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Comparison Based on Energy and Exergy Analyses of a Selected Cement Manufacturing Plant in Nigeria

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Abstract:*Several studies were already carