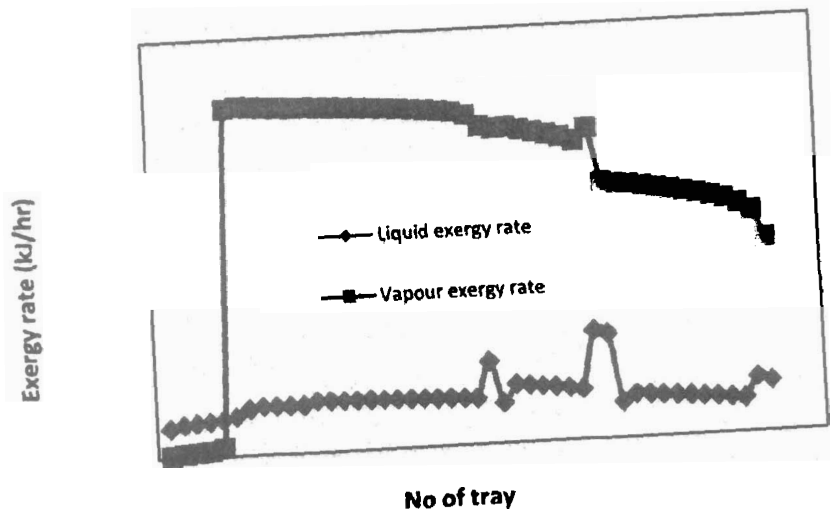


Figure 3: Exergy rate profile for CDU of Warri Refinery (Base Case) (Osuolale, 2010)

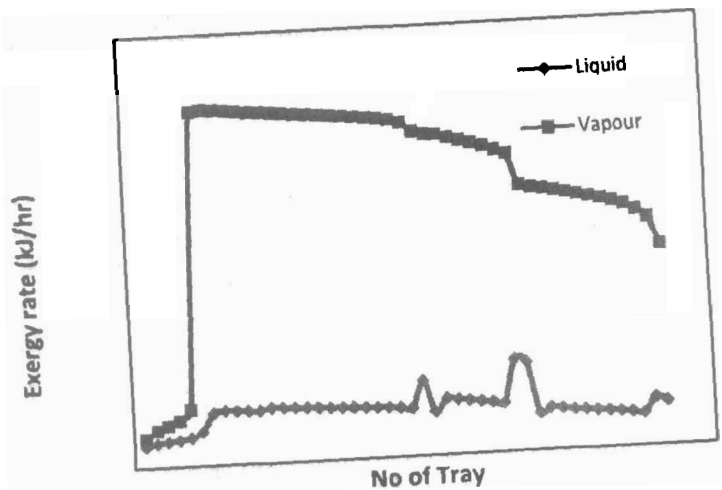


Figure 4: Exergy rate profile for CDU of Warri Refinery (Crossing removed) (Osuolale, 2010)

Sometimes the specific thermodynamic properties of streams can be negative. This creates a lot of difficulty in trying to interpret the results of exergy analysis of processes. To overcome this problem, the property shifting method was introduced. This methodology involves addition of a positive value that is greater than the most negative value to both vapour and liquid phase properties. The method was first introduced in exergy analysis of binary plate distillation column operations (Anozie *et al.*, 2009A). Shifting of negative thermodynamic properties in distillation operations removes the distortion in the trend of liquid and vapour stage-exergy rate profiles. The property shifting method has also been used in exergy analysis of Linde methane liquefaction process (Anozie *et al.*, 2014) and propane mixed refrigerant process scheme in liquefied natural gas plant (Anozie and Alamu, 2009).

3.1.4 Applications of exergy analysis to processes

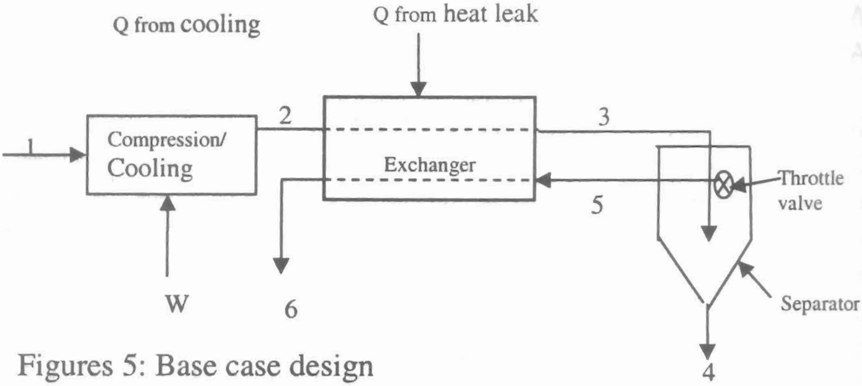
Quantification of process efficiencies and irreversibilities

Exergy analysis affords a means of quantifying the second-law efficiencies and thermodynamic irreversibilities in processes, sub-processes and units. The results of the analysis are used to identify areas of large thermodynamic inefficiency where process improvements can be made. However, the question is still asked whether all the areas of process improvement which were identified with exergy analysis could not also have been identified from heat and mass balances alone. The answer to this is that there is increasing evidence that all the opportunities for improvement within the process boundaries with the view of reducing the primary energy requirements in several ways may not be identified with the first-law energy balance. The insight provided by exergy analysis often proves very useful and leads to process improvement (Anozie, 1994). Proper energy management makes it necessary to account for the quality (exergy) as well as the quantity (heat) of energy used. This means that traditional first-law heat and mass balances must be supplemented by second-law exergy balance. We have reported exergy analysis of the following processes: thermal power plant (Anozie *et al.*, 2009B; Osuolale *et al.* 2009; Ayoola and Anozie, 2012); liquefied natural gas plant

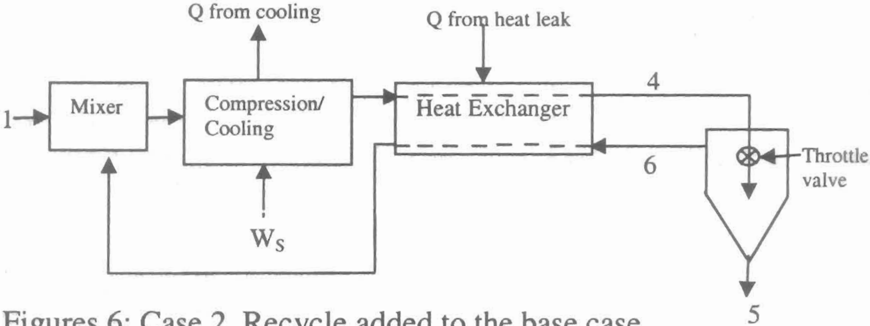
(Anozie and Alamu, 2009) and Linde methane liquefaction plant (Anozie *et al.*, 2014).

Evaluation of different design configurations

Exergy analysis can be used for comparison and selection of design alternatives. This is particularly important at the process development stage in process design. Analysis and comparison of the conventional fractionation and vapour recompression schemes for separating a propane-butane mixture has been reported (Vruggink and Collins, 1982). Anozie *et al.* (2014) compared four different designs of a cryogenic process (Linde methane liquefaction) using exergy and process economic analyses. The four designs are shown in Figures 5, 6, 7 and 8. The exergy efficiency for the base case (case 1) was 5.2%. Case 2 was obtained when a recycle was added to the base case and the exergy efficiency was 5.3%. Case 3 was obtained when a recycle and a turbine were added to the base case and the exergy efficiency was 28.7%. Case 4 was obtained when a recycle was added and the valve was replaced with a turbine in the base case and the design gave an exergy efficiency of 39.5%. Process economic analysis based on 1 kg/h throughput showed that Cases 2 and 4 have highest venture profits, very close values with negligible difference, followed by Case 3 and finally Case 1 having the lowest venture profit. Since it is known that throughput has effect on venture profit, it was concluded that case 4 with the highest exergetic efficiency would have the best venture profit at higher throughput. This will be investigated in further studies at higher throughput. Also exergy analysis has been used to study three process schemes for the propane mixed refrigerant (C3MR) natural gas liquefaction technology (Anozie and Alamu, 2010).



Figures 5: Base case design



Figures 6: Case 2. Recycle added to the base case

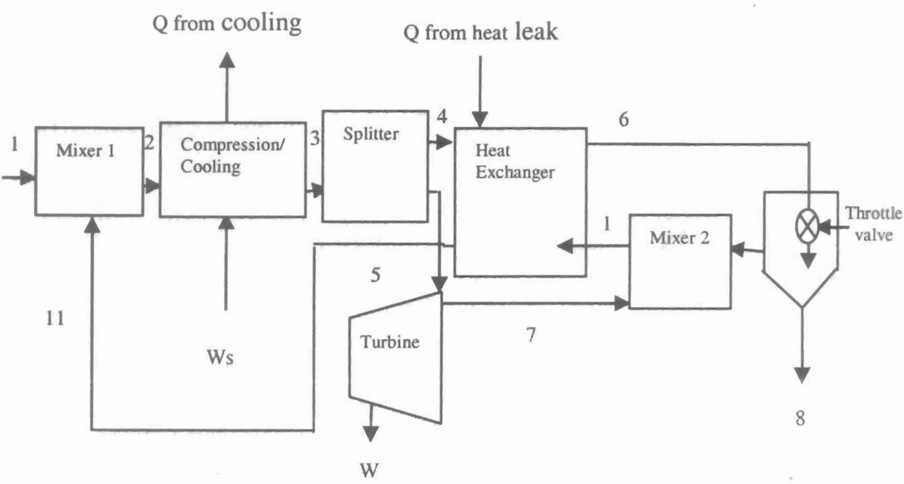


Figure 7: Case 3. Recycle and turbine added to the base case

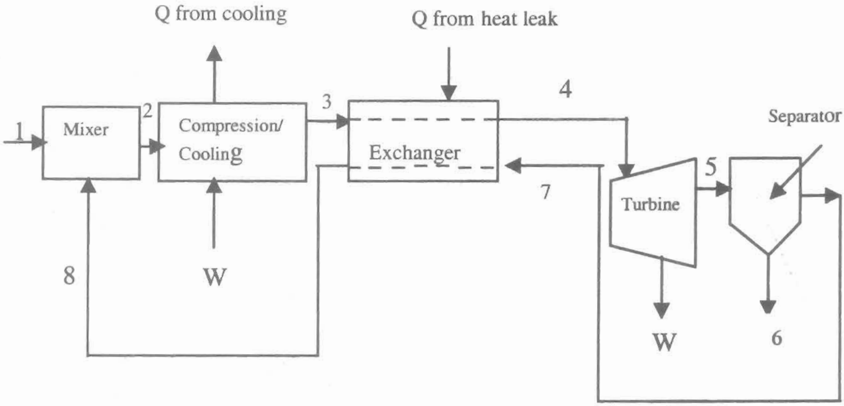


Figure 8: Case 4. Recycle added and throttle valve replaced with turbine

Optimization of binary plate distillation column design using stage-exergy rate profiles

Exergy analysis has been used in distillation design to optimize feed conditions and reflux ratio, number of trays, diameter and length of column (Maia and Zemp, 2000; Lynd and Grethlein, 1986). In distillation column design, the reflux ratio is a design parameter since it influences the number of trays. A method for determining suitable reflux ratios with the corresponding minimum number of trays for binary plate distillations using stage-exergy rate profiles has been reported (Anozie *et al.,* 2010A). The reflux ratios were varied and only reflux ratios that gave feasible stage-exergy rate profiles were selected for further analysis using second-law efficiency and irreversibility rate as criteria for judgment. The benzene-toluene and ethanol-water mixture were used for the study. The exergy analysis results were compared with the base case. The results for the methanol-water mixture are presented in Table 3.

Table 3: Variation of reflux ratio with number of trays and exergetic parameters for optimization of methanol-water system

S/N	*Reflux Ratio*	*No. of Trays*	*Stage-Exergy Rate Profile*	*2^{nd} Law Efficiency, ψ (%)*	*Irreversibility Rate, $I.10^{-6}$ (kJ/hr)*
1	0.9	9	Constricted	26.4	2.53
2	0.96	9	Constricted	28.6	2.31
3	1.029^{+}	8	Feasible	26.1	2.61
4	1.079^{*}	7	Feasible	28.0	2.26
5	1.2	7	Feasible	27.1	2.47
6	1.5	6	Feasible	21.2	3.29
7	2.0	6	Feasible	20.2	3.79
8	2.5	5	Large Driving Force	21.8	3.58
9	3.0	5	Large Driving Force	25.5	3.84

$^{+}$Base case design reflux ratio
*Optimum exergetic reflux ratio

Table 3 shows variation of reflux ratio with number of trays and exergetic parameters namely: stage-exergy rate profile, second law efficiency and irreversibility rate for methanol-water system. The use of stage-exergy rate profiles narrowed the search region. Only the feasible profiles were then subjected to further analysis using the second-law efficiency and irreversibility rate as criteria for judgment. For the feasible profiles, the highest second law efficiency of 28% and the lowest irreversibility rate of 2.26×10^6 kJ/hr were obtained at exergetic optimum reflux ratio of 1.079 with 7 trays. If second law-efficiency alone had been used, it would have led to a wrong reflux ratio of 0.96 with second law efficiency of 28.6% but with constricted profile in the column as the optimum.

Optimization of operating variables in processes using response surface methodology

Little work has been done in the use of exergetic parameters for optimizing the operation of chemical plants. This is partly due to the difficulty encountered in carrying out process simulation and exergy analysis. Process simulation, exergy analysis and statistical optimization can be used to determine the optimum operating variables in complex chemical processes. Statistical optimization can be grouped under search techniques and is suitable for complex, multivariable, non-linear problems (Beveridge and Schechter, 1970). The operating conditions of a nitric acid plant, a complex chemical plant, have been optimized for improved energy conservation measures (Anozie, 1997B). An exergy objective criterion, the maximization of the net primary exergy recovery, and an economic objective criterion, the minimization of the plant operating cost, were used separately in the optimization study. It was decided to optimize the plant at the lower throughput, the 70% design throughput, because the need for energy conservation at lower throughput is greatest (Grant, 1979). The limits of the three operating variables chosen for optimization were set by practical plant constraints and the variables were: ammonia/air ratio to reactor, the total flow to compressor, and the absorber pressure ratio. Statistical design of experiments was used to produce response surface models for the two objective criteria which were used for optimization. The results of the optimization are shown in Table 4.

Table 4: Base case and Optimization Results for Nitric Acid Plant

	Base Case	$Y_{1,opt}$ *(Exergy)*	$Y_{2,opt}$ *(Op. Cost)*
NH_3/Air Ratio, X_1	0.1263	0.1263	0.1263
Total flow to compressor, lb moles/hr., X_2	5679.46	5679.46	5679.46
Absorber pressure ratio, X_3	0.8172	0.7258	0.7641
Net primary exergy recovery, Btu/lb-acid	106.79	125.37	115.19
Operating cost, £/tone-acid	137.77	137.26	136.71

From the results in Table 4, it is seen that at the optimum net primary exergy recovery settings and at the optimum operating cost settings the plant shows an increase in net primary exergy recovery. Also at the optimum settings for net primary exergy recovery and operating cost, the plant shows a decrease in operating cost. The two results are meaningful and in agreement, that is, an increase in efficiency corresponds with a decrease in operating cost. However, the net primary exergy recovery is seen to be a more sensitive objective criterion than the operating cost. Also optimization of operating variables in binary plate distillation column by response surface methodology has been carried out and reported (Anozie *et. al.*, 2010B).

Investigative studies in exergy analysis

Investigative studies have been carried out to determine how some thermodynamic and process parameters affect exergy analysis results of processes. One of such thermodynamic parameters is chemical exergy. Opinion is divided about the usefulness of inclusion of chemical exergy (from compositional equilibrium with the environment) in the exergy analysis of processes. One school of thought maintains that for continuous flow processes, it suffices to define the reference environment with respect to only temperature and pressure and to treat any chemical reaction occurring within the system as is normally done for heat or work crossing the system boundary (Sussman, 1980). This school of thought asserts that chemical exergy has some significance only for closed systems and not for continuous flow processes. The second school of thought maintains that chemical equilibrium with the environment should be included in the basic definition of exergy, and in this way it is hoped to account for the chemical reactions accompanying energy conversions (Riekert, 1977; Gaggioli and Petit, 1977). The contribution of chemical exergy in exergy analysis of a crude oil distillation unit has been found to be negligible (Anozie and Osuolale, 2010).

The influence of reference temperature on exergetic and exergoeconomic parameters has been found to be quite significant

(Odejobi and Anozie, 2013). This implies that care should be taken when specifying the reference temperature in exergy analysis studies and when comparing results from different workers which are based on different reference temperatures.

The influence of throughput on exergetic parameters of processes has been found to vary from process to process. Throughput was found to have effect on second-law efficiency of a nitric acid plant (Anozie and Grant, 1993). Throughput was found not to significantly influence the exegetic efficiency of a thermal power plant (Anozie and Ayoola, 2012).

3.2 Process integration studies

Since the energy crisis of the 1970s much attention has been directed at better process design in the area of process network design or process synthesis or process integration. A process integration method, based on thermodynamic principles and graph theory, called the pinch design method (pinch technology) was developed in the late 1970s. The success of the pinch design method was due to the discovery of the heat recovery pinch phenomenon (Linnhoff and Flower, 1978). The heat recovery pinch is illustrated in Figure 9 below. The point where the hot composite curve and the cold composite curve approach most closely is the pinch point (Linnhoff and Flower, 1978; Linnhoff *et al.*,1983). The overlap between the composite curves represents the maximum amounts of heat recovery possible within the process. The overshoot of the cold composite curve represents the amount of minimum external heating required and the overshoot of the hot composite curve represents the minimum amount of external cooling required. Another important feature of pinch technology is the introduction of grid diagram for representation of heat exchanger networks rather than the network representation. The grid representation of a heat exchanger network is shown in Figure 10 below.

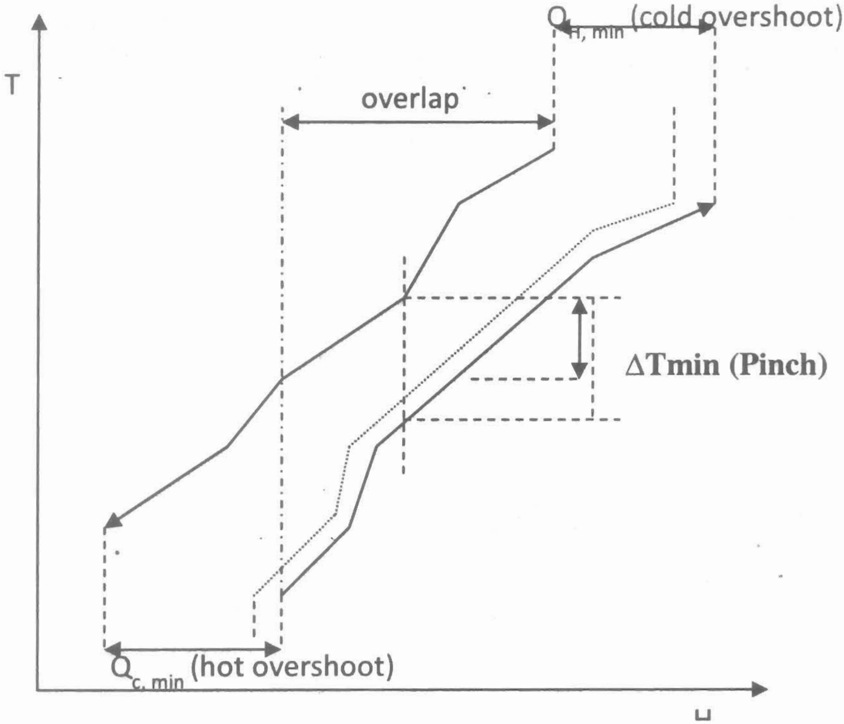


Figure 9: Representation of Heat Recovery Pinch

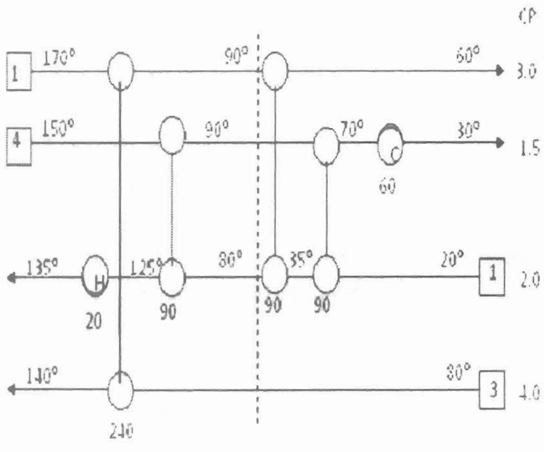


Figure10: Grid Representation of Heat Exchanger Network

For maximum energy recovery design, the pinch principles require that there should be no energy transfer across the pinch. But maximum energy recovery design usually requires many heat exchangers, that is, high capital cost. In practice a trade-off between energy cost and capital cost is made. Pinch technology determines the absolute minimum energy requirement of a plant for a specified minimum temperature of approach. Using thermodynamic principles, pinch technology shows how heat can be recovered between areas of heat surplus and heat demand in a plant. It has been reported that energy cost savings of 50% in new designs and six months payback in retrofits were obtained from the application of pinch technology techniques (Linnhoff and Vredeveld, 1984).

3.2.1 Evaluation of design of crude distillation units of Nigerian oil refineries

Refineries designed and installed before 1980 did not enjoy the benefit of insights from pinch technology (Dorgan *et al.*, 2003). By late 1980s all the refineries in Europe and America had been retrofitted using pinch design methods. All the four refineries in Nigeria belong to the old refineries that were not designed by pinch technology methods. The designs and energy efficiencies of the heat exchanger networks (HENs) in the crude distillation units (CDUs) of the four refineries in the country have been evaluated and reported (Anozie and Odejobi, 2009). The four refineries are the New Port-Harcourt refinery, the Kaduna refinery, the Warri refinery and the Old Port-Harcourt refinery. The grid representation of heat exchangers in the crude distillation units of the four refineries are shown in Figures 11, 12, 13, and 14 for the New Port-Harcourt, Kaduna, Warri and Old Port-Harcourt refineries, respectively. It is seen that there are heat exchangers working across the pinch in all the CDUs. The pinch design method states that there must be no heat transfer across the pinch. The heat exchangers crossing the pinch are the "culprit" heat exchangers that have broken the pinch rule of no heat transfer across the pinch. Any heat transfer across the pinch is excess heat which is wasted. The energy efficiency of a heat exchanger network may be evaluated by the equation (Anozie and Ojoboh-Daniel, 2006):

$$\eta = Q_{H,\min} / Q_{H,operating} \quad (8)$$

where $Q_{H,min}$ is the minimum energy required by the network and $Q_{H,operating}$ is the actual operating heat load. Results of energy efficiencies of the CDUs of the four refineries in Nigeria are shown in Table 5. It was observed that the crude unit of the old Port-Harcourt refinery is the most inefficient in energy consumption. It is the oldest of all the refineries. It was designed at a time when energy was very cheap and process designers paid little attention to energy efficient designs. The second generation refineries are the Warri and Kaduna refineries and the energy efficiencies of their crude units are very close to each other and higher than that of the Old Port-Harcourt refinery. The CDU of the New Port-Harcourt refinery, the third generation refinery, has the highest energy efficiency compared to the other three refineries. The results of the analysis are in agreement with the historical facts that are available.

Table 5: Energy efficiencies of HEN in CDU of Nigerian refineries

Refinery	$Q_{H,min}$ *(MW)*	$Q_{H,operating}$	*Energy Efficiency (%)*
New Port-Harcourt	89.80	98.94	90.8
Kaduna	25.83	32.84	78.7
Warri	72.52	87.50	82.9
Old Port-Harcourt	51.61	97.05	53.2

3.2.2 Retrofitting of CDUs of Nigerian refineries

The retrofit of the crude distillation units of the four Nigerian refineries has been carried out. The heat exchangers working across the pinch are eliminated or properly placed and reused as the case may be. New exchangers are positioned where required and where possible exchangers removed in the previous step are reused. The retrofitted network of the Kaduna refinery (Odejobi and Anozie, 2007) is shown in Figure 15.

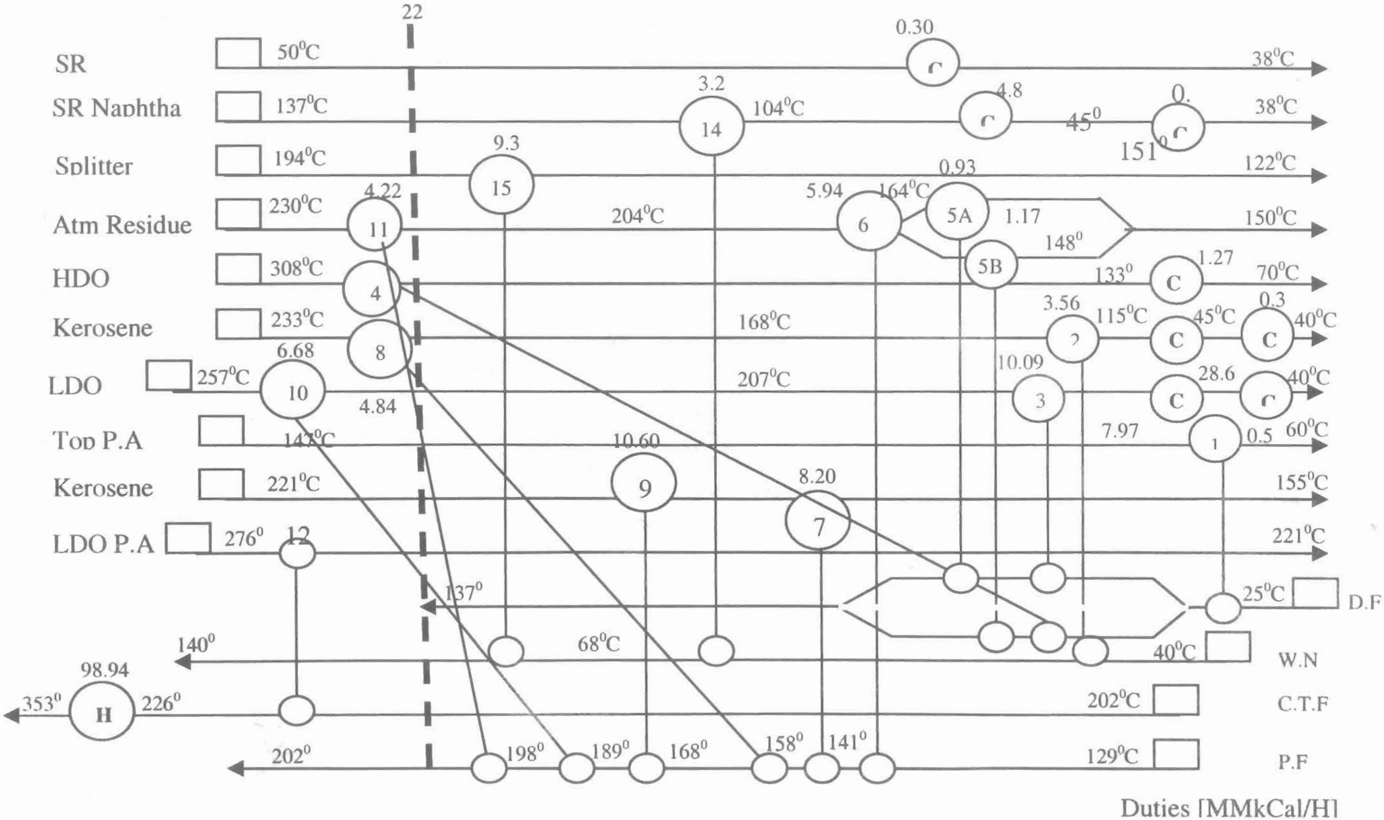


Fig. 11: Grid representation of HEN in the CDU of New Port-Harcourt Refinery Showing Heat Exchangers Working across the Pinch.

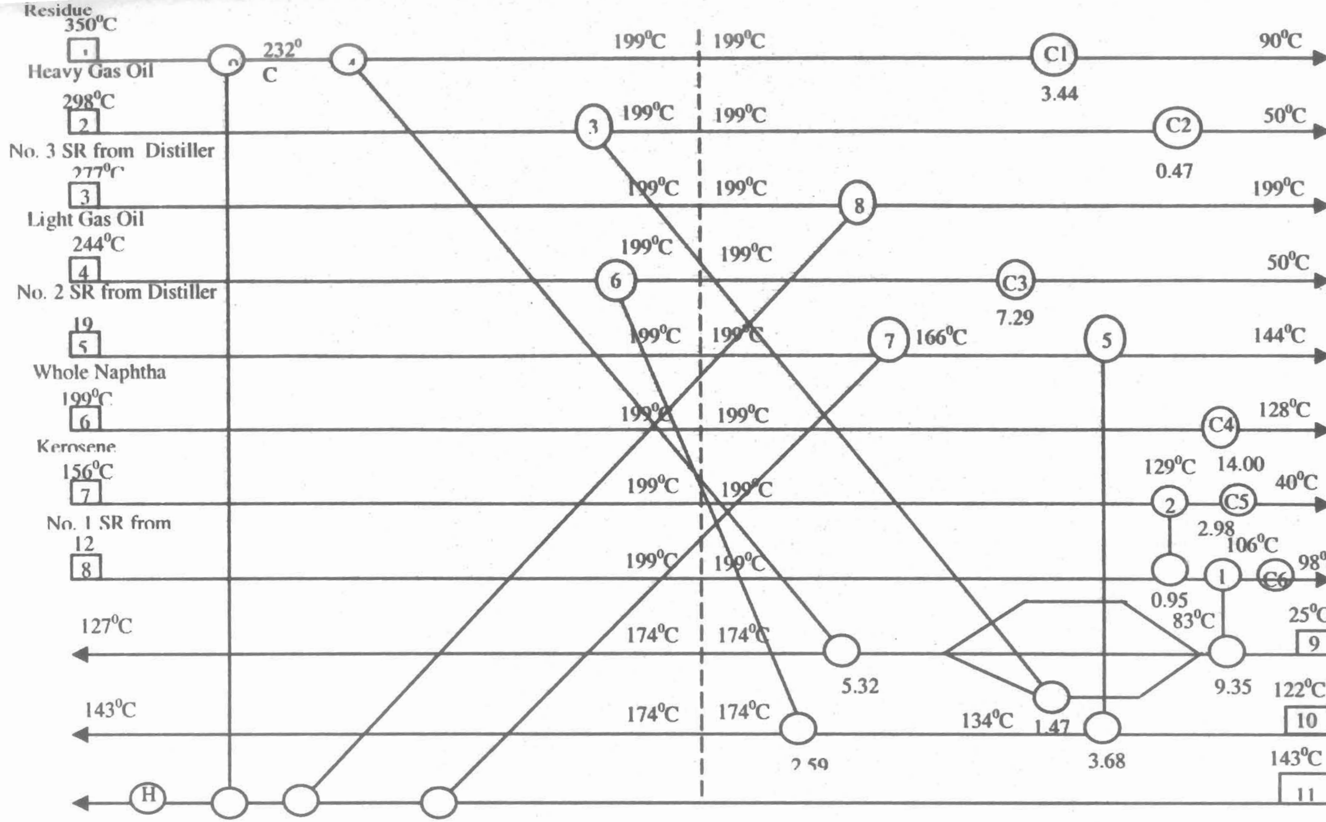


Fig 12: Grid representation of HEN in the CDU of Kaduna Refinery Showing Heat Exchangers Working across the Pinch.

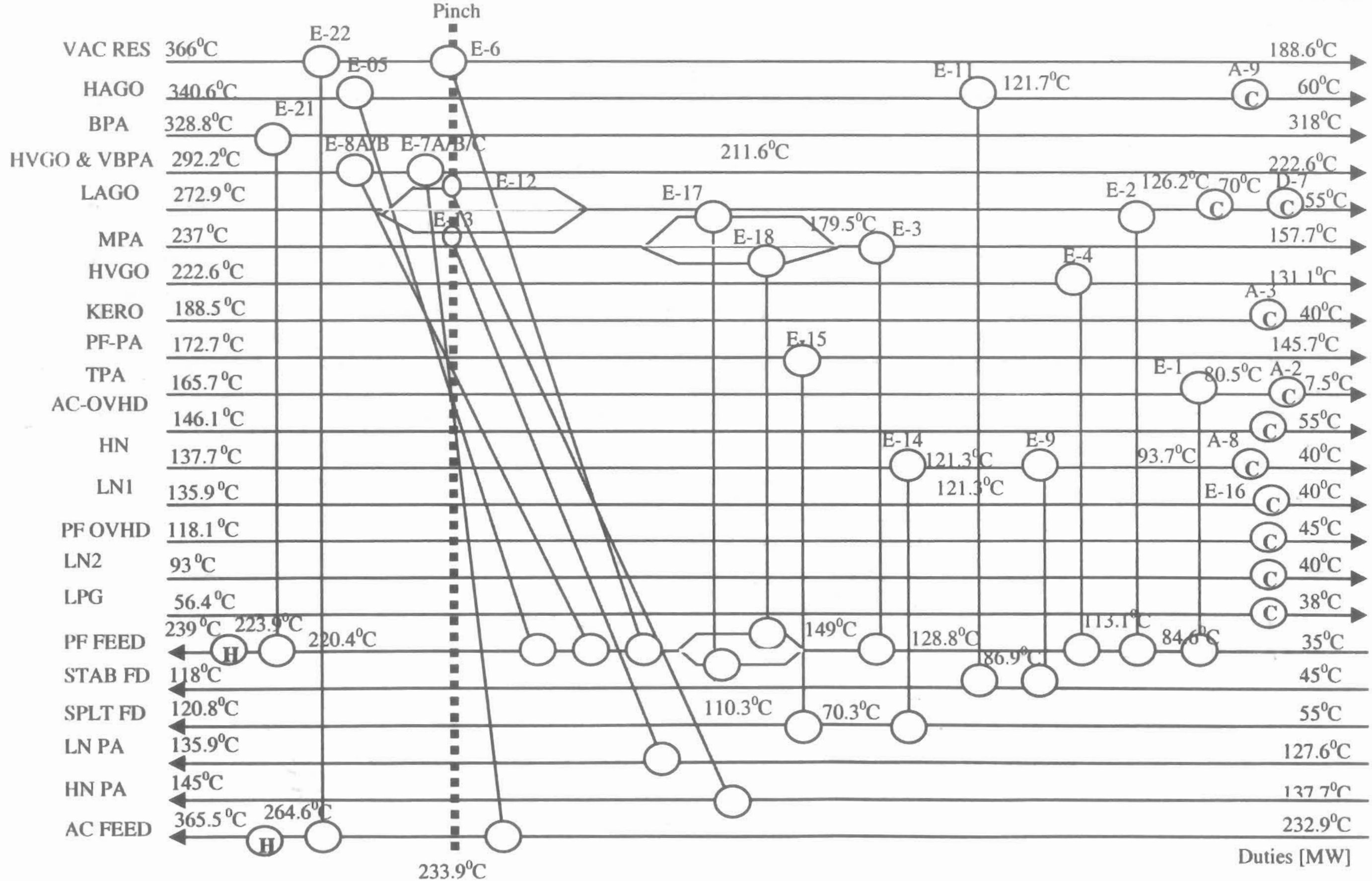


Fig 13: Grid representation of HEN in the CDU of Warri Refinery Showing Heat Exchangers Working across the Pinch.

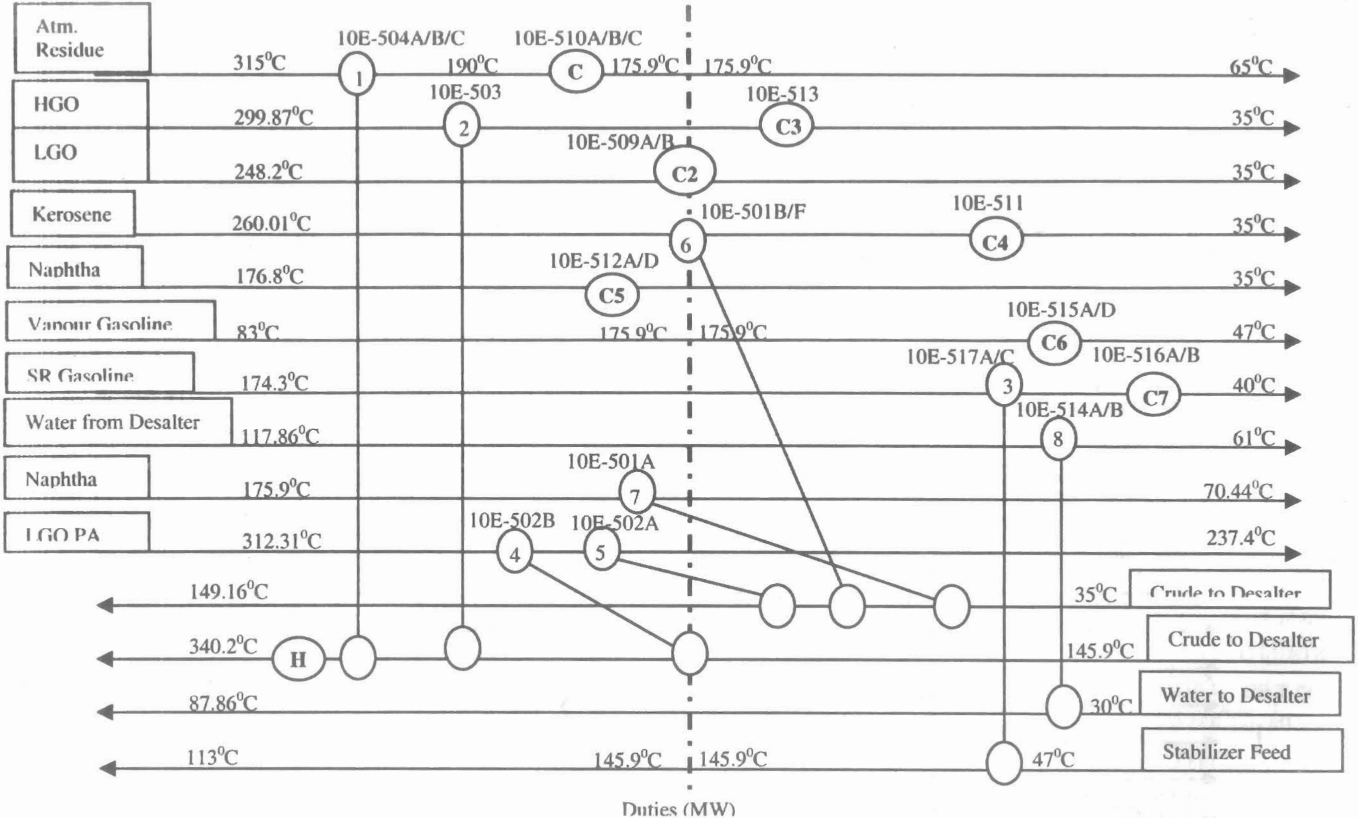


Fig.14: Grid representation of HEN in the CDU of Old Port-Harcourt Refinery Showing Heat Exchangers Working across the Pinch.

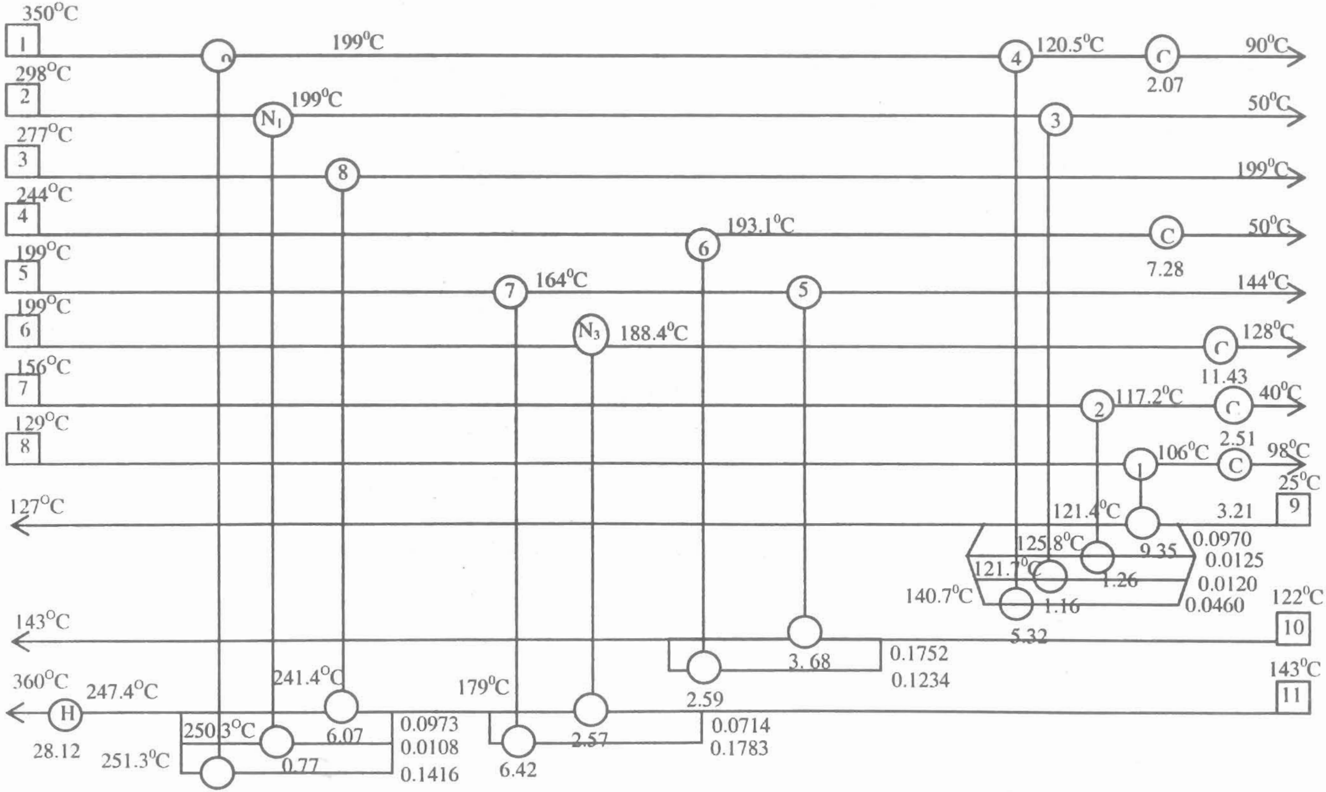
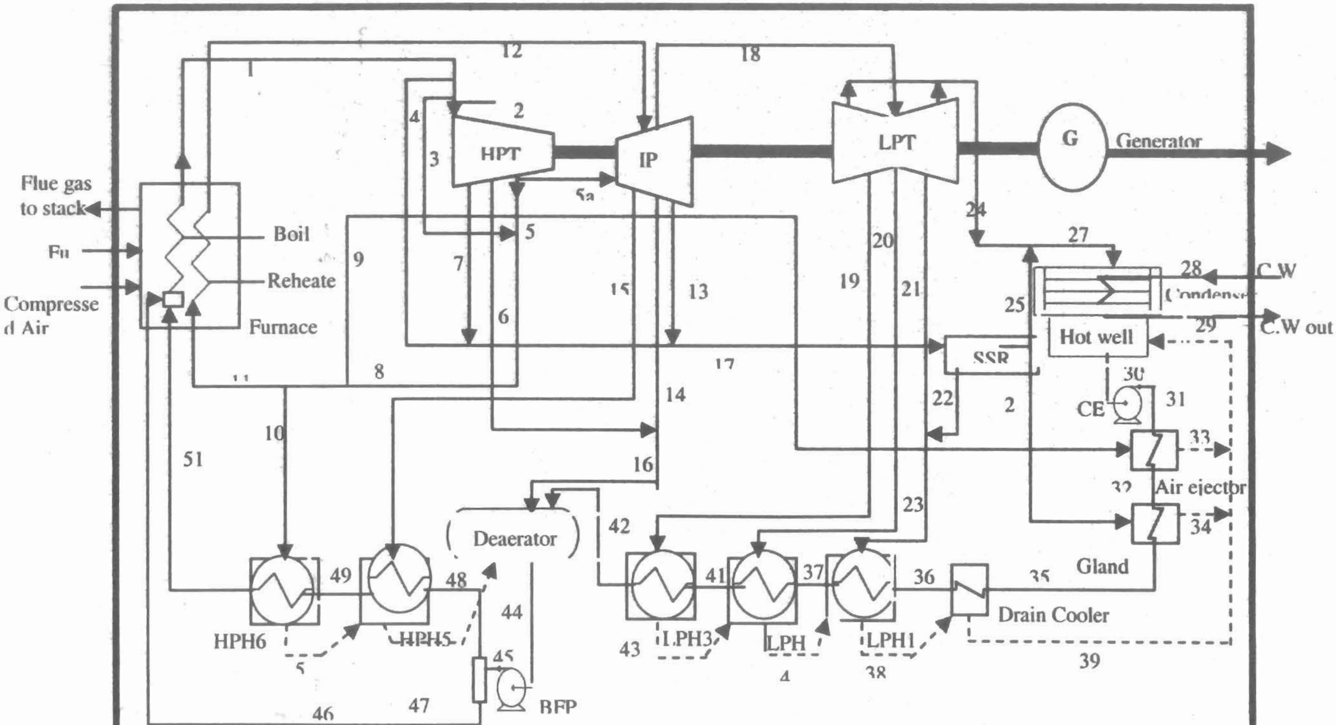


Fig.15: Best Evolutionary Design at ΔTmin for Kaduna refinery = 20°C

3.2.3 Search for optimum condenser cooling water flow rate in a thermal power plant

The retrofit of heat exchangers in a thermal power plant has been carried out using an entirely different method from pinch method. The method was focused on the search for optimum condenser cooling water flow rate in Egbin thermal power plant using energy analysis (first-law of thermodynamics) and optimization (Anozie and Odejobi, 2011). The process flow diagram of the power plant is shown in Figure 16. The total cost, comprising cost of retrofitting the heat exchangers and energy cost, and cycle efficiency were used as objective indices, and the simple method of graphs and tables were used to determine the optimum value. Computer program codes were developed in Microsoft Excel macros for simulation of the thermal plant at various circulation water flow rates, to determine the optimum condenser cooling water flow rate for the process. The study revealed that operating the condenser at a reduced cooling water flow rate of 32,000 m^3/h instead of the base case scenario of 32,660 m^3/h, reduced the total heat transfer area requirement with the condenser making the highest contribution to heat transfer area reduction. There was reduction in annualized capital cost, 2% increase in cycle efficiency, and fuel saving of 3.8%. The economic implications of heat recovery improvement were modifications to the air ejector, gland condenser, and replacement of the drain cooler, low pressure heater and high pressure heaters. The payback period for the retrofit expenses was 1.8 years which is very attractive.



High Pressure Turbine (HPT); Intermediate Pressure Turbine (IPT); Low Pressure Turbine (LPT) ; Steam Seal Regulator (SSR); Cooling Water (CW); Low Pressure Heater (LPH); High Pressure Heater (HPH); Condensate Extraction Pump (CEP);

Figure 16: Egbin Thermal Power Plant Process Flow Diagram

3.3 Energy and environmental emission reduction studies

Studies have been carried out to develop and analyze products and processes for renewable and sustainable energy generation.

3.3.1 Studies on biogas

(i) Biogas is a renewable energy source that is attracting attention today, especially in developing nations. One of the most critical problems facing many developing nations today is that of alarming rate of depletion of traditional sources of energy, largely fuel-wood and charcoal, which together command the largest share of energy used in the developing nations (Adegbulugbe and Akinbami, 1995). This has resulted in soil erosion, degradation of the land, reduced agricultural productivity, and potentially serious ecological change. The sludge from biogas plants could be used as nutrient rich manure in farms and could tremendously improve agricultural production. Thus the potential for biogas production appears very attractive (Coombs, 1990). A batch, pilot-scale biogas digester was designed, fabricated and tested for gas production (Anozie *et al.*, 2005). Four substrates, namely, poultry droppings, cow dung, corn stalk and their mixture were used for gas production, and their variations in gas production were determined using water displacement method. The results showed that the average daily gas production from poultry droppings was the highest while corn stalk produced the least. Laboratory analysis showed that the biogas contained 60% methane while carbon dioxide and other trace gases made up the balance of 40%. The biogas produced burnt well in a Bunsen burner with a blue flame. A maximum reactor pressure of 1.34 bars was recorded for a period of seven days of no gas harvest when poultry droppings were used as substrate, indicating that biogas production in a reactor is a relatively low pressure operation.

(ii) A study was conducted to develop correlations of the average biogas production rate with working volume of digester in batch anaerobic digestion of cattle and poultry manures (Anozie and Adeboye, 2009). A correlation for small working volumes of digester was developed as follows:

$$G = \alpha\beta V\left[1 - \{A + B/V\}\right] \tag{9}$$

where G is the average gas production rate (L/d); α is the average gas produced (L/g COD or TVS reduced per day); β is the total COD or TVS reduced (g/L); V is the working volume used for gas production (L); A is a dimensionless constant coefficient and B is a constant coefficient with units of volume (L). Values of α, β, A and B in equation (9), for poultry manure and cattle manure, were established from experimental data. The gas production estimates from the correlations for both manures were in excellent agreement with experimental results at low working volume of digester. An equation for the case of large working volumes of digester was proposed as follows:

$$G = \alpha\beta V\left[1 - \{A + B/V - CV\}\right] \tag{10}$$

where C is another constant coefficient with units of inverse volume (L^{-1}). The CV term in equation (10) was added because at large volumes the term B/V approaches zero. This equation is yet to be verified with experimental data for large volumes of digester.

3.3.2 Evaluation of household energy in Nigeria

A cooking "energy crisis" occurred in Nigeria in mid 1990s. There was scarcity of kerosene and cooking gas. Many households were forced by prevailing circumstances to switch from one type of cooking energy to the other. Nationwide consumption of cooking energy is increasing daily due to the growing population. Unfortunately, the energy supply (petroleum products) to the household sector has been dwindling over the past 30 years due to economic, social and political problems. There is need for energy studies in the household energy sector in Nigeria. Anozie *et al.* (2007) evaluated the cooking energy costs in Nigeria in 1995, 2001, and 2004; the cooking energy consumption efficiencies; the cooking energy intensity; the air pollution impacts of cooking energy consumption; and the impact of the energy policy in the cooking energy sector in Nigeria. Four cooking energy sources were considered, namely: fuel-wood, kerosene, liquefied petroleum gas (LPG), and electricity. The food items considered were water, yam and beans. Water boiling and cooking experiments and energy surveys were carried out. It was found that fuel-wood was the least expensive cooking energy source and LPG was the most expensive. The energy consumption efficiency was highest when electricity (hot plate) was used, followed by gas cooker, kerosene, and fuel-wood coming last. The energy intensity which was defined as the energy consumed per unit of food material cooked was found to have a correlation with cooking energy consumption efficiency, that is, low energy intensity corresponded with high energy consumption efficiency. The impacts of air pollution from household cooking using the energy sources considered except electricity, suggested a possibility of significant air pollutants contributions to the ambient environment. The cooking energy use patterns in the rural areas and in the urban areas revealed that the energy policy in the country had made no impact in the cooking energy sector. Recommendations for improving the cooking energy supply situation were given.

3.3.3 Studies on sawdust

(i) A screw press for briquetting sawdust was designed, fabricated and used to produce sawdust briquettes (Anozie *et al.*, 2008). Figure 17 shows the front view of the screw press. The screw press has three distinct zones, namely: The drive zone, the speed zone and the extrusion zone. Figure 18 shows details of the screw shaft. It comprises the feed zone, mixing zone, compression zone and the forming zone. The screw shaft was made of steel. The measured throughput of the press was 40 kg of briquettes per hour and the power consumption was 0.13 kWh/kg. The Vice Chancellor Sir, the screw press machine fabricated from these engineering drawings won an award at the Federal Ministry of Science and Technology Exhibition from Nigerian Universities at Abuja in 2005. The fuel characteristics of the sawdust briquettes were evaluated. The partially dried sawdust was densified with sodium silicate and bitumen as binders. The moisture content, density, ash content, higher heating value (HHV) and energy consumption efficiency of the densified briquettes were established. The briquettes produced were strong and stable. However, there is need to further improve the technology of screw press briquetting machine in Nigeria such that binders will not be added to the sawdust to form the briquettes.

(ii) The surest way of reducing carbon emissions into the atmosphere is by reducing energy generation from fossil fuels and increasing energy generation from renewable energy sources. Nigeria has numerous sawmills which generate sawdust. The reduction of carbon emissions by using sawdust in a cogeneration system was estimated (Anozie *et al.*, 2009C). Sawdust briquettes were produced using a screw press and the briquettes were characterized. The energy and material balances of a 25MW combined heat and power plant and the estimation of emissions in the plant and baseline emissions were carried out using Inter-governmental Panel on Climate Change (IPCC) emission default factors. To make the required impact, five of such plants were recommended to be built in Lagos State of Nigeria, giving total emission reduction of 545,655 tonnes CO_2/yr. If registered under the Clean Development Mechanism (CDM) project and traded at the carbon market, the annual revenue from carbon emission reduction was estimated as US $2,728,275.00/yr, which will assist implementation of the project.

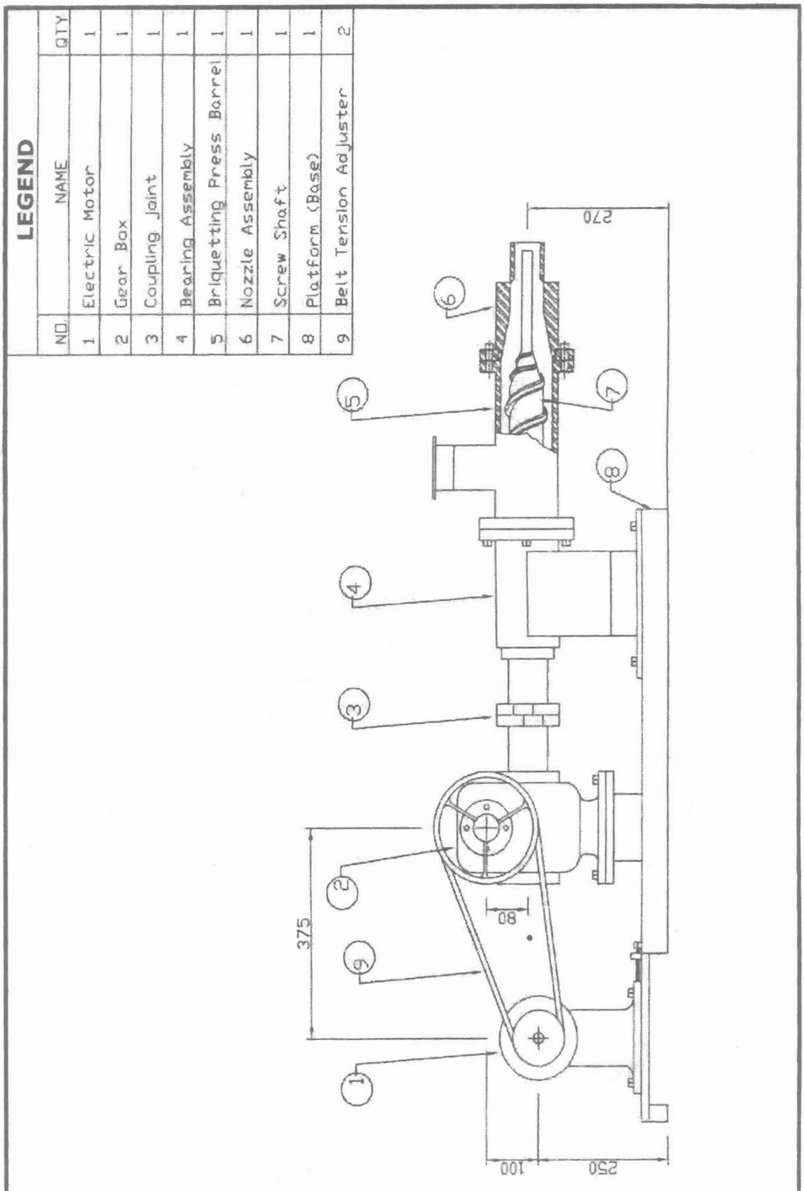


Figure 17: Screw Press Briquetting Machine (Front view)

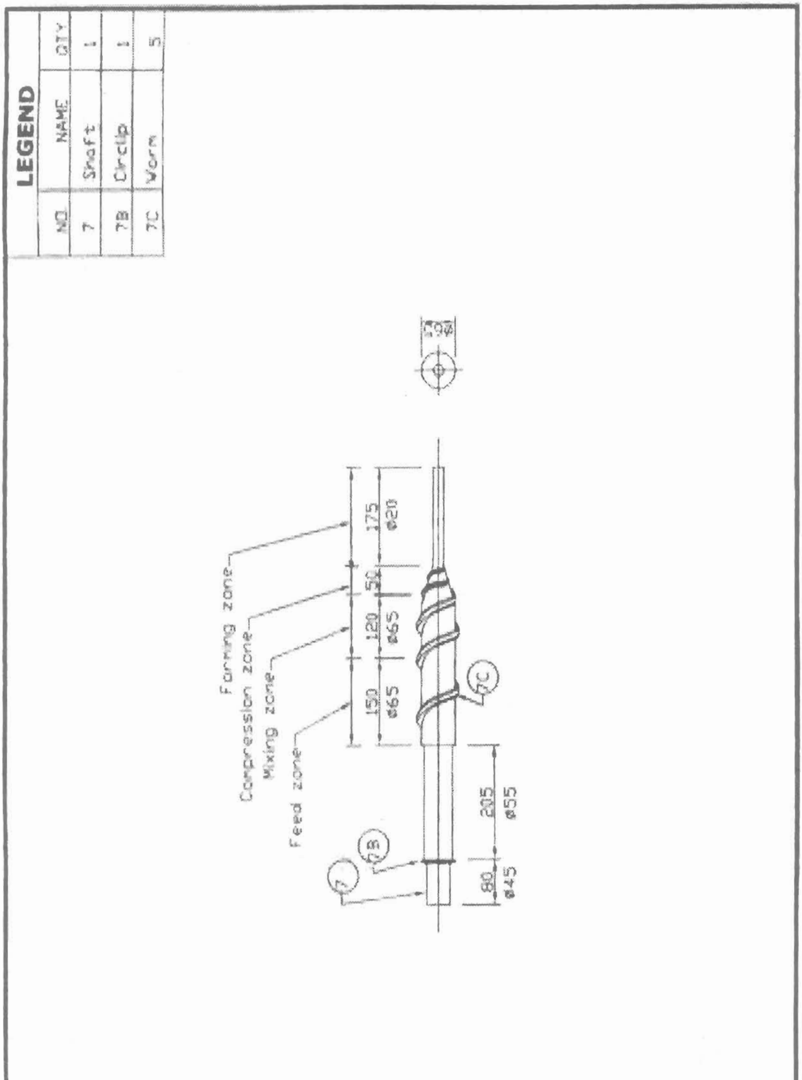


Figure 18: Details of the Screw Shaft

3.4 Raw materials research and development studies

Research and development studies have been carried out on local raw materials which will provide data for the design of processes for the production of the raw materials.

3.4.1 Development of bleaching clays

(i) Despite the abundance of many deposits of clay in the country, bleaching clays are currently being imported. There is need for the production of bleaching clays from local clays (Ibemesi and Achife, 1990). The bleaching performance of nine local clay samples were investigated in their natural and activated forms (Anozie *et al.*, 1993). The activation was done with hydrochloric acid. Palm oil was used for the bleaching experiments. It was observed that none of the clays had good bleaching performance in its natural form using a performance index of 70% colour removal as good performance but five of them had bleaching performances above 70% after acid activation. The mineralogical and chemical compositions of the clays were also determined. It was observed that the clays contained at least 75% kaolinite and are thus kaolinitic clays. Traditionally kaolinitic clays are used for refractory, ceramics and pottery while montmorillonite clays like Fuller's earth are usually and commonly used as bleaching clays. The silica to alumina ratio was calculated from the chemical composition and was less than 2 for all the samples. This indicated that the clays have high oil retention after bleaching which is not desirable.

(ii) In another study on clays, five clay samples obtained from different economic deposits in Southwestern Nigeria were used to bleach palm oil and their bleaching performances in both the raw and activated states were determined (Emofurieta *et al.*, 1999). The results showed that the bleaching performances of both the raw and activated clay samples were over 75% with the activated clays having higher bleaching performances. A clay sample obtained from Benin area bleached better than the imported Fuller's earth both in the natural and activated forms. The Benin sample gave 95% colour removal in the natural form and 98% colour removal in the activated form. The mineralogical and chemical composition of the clays showed that clay samples from Auchi, Benin and Bauchi are montmorillonite clays and have silica to alumina ratio greater than 2. These results are considered as excellent performances. Given these encouraging results, the country is in a very comfortable disposition to harness these clay deposits and reduce our dependence on the importation of bleaching clays. This will save the nation millions of foreign exchange and provide significant economic relief.

3.4.2 Production of fatty acids from vegetable oils

Fats and oil (triglycerides) react with water under specified and suitable conditions to produce fatty acids and glycerol (Sonntag, 1979; Morrison and Boyd, 1983). Despite the fact that the fatty acids processing technology has been an established industry for over a century, there exists a dearth of technical data in the literature. The kinetics of the hydrolysis of palm oil and palm kernel oil to produce fatty acids in a batch process has been studied (Anozie and Dzobo, 2006). This study was undertaken as part of the technical survey to generate the necessary chemical kinetic and process data for the preparation of fatty acids. These data will elucidate the process dynamics which will form the basis for further studies in the development of an indigenous fatty acids processing technology. The kinetic model was developed and it was found that the kinetics was one of shifting order from zero order to higher order as the reaction progressed from zero time. The integral analysis of the overall rate equation, equations for the evaluation of resistances to mass transfer and chemical reaction, and equation for the reaction mechanism were developed. The total resistance represented the lumped effect of the resistances to mass transfer and chemical reactions, and it was found to be a good measure of the extent of reaction.

3.4.3 Dehydration of ethanol-water mixture using adsorbents

The highest ethanol concentration that can be obtained by simple fractional distillation is about 95% (w/w) because it forms an azeotrope with water at this composition. Azeotropic distillation which involves the addition of a third component (called an entrainer) to the mixture has been used to overcome this problem for large scale production of anhydrous ethanol (Treybal, 1981). However, the problems associated with azeotropic distillation make the production of anhydrous ethanol by azeotropic distillation on a small scale not feasible. The dehydration of ethanol-water mixture using activated carbons from sawdust and palm kernel shells (PKS) has been studied (Anozie *et al.*, 2010C). The sawdust was chemically activated with ammonium chloride while the PKS was carbonized and steam activated. Different particle sizes of the activated carbons were used in the study. The optimum conditions for preparing the activated carbons were established. It was found that only the chemically activated sawdust particle sizes could break the ethanol-water azeotropic composition in feed solutions containing 5-9% (v/v) water to produce anhydrous ethanol. Powdered chemically activated sawdust particles had the highest adsorption capacity compared to all the other particle sizes. The water removal efficiency, selectivity of water-to-ethanol adsorption, and adsorption capacity were higher at low initial water concentrations.

4. A NOVEL METHOD OF INTEGRATION OF RESOURCES FOR CREATION OF INDUSTRIES IN NIGERIA.

4.1 Introduction

The Vice Chancellor Sir, in December 2007 I received an inspiration to apply my knowledge of process synthesis to develop a method that will integrate the resources of Nigeria to bring about creation of industries. I engaged my mind on this problem for several years, taking down notes of ideas that came to my mind, testing and analyzing them to ensure their workability. Finally, I completed the task in December 2014, having developed and stated clearly the practical ways of implementing the creative ideas. I am highly delighted to present in my inaugural lecture the final version of the work that has engaged my mind for the past seven years.

It is a well known fact today that there is problem of job creation and unemployment in many nations of the world. This is because employment opportunities have not increased as the number of graduates from universities and polytechnics increased. Unemployment is one of the problems any nation must tackle with population growth. This problem must be tackled not only by economists, social scientists, policy makers and analysts but also by process design engineers using creative and innovative method of integration of resources of a nation.

4.2 The resources for industries creation

The resources for the creation of industries in a nation consist of the following: research & development institutions/agencies, software houses, process design experts/consultants, equipment manufacturers, contractors (design & construction plus guarantees), operating companies, finance, raw materials, labour, markets, transportation and utilities. These resources can be grouped into three, namely: human resources, material resources and financial resources. Of these three groups of resources, the human and financial resources are the most important. The raw materials for an industry may not be in existence in a nation but can be imported from elsewhere.

4.3 The scenario in developed economies

The environment for industries creation, that is, the resources and the linkages between the various resources for industries creation, are already well developed in the developed countries and this is illustrated in Figure 19. The development of the resources, especially operating companies, contractors (design & construction plus guarantees) and equipment manufacturers, with huge financial bases and the linkages between the resources led to the establishment of several industries, that is, modern industrial revolution in Europe, America and Asia. Today there are about 3000 different process industries in the developed economies worldwide. Economic growth is due mainly to the creation of industries. History records that it took Europe and Asia over 1000 years to attain modern industrial revolution whereas it took America about 125 years to achieve the same feat (Ogbimi, 2006). It took all these nations a long time to attain modern industrial revolution because they learnt it by the traditional method which follows the learning curve trend. It took America a shorter time to attain modern industrial revolution because

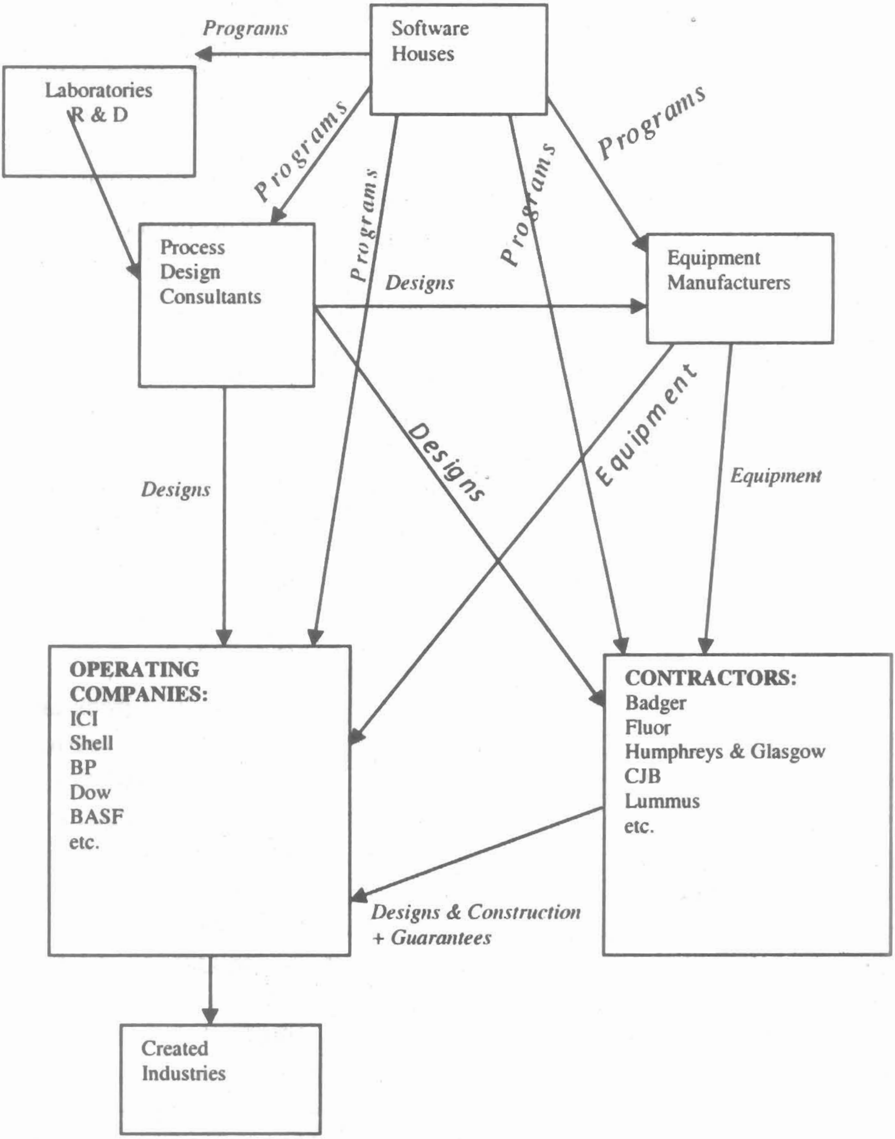


Figure 19: The environment (resources and linkages) for creating industries in developed countries (Source: Adapted from Linnhoff, 1981)

America first developed agriculture to feed the nation, established public schools early, emphasized education for all children as well as acquisition of practical skills.

4.4 The method of integration of resources for the creation of several industries in developing economies

Just as process integration method for the creation of a single process industry (first level process integration) was developed in the 1970s as a result of energy crisis, the process integration method for the creation of several process industries (second level process integration) was developed to bring about rapid industrialization and solve the problems of unemployment in developing countries. The second level process integration deals with integration that is similar in concept to the case of developing energy and economically efficient single process industry. The differences are that now we are talking of not creating only one process industry but several process industries; secondly, the inputs to the design problem in the two cases are different; and thirdly, the design method is peculiar to each case.

The method of integration of resources is a creative and innovative method to fast-track the creation of industries in developing countries. For developing countries, some critical resources for industries creation are non-existent and the linkages between all the required resources do not exist and is a big deterrent for the creation of industries. **The greatest challenge today in the developing economies is the absence of indigenous operating companies with huge financial base to embark on medium- and large-scale industries.** All scales of industries, namely: micro-, small-, medium- and large-scale industries are important for economic development. Large-scale industries provide the raw materials for the micro-, small- and medium-scale industries.

(a) Creation of new resources

What is actually needed in a developing economy like Nigeria is to create a robust, sustainable and an indigenous financing model and a project management model to drive industrialization. The financing model to be created is a contributory financing scheme called – **Contributory Industries Creation Fund Scheme (CICFS)** for creating the capital required for establishing industries and which will be coordinated by a Finance Commission called **National Industries Creation Fund Commission (NAICFCOM).** The project management model to be created is a private sector run project managers called **Industries Creation Fund Project Managers (ICFPMs)** and will have the responsibility of creating medium- and large-scale industries using the finances generated from the contributory financing scheme. NAICFCOM and ICFPMs are the two new resources to be created in developing economies for rapid growth of industrialization and the economy.

(b) Method of implementation

The method of implementation recommended is that Government should take the responsibility of creating and sustaining the finance commission, NAICFCOM, and should approve and grant licenses to some private sector industries creation fund project managers, ICFPMs. This method of implementation frees Government from the burden of heavy financial expenses required for building industries, gives Government opportunity to contribute in a modest way to the industrial development of the country, and puts Government in a position to regulate the activities of all the players in the new scheme. The functions of NAICFCOM and ICFPMs are given in Anozie (2014).

ICFPM is different from previous establishments established in Nigeria for industrialization. ICFPM is a private sector engineering practice outfit to be charged solely with the responsibility of creating industries in Nigeria. No establishment has received such a mandate before in Nigeria. Industries can be created using the latest technology in the world if capital is available. Some wealthy Nigerian entrepreneurs have demonstrated this fact. **ICFPM is not a research and development agency like Raw Materials Research and Development Council (RMRDC) nor is it trying to develop**

science and technology from grassroots like National Science and Engineering Infrastructure (NASENI). The operations of ICFPMs are to be regulated by NAICFCOM. For example, NAICFCOM will cross check the cost estimates of projects prepared by ICFPM to ensure that they are realistic.

The resources which have been created and the linkages between them and other existing resources to create the enabling environment for industries creation in a developing country are shown in Figure 20. The flow of funds from the general public to ICFR, ICFC and ICFPMs is also shown in Figure 20.

4.5 The roles of government

The major roles of Government in this regard shall be to:

(i) Grant permission and give guidelines for the private sector to begin to form ICFPMs.

(ii) Assemble a team of administrators, economists, engineers and legal experts to draft a document on the regulations governing the various organs (CICFS, NAICFCOM, ICFR, ICFC and ICFPMs) involved in the proposed integration method and in a form ready to be submitted to the National Assembly for the due process of consideration for enactment into law;

(iii) Submit the document to the National Assembly seeking approval for these organs to come into existence by an Act of the National Assembly;

(iv) Provide offices, facilities, vehicles, security, operating grants and staff salaries for NAICFCOM; and

(v) Appoint Director for NAICFCOM. The person appointed should be a charismatic leader with integrity, vision, experience, sound qualification and productivity. The Director is to engage a professional Recruitment Company to recruit highly qualified and experienced staff for NAICFCOM. A modest number of staff is needed at the very beginning but there should be room for expansion as things get well established and progress is made.

4.6 The roles of the private sector

It will become the responsibility of the private sector to form private companies that will act as project managers for assembling industries when permission is given by the Government to do so. This will bring together a number of individuals with large capital as financiers who will contribute money to start the project management companies. The financiers will now seek for experts to form the management team. Engineers, technocrats, finance and administration experts who have experience and capabilities required to set up industries will be needed in forming the management team. The Professional Associations in the country and professional Recruitment Company should be consulted for recruitment of the management team. A few experts can be hired from foreign countries but a majority of them has to be Nigerians. Recruitment Company should also be used to fill in the rest of the company work-force who should be tested and competent work men and women.

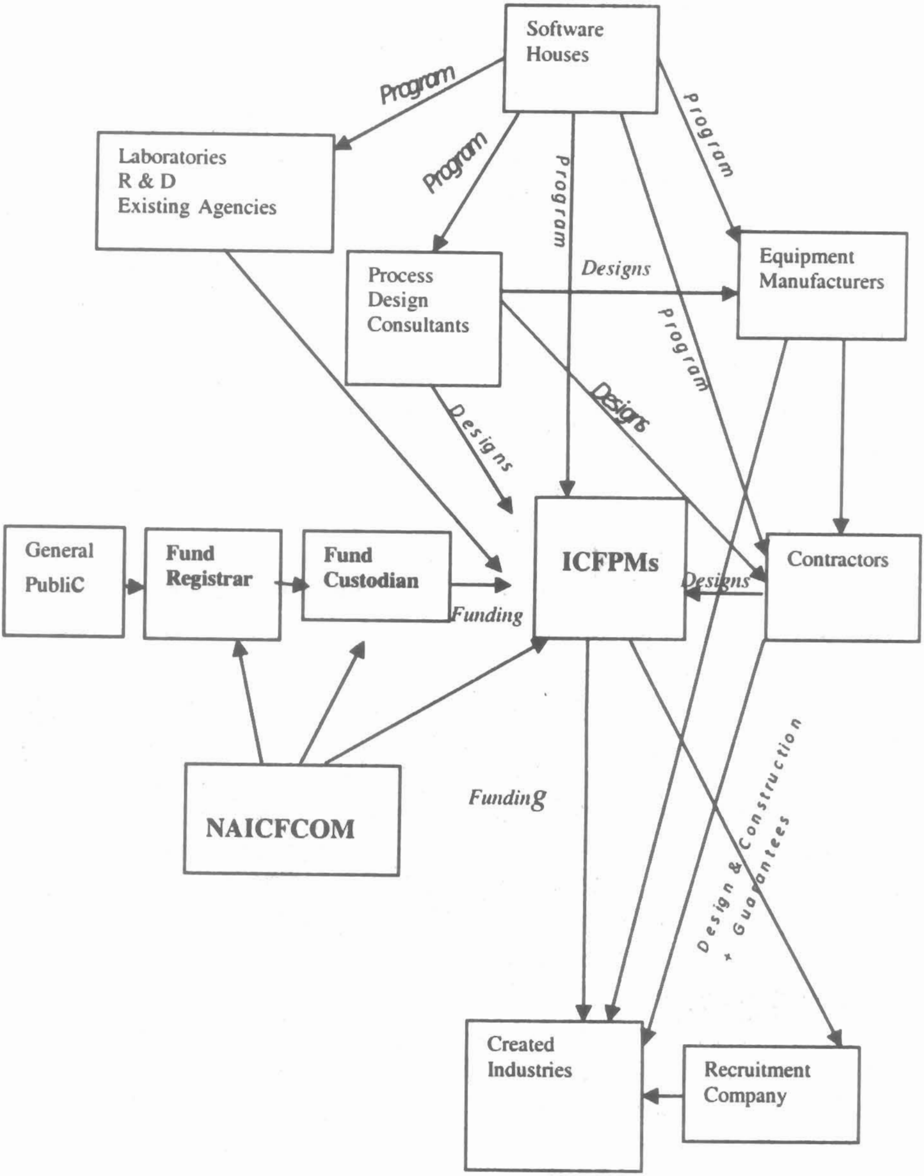


Figure 20: Creating an enabling environment (created resources, existing resources and linkages) for creation of industries in a developing country

The private sector project managers must have capital to provide offices, facilities, vehicles, security, operating expenses and staff salaries for the first one year. The starting capital to meet all these expenses was estimated to be 2 billion naira. Also a fixed deposit of 1billion Naira with an approved bank (fund custodian) as collateral will be required. These requirements must be met before the project managers receive license from NAICFCOM to begin operation. After the first year when ICFPMs are fully established and on ground, the grants for operating expenses, salaries and welfare of staff of ICFPMs will come from a certain percentage of the contributed fund, thereby reducing initial capital required for starting the private companies. About 10% of the total cost of the project should be given to the project managers as grants to cover expenses for execution of the project and about 2% of the total cost of project should also be given to them as profit for investing their capital to start the project management companies. This profit will be paid after successful completion of projects. Non-performing ICFPMs will be stopped and their assets acquired by NAICFCOM.

Nigeria is capable of forming private sector project managers to create new industries. Today there are many private universities in Nigeria. When Government approved private universities in Nigeria no one knew that the number will be as large as it is today. The formation of private sector project managers to assemble industries in Nigeria will be very attractive to Nigerians and will be a step in the right direction. It will provide opportunities to create industries where the teeming graduate students from the universities and polytechnics can be employed.

The private sector project managers will cover the whole spectrum of industries (primary, secondary and tertiary) such as: Electricity, Agriculture, Oil and Gas, Mining, Food processing, Chemicals, Petrochemicals, Pharmaceuticals, Mechanical, Electrical and Electronics. It will be necessary for one company to focus in one sector of industries.

4.7 Remarks on the integration method

(i) It was very exciting to discover that the Contributory Industries Creation Fund Scheme (CICFS) developed in this work from method of integration of resources ended up being comparable to the Contributory National Pension Fund Scheme (CNPFS). The major organs in the Pension Scheme are: National Pension Commission (PENCOM), Pension Fund Custodians (PFCs) and Pension Fund Administrators (PFAs). The parallel organs in the two schemes are as follows:

CNPFS/PENCOM ≡ CICFS/NAICFCOM/ICFRs

PFCs ≡ ICFCs

PFAs ≡ ICFPMs

PENCOM is both a regulatory organ as well as the organ for collecting contributions from employers and employees. NAICFCOM is also a regulatory and fund collection organ. It regulates funds given to ICFPMs and uses ICFR to collect funds from the citizens. The PFC keeps custody of the pension fund and the PFA manages the pension fund. Similarly, ICFC keeps custody of the contributed fund for industries creation and ICFPM uses the contributed fund to create industries. The pension scheme in Nigeria despite some setbacks is waxing stronger and proving to be one of the wise decisions taken by Government in Nigeria. Similarly, the industries creation fund scheme would be another wise decision taken by Government in Nigeria.

(ii) Capitalism recognizes the fact that it is better for individuals or groups of individuals to own businesses than the State to do so. State owned businesses in Nigeria have never done well. But capitalism puts a limit on the number of people to own a business. In the capitalist orientation a partnership is defined as a business owned by a limited number of people. The contributory scheme proposed here for industries creation is based on the principles of capitalism and cooperation of citizens. The scheme recognizes the fact that there is tremendous power in cooperation of citizens which can be tapped for a common good such as raising capital for industrial development. The scheme does not put a limit on the number of people to own a business.

(iii) The principles used in the integration of resources method for the creation of industries are based on the combination of science of analysis and integration. The functions of ICFPM and NAICFCOM involve both analytical and integration techniques. Experience from process engineering design has shown that designs based on the principles of analysis and integration give better and efficient designs.

(iv) The Stock Exchange market cannot solve the present day economic problems of a developing nation. A business has to be first started and successful before going to the stock market to raise more capital. This is because it is only when a business is successful that people will have confidence to buy into it. But the harsh economic realities in the world today make it difficult for individuals to go into large scale manufacturing industries. Government support for the contributory scheme for industries creation, regulatory controls and checks on ICFR, ICFC, NAICFCOM and ICFPMs to ensure good performance and service delivery will help to create confidence in the minds of people to invest in certified, feasible and profitable industrial projects before the projects come into existence. Furthermore, to ensure transparency of the scheme a method has to be developed for people to verify their contributions and the total amount contributed for a project. The collection of funds will be closed immediately the target amount for a project is met.

4.8 Advantages of the integration method

The creative and innovative method presented here is revolutionary and visionary and will bring about industrial revolution in a developing country such as Nigeria. The method has several advantages.

(i) It is driven by a contributory private sector investment scheme that takes away the burden of providing huge capital for investment in industries by Government or a few entrepreneurs.

(ii) The method of funding proposed is sustainable in that the citizens of the nation and even those in the Diaspora can invest and recover the money invested.

(iii) The method of funding advocated here has the vision of eventually making participating citizens shareholders in an industry and thereby eradicating poverty at the grassroots.

(iv) The regulatory controls built into the investment and management schemes will guarantee the safety of contributed funds and efficient use of funds. Investors will rest assured that they will not be defrauded.

(v) The contributory financing scheme for capital creation will generate indigenous investment capital for creation of industries. The idea of relying heavily on foreign investors for capital for industries creation will not solve the problems of Nigeria in her efforts to become an industrialized nation. This is because some essential and necessary industries will not be attractive to foreign investors.

(vi) The integration method will fast-track industrial development and make the vision of Nigeria becoming a developed economy a reality within a short time. All the previous efforts to establish industries in Nigeria can be described as the "traditional method" which follows the learning curve trend. The traditional method will take hundreds of years to begin to show tangible results. The creative and innovative integration method will generate results much faster. The Vice Chancellor Sir, if the integration method had been discovered and used since 2009, when Vision 20: 2020 (2009) was conceived, the vision of Nigeria becoming a developed economy by year 2020 would have been realised. However, it is not too late if Nigeria can now adopt the integrated resources economic framework presented in this lecture which is truly creative, innovative, visionary and revolutionary.

(vii) The method developed in this work can be described as a truly Public Private Partnership (PPP) which has been recognised as the new way of Government and the private sector doing business for national development.

4.9 Benefit-cost ratio

The cost-benefit analysis is based on what it will cost the Government to bring this scheme into operation and what the citizens of the nation will benefit from it. The only costs to be borne by the Government are the costs for establishing the scheme, forming and sustaining NAICFCOM. History supports a considerable amount of evidence showing that industrial production almost never expanded unless there was government support for it (Sabillon, 2008). The benefit-cost ratio of 30.7 for the first four years of operation was obtained from the analysis carried out. This means that the money the Government has invested in four years of the scheme will be multiplied 30.7 times as benefits for the citizens. It is seen that the benefit-cost ratio of 30.7 is very high and attractive; indicating that this is a very powerful means the Government can use to create wealth and empower the citizens. The benefit-cost ratio will increase as the number of industries created and the numbers of persons employed directly and indirectly increase.

Moreover, the profits from the operations of the industries have not been considered for these can only be estimated when detailed design data and selling prices of products of a specific industry are known. These profits will go to the citizens that contributed capital for the industrial projects. Also the profits made by ICFPMs have not been considered. It was recommended that 2% of the total cost of setting up an industry be given to the project managers as profit. The total benefits the country will derive from this scheme far outweighs the total costs to be borne by the Government and the private sector.

4.10 Examination of Nigeria Industrial Revolution Plan

The Nigeria Industrial Revolution Plan (NIRP) (Internet #1) has some merits. It has identified areas where Nigeria has competitive and comparative advantage such as agriculture and agro-products, metals and solid minerals, oil and gas, construction and light manufacturing services. It has identified industries groups where the country has comparative advantage such as the sugar backward integration plan, auto industry strategy and cement sector. It addressed the physical constraints that have consistently inhibited the growth of manufacturing and measures to alleviate them. However, it has no robust, sustainable and indigenous financing model to drive it. It rests on attraction of foreign investors and perhaps few indigenous investors, which will not drive the economy. This is the problem with all the industrialization policies Government has been trying to implement since Nigeria's independence such as Vision 20:2020 of 2009. The models developed in this work can be used to drive the NIRP.

Large scale industries are very expensive. The electric power reform in Nigeria is an example. The sector needs more capital to make it more efficient. It is true that some private companies have bought the assets in the power industry. But NAICFCOM can still raise capital for these companies from the citizens to be given to the companies at a low interest rate of say 12%. NAICFCOM will then pay back to the citizens who contributed money to bail out the electric power companies at an interest rate of about 10%. NAICFCOM will retain 2% interest for administrative charges. The same thing can be done for the development of other infrastructures in the country. This will leave enough capital for Government to develop other sectors such as education, health and welfare.

4.11 Summary

Economic growth has been mainly due to creation of industries. If the developing nations fail to establish industries, they will continue to have poor economic growth. The earlier civilizations learnt by the traditional method and that is why it took them hundreds of years to develop. Efforts by Government of Nigeria so far belong to the traditional method. Using only that method will not achieve the desired results for it will take the nation hundreds of years to develop. The creative and innovative method of integration of resources presented here is vital to the creation of private sector funded industries essential for rapid industrialization. The method has many advantages and an impressive benefit-cost ratio. Further delays in creating industries in Nigeria with the rapid rise in population growth will heighten economic stress and restiveness of the youths of this country with attendant security problems. Policy recommendations should reflect the method of integration of resources for creation of industries that will lead to attainment of fast and sustainable economic growth in Nigeria.

5. HIGHLIGHTS OF MY CONTRIBUTION

The Vice Chancellor Sir, permit me to recount some of my contributions and achievements in my career and professional life. I have succeeded in establishing a new research area in the Department of Chemical Engineering of Obafemi Awolowo University, Ile-Ife, called "Applied Thermodynamics, Process Design and Energy Research Group." This is a cutting edge research in the world today. Exergy analysis and process integration have revolutionized chemical engineering education and industrial practice in the developed countries.

During my Ph.D. studies in UK, I met an American professor at a conference who offered me post doctoral fellowship when I completed my studies. He wanted me to come and join his research team in a university in USA. When I completed my studies I decided to return to Nigeria. I told myself then that I had to return home to contribute to the development of my country. I have imparted my knowledge in exergy analysis and process integration to my undergraduate and postgraduate students of the Department of Chemical Engineering, Obafemi Awolowo University, Ile-Ife. Many students from our Department have gone into this area of research in overseas universities and are doing very well. I have supervised and mentored several M.Sc. students and four Ph.D. students in their theses work. Some of my project students are lecturers in universities in Nigeria and overseas.

The Vice Chancellor Sir, with all humility and boldness I wish to state that I am one of the experts and consultants on exergy analysis and process integration in Nigeria and there are very few of us. I have made substantial contribution in the development of fundamental concepts of exergy, methods of calculation of exergy and interpretation of results, and applications of exergy analysis and process integration to process design. Our professional Society, the Nigerian Society of Chemical Engineers, Edo/Delta Chapter, has appointed me on several occasions as a resource person for training sessions on process integration for industry staff. The National Body of our Society has also appointed me on one occasion as a resource person for a training session for NNPC staff in 2009.

The Vice Chancellor Sir, our research group has carried out extensive research on the four refineries in Nigeria, identified the problems with the original designs and went further to redesign the crude distillation units of the four refineries. The crude unit is the major consumer of energy in the refinery. We did all this with our own money. But the Industry and/or the Government have not made use of our research findings. If our research findings had been used, all the problems of "bottle-necking" of our refineries could have been removed a long time ago.

The Vice Chancellor Sir, by divine inspiration, I have been led to develop a creative and innovative method of integration of resources of a nation for the creation of industries in Nigeria. The integration method of industrialization is visionary and revolutionary. It has a financing model and a project management model to drive it. If this method is adopted Nigeria will become industrialized within a short time.

6. CONCLUSIONS AND RECOMMENDATIONS

The Vice Chancellor Sir, it is said that necessity is the mother of invention. It was the "energy crisis" of the early 1970s that triggered off research in process design in industry and academia in overseas countries. Exergy analysis and process integration have greatly impacted the way process design is taught in universities and practised in industry today. I consider myself fortunate to have acquired this knowledge and I have been struggling to disseminate this knowledge in academia and industry in Nigeria.

The benefits that exergy analysis and process integration in process design have brought into the national economy and health in overseas countries are many. These tools have enabled process design engineers to evolve creative and innovative designs that are not only more efficient in energy consumption but offer other advantages such as reduction of capital costs and operating costs, increase in profits, reduction of air pollutants emissions, better controllability and safety in industry. These benefits will come to Nigeria if exergy analysis and process integration are vigorously taught in universities and practised in industry in Nigeria.

The creative and innovative method of integration of resources presented in this lecture is vital to the creation of private sector funded industries essential for rapid industrialization in Nigeria. The method has many advantages. Policy recommendations should reflect the method of integration of resources for creation of industries that will lead to the attainment of fast and sustainable economic growth in Nigeria.

The facilities and staff strength of the "Applied Thermodynamics, Process Design and Energy Research Group" in the Department of Chemical Engineering, Obafemi Awolowo University, Ile-Ife, are not adequate at the moment. This research area is a cutting edge one and needs a lot of staff and modern software for process integration.

My experience and observation is that industries in Nigeria are not interested in collaborative research with universities. There is need to evolve policies that will link up Universities, Industry and Government in Nigeria in research funding as is done in overseas countries. It is only the Government and few multinationals that bear this burden in Nigeria today. Researches in our universities are meant to improve national economy, health and living standards of the citizens.

7. APPRECIATION AND GRATITUDE

The Vice Chancellor Sir, at this juncture I wish to express my appreciation and gratitude to all who have contributed in making me what I am today or helped to make my life a happier one. First and foremost, I give glory and honour to Almighty God, whose guiding and intervening hand has preserved my life and lifted me to the position where I am today.

I remember in a very special way my late parents, Mr. Felix Anozie and Mrs. Sussana Anozie (may their souls rest in peace), for their love, kindness and discipline when we were growing up as children. I remember in a very special way our eldest brother, late Mr. Solomon Anozie (may his soul rest in peace), who made the sacrifice to give university education to his younger brothers. May his labour of love not be in vain! I remember my two other brothers and late sister (may her soul rest in peace) for the love we shared and are still sharing.

I wish to express my profound gratitude to this University. The University nominated me for the National Scholarship Award, a Federal Government Scholarship, given to the best ten students after the preliminary year examination in the University. Again when I graduated I was offered appointment as graduate assistant in the Department of Chemical Engineering and rose to become a professor. For all these I am really grateful.

I want to thank my teachers who helped in no small measure in making me what I am today. I remember my teachers in primary and secondary schools. I remember my teachers in the Universities. In a special way I remember and thank my lecturers in this University, namely: Emeritus Prof. S.A. Sanni, Dr. S.R.A. Macaulay, Dr. Ogunbamiro, Prof. A. Susu, Prof. Toks Oshinowo and Prof. Omatete. I thank my lecturers at McGill University, Montreal, Canada. I remember Prof. A. Mujumdar, Prof. Fuller and Prof. Grace. I thank my research supervisor at University of Strathclyde, Prof. C. D. Grant, for the manner he directed and supervised my research work, and the then Head of Department of

7. APPRECIATION AND GRATITUDE

The Vice Chancellor Sir, at this juncture I wish to express my appreciation and gratitude to all who have contributed in making me what I am today or helped to make my life a happier one. First and foremost, I give glory and honour to Almighty God, whose guiding and intervening hand has preserved my life and lifted me to the position where I am today.

I remember in a very special way my late parents, Mr. Felix Anozie and Mrs. Sussana Anozie (may their souls rest in peace), for their love, kindness and discipline when we were growing up as children. I remember in a very special way our eldest brother, late Mr. Solomon Anozie (may his soul rest in peace), who made the sacrifice to give university education to his younger brothers. May his labour of love not be in vain! I remember my two other brothers and late sister (may her soul rest in peace) for the love we shared and are still sharing.

I wish to express my profound gratitude to this University. The University nominated me for the National Scholarship Award, a Federal Government Scholarship, given to the best ten students after the preliminary year examination in the University. Again when I graduated I was offered appointment as graduate assistant in the Department of Chemical Engineering and rose to become a professor. For all these I am really grateful.

I want to thank my teachers who helped in no small measure in making me what I am today. I remember my teachers in primary and secondary schools. I remember my teachers in the Universities. In a special way I remember and thank my lecturers in this University, namely: Emeritus Prof. S.A. Sanni, Dr. S.R.A. Macaulay, Dr. Ogunbamiro, Prof. A. Susu, Prof. Toks Oshinowo and Prof. Omatete. I thank my lecturers at McGill University, Montreal, Canada. I remember Prof. A. Mujumdar, Prof. Fuller and Prof. Grace. I thank my research supervisor at University of Strathclyde, Prof. C. D. Grant, for the manner he directed and supervised my research work, and the then Head of Department of

Chemical and Process Engineering at University of Strathclyde, the late Prof. G.S.G. Beveridge.

I salute all the members of Chemical Engineering Department of Obafemi Awolowo University, Ile-Ife. It is said that a tree cannot make a forest. Everyone has played his or her part to make the individual and corporate achievements in the Department possible. I salute them for the spirit of comradeship which exists in the Department. I sauté the members of the Faculty of Technology and the entire University Community of Obafemi Awolowo University, Ile-Ife.

I thank the Parish Priest and members of my Church on Campus, the Catholic Community of Our Lady of Perpetual Light Chapel, and the members of Prayer Fellowships that I belong to, for their love and prayers. I thank all our family friends, members of Umunna Social Club, the Ibo Community in Ile-Ife, and all who live in Ile-Ife.

Finally, I want to express my appreciation to my family. I thank my dear wife, "the bone of my bones and flesh of my flesh," for the encouragement and caring she gave to me and the family. I thank my children for their love and prayers for daddy. I thank my sons-in-law, daughter-in-law and grandchildren for their love and support.

I thank everyone in this hall for coming to listen to me. I thank all those who have come from outside Ile-Ife. God bless you all.

REFERENCES

Anozie, A.N. (1994) "Exergy analysis of chemical processes." Jour. of the Nigerian Society of Chemical Engineers, Vol. 13, No. 1 & 2: 1-6.

Anozie, A.N. (1997A) "Thermo-economic analysis of a chemical plant." Jour. of the Nigerian Society of Chemical Engineers, Vol. 16, No. 1 & 2: 57-60.

Anozie, A.N. (1997B) "Thermo-economic optimization of a nitric acid plant." Jour. of the Nigerian Society of Chemical Engineers, Vol. 16, No. 1 & 2: 50-56.

Anozie, A.N. (2014) "Creativity and innovation: The synthesis of resources method for the creation of manufacturing industries in Nigeria." The 44th Annual Conference of NSChE, Owerri, November, DVD Paper No. 8.

Anozie, A.N. and Adeboye, Y.B. (2009) "Correlations for gas production rate in batch anaerobic digesters." Energy sources, Part A, Vol. 31:1131-1140. (USA).

Anozie, A.N. and Alamu, O.B. (2009) "Thermodynamic analysis of a liquefied natural gas plant." The 39th Annual Conference of NSChE, Abuja.

Anozie, A.N. and Alamu, O.B. (2010) "Evaluation of energy and exergy efficiencies of three process schemes of the NLNG plant." The 40th Annual Conference of NSChE, Port-Harcourt, November, pp. 177-188.

Anozie, A.N. and Ayoola, P.O. (2012) "The influence of throughput on thermodynamic efficiencies of a thermal power plant." Int. Journal of Energy Engineering, Vol. 2(5):266-272 (USA).

Anozie, A.N. and Dzobo, J.M. (2006) "Kinetics of the hydrolysis of palm oil and palm kernel oil." Industrial and Engineering Chemistry Research, Vol. 45:1604-1612. (USA).

Anozie, A.N. and Grant, C.D. (1993) "Evaluation of overall second-law efficiency of chemical processes." Jour. of the Nigerian Society of Chemical Engineers, Vol. 12, No. 1 & 2:81-88.

Anozie, A.N. and Odejobi, O.J. (2009) "Evaluation of heat exchanger network design and energy efficiency in the crude distillation units of Nigerian oil refineries." Jour. of the Nig. Soc. of Chemical Engineers, Vol. 24, No. 1&2: 48-59.

Anozie, A.N. and Odejobi, O.J. (2011) "The search for optimum condenser cooling water flow rate in a thermal power plant." Applied Thermal Engineering, Vol. 31:4083-4090. (USA).

Anozie, A.N. and Ojoboh-Daniel, E. (2006) "Simulation and energy targeting of the crude distillation unit of the old Port-Harcourt refinery in Nigeria." AMSE, Modelling D, Vol. 27, No, 3: 25-36. (France).

Anozie, A.N. and Osuolale, F.N. (2010) "Thermodynamic analysis of a crude oil distillation unit." Ife Journal of Technology, Vol. 19, No. 1:53-57.

Anozie, A.N., Ezomo, F.A.S. and Emofurieta, W.O. (1993) "Bleaching performance of some Nigerian clays." Journal of Mining and Geology, Vol. 29, No. 1:57-62.

Anozie, A.N., Layokun, S.K. and Okeke, C.U. (2005) "An evaluation of a batch pilot-scale digester for gas production from agricultural wastes." Energy Sources, Vol. 27, No. 14: 1301-1311. (USA).

Anozie, A.N., Bakare, A.R., Sonibare, J.A. and Oyebisi, T.O. (2007) "Evaluation of cooking energy cost, efficiency, impact on air pollution and policy in Nigeria." Energy, Vol. 32:1283-1790. (USA).

Anozie, A.N.. Odejobi, O.J. and Alozie, E.E. (2008) "Evaluation of fuel characteristics of sawdust briquettes." Jour. Nig. Soc. of Chemical Engineers, Vol. 23, No. 1 &2: 77-87.

Anozie, A.N., Osuolale, F.N. and Osunleke, A.S. (2009A) "Exergy analysis of binary plate distillation column operations." Int. J. Exergy, Vol. 6, No. 5:715-782. (UK).

Anozie, A.N., Odejobi, O.J. and Ayoola, O.P. (2009B) "Relevance of exergy analysis in the assessment of thermal power plant performance." Ife Journal of Technology, Vol. 18, No. 2:42-50.

Anozie, A.N., Odejobi, O.J. and Alozie, E.E. (2009C) "Estimation of carbon mission reduction in a cogeneration system using sawdust." Energy Sources, Part A, Vol. 31:711-721. (USA).

Anozie, A.N., Osuolale, F.N. and Asepeeri, T.C. (2010A) "Use of stage-exergy rate profiles in determining binary plate distillation column reflux ratio." LAUTECH Journal of Engineering and Technology, Vol. 6, No. 1:79-86.

Anozie, A.N., Osuolale, F.N. and Aseeperi, T.C. (2010B) "Exergy analysis and optimization of binary plate distillation column operations." Int. J. Exergy, Vol. 7, No. 5, 593-606 (UK)

Anozie, A.N., Okuhon, E.E., Osuolale, F.N. and Adewole, J.J. (2010C) "Dehydration of ethanol-water mixture using activated carbons from sawdust and palm kernel shells." Separation Science and Technology, Vol 45 (10): 1482-1489. (UK).

Anozie, A.N., Braimah, M.N, Odejobi, O.J. and Ayoola, O.P. (2014) "Improving design of a cryogenic process by exergy and process economic analyses." British Journal of Applied Science & Technology, 4(17): 2489-2500 (UK).

Adegbulugbe, A.O. and Akinbami, J.F.K. (1995) "Urban household energy use pattern in Nigeria." Natural Resources Forum, 19(2):125-133.

Ayoola, P.O. and **Anozie, A.N.** (2012) "A study of sections interaction effects on thermodynamic efficiencies of a thermal power plant." British Journal of Applied Science & Technology, 3(4):1201-1214 (UK).

Beveridge, G.S.G. and Schechter, R.R. "Optimisation: Theory and Practice." McGraw-Hill (1970).

Coombs, J. (1990) "The present and future of anaerobic digestion." In Anaerobic Digestion – A waste Treatment Technology. London: Elsevier Applied Science: 1-42.

Dhole, V.R. and Linnhoff, B. (1993) "Distillation column targets." Computers and Chemical Engineering, Vol. 17:549-560.

Demirel, Y. (2006) "Retrofit of distillation columns using thermodynamic analysis." Separation Sciences and Technology, Vol. 41:791-817.

Denbigh, K.G. (1956) "The second-law efficiency of chemical processes." Chem. Eng. Sc., Vol. 6, No. 1:1-

Dorgan, J.R., Way, J.D., Bryan, P., Huff, G. and Stewart, F. (2003) "Energy saving technologies for the petroleum refining industry: An Industry-University-National Laboratory Partnership." Colorado School of Mines, Golden, CO, USA.

Emofurieta, W.O., Odokuma, O. and **Anozie, A.N.** (1999) "Bleaching characteristics of some montmorilonite clays in South Western Nigeria." Tropical Journal of Environmental Science and Health, Faculty of Science, University of Benin, Vol. 2 (1): 1-7.

Gaggioli, R.A. (1961) "The concept of available energy." Chem. Eng. Sc., Vol. 16:87-

Gaggioli, R.A. and Petit, P.J. (1977) "Use the second-law, first." Chemtech, August:496

Gibbs, J.W. "Collected Works (Vol. 1)." Longmans, New York, 1928.

Grant, C.D. "Energy conservation in the chemical and process industries." George Godwin, London, England, 1979.

Grant, C.D. and Anozie, A.N. (1985)" The relationship between exergy analysis and operating cost for energy conservation in chemical processes." Fourth International Chemical Engineering Conference, Coimbra, Portugal, Paper No. 41: 1-12.

Gurteen, D. (1998) "Knowledge, creativity and innovation." *Journal of Knowledge Management*, Vol. 2, No. 1: 5-13.

Hornby, A.S., "Oxford Advanced Learner's Dictionary". Oxford University Press, Oxford, UK, 6th Edition (Special Price Edition), 2001.

Ibemesi, J.A. and Achife, E.C. (1990) "Use of local clays as decolorizing agents for vegetable oils." J. Mining and Geology, 26:127-131.

Keenan, J.H. "Thermodynamics." Wiley, New-York, 1941.

Kryssanov, V.V., Tamaki, H. and Kitamura, S., 2001. "Understanding design fundamentals: How synthesis and analysis drive creativity, resulting in emergence". *Artificial Intelligence in Engineering,* Vol. 15, Issue 4, pp. 329-342.

Internet # 1, Nigeria Industrial Revolution Plan, www.nipc.gov.ng

Le Goff, P., Cachot, T. and Rivero, R. (1996) "Exergy analysis of distillation process."Chemical Engineering and Technology, Vol. 19:478-485.

Linnhoff, B. "Design of heat exchanger networks, A short course". Private Communication, 1981.

Linnhoff, B. (1994) "Use pinch analysis to knock down capital cost and emissions." *Chemical Engineering Progress,* August: 33-55.

Linnhoff, B. and Flower, J.R. (1978) "Synthesis of heat exchanger networks. Parts 1 and 2." *AIChE Journal*, 24(1): 633-654.

Linnhoff, B. and Turner, J.A. (1981) "Heat recovery networks: New insights yield big savings." *Chemical Engineering,* 56(2), pp. 56-70.

Linnhoff, B. and Vredeveld, D.R., (1984) "Pinch technology has come of age". *Chemical Engineering Progress*:33-40.

Linnhoff, B., Dunford, H., and Smith, R. (1983) "Heat integration of distillation column into overall processes". *Chemical Engrg Sc*. 38(8): 1175-1188.

Lynd, L.R and Grethlein, H. E (1986) "Distillation with intermediate heat pumps and optimal sidestream return". *AIChE Journal*, 32(8): 1347-1359.

Maia, M.L.O. and Zemp, R.J. (2000) "Thermodynamic analysis of multi-component distillation column: identifying optimal feed conditions". *Brazilian J. Chem.Eng.*, 17: 751-763.

Morrison, R.T. and Boyd, R.N. "Organic Chemistry". 4th Ed, Allyn and Bacon Inc., New York, 1983.

Odejobi, O.J. and **Anozie, A.N.** (2007) "Economic optimization of heat exchanger network retrofits in the crude distillation unit of Kaduna refinery." Jour. Nigerian Society of Chemical Engineers, Vol. 22, No. 1& 2: 21-23.

Odejobi, O.J. and **Anozie, A.N.** (2013) "Influence of reference temperature on exergy and exergoeconomic performance parameters of a natural gas fired thermal power plant in Nigeria." Int. J. of Exergy, Vol. 13, No. 1:102-123. (UK).

Ogbimi, F.E., 2006. "Promoting Rapid Industrialization: Indispensable to Increasing Nigerian Content in the Oil and Gas Industry". *Proceedings of the 36th Annual Conference, Nigerian Society of Chemical Engineers, Ibadan*, Paper T3.3.

Osuolale, F.N. "Thermodynamic analysis of crude distillation unit of Warri and Kaduna petroleum refineries". PhD Thesis, Department of Chemical Engineering, OAU, Ile-Ife, 2010.

Osuolale, F.N., **Anozie, A.N.** and Obisanya, A.A. (2009) "Energy and Exergy Analyses of a 220 MW Steam Power Plant." LAUTECH Journal of Engineering and Technology, Vol. 5, No. 1:1-6.

Reistad, G.M. (1975) "Available energy conversion and utilization in the United States." Jour. of Eng. for Power (Trans. ASME), July:429.

Riekert, L. (1974) "The efficiency of energy-utilization in chemical processes." Chem. Eng. Sc., Vol. 29:1613.

Rudd, D.F., Powers, G.J. and Siirola, J.J. "Process Synthesis" Prentice Hall Inc., Englewood Cliffs, New Jersey, 1973.

Sabillon, C., "On the Causes of Economic Growth: Lessons of History," Algora Publishing, New York, 2008.

Smith, J.M. and Van Ness, H.C. "Introduction to Chemical Engineering Thermodynamics". McGraw-Hill, New York, 3rd Ed., 1975.

Sonntag, N.O.V. (1979) "New developments in the fatty acid industry." J. Am. Oil Chem. Soc., 56 (II): 861A-864A.

Sussman, M.V. "Standard chemical availability." Chem. Eng. Prog., January: 1980.
Treybal, R.E. Mass transfer operations, 3rd Ed. McGraw-Hill Book Company, Singapore, 1981.

Vision 2020: "National Technical Working Group, Report of Vision 2020", National Technical Working Group on Manufacturing, Abuja, Federal Government of Nigeria, 2009.

Vruggink, R.S. and Collins, T.F. (1982) "Apply thermo laws with care." Hydrocarbon Processing, July:129

Wilkie, D.R. (1973) "Free energy of non-isothermal systems." Nature, Vol. 245, October: 26.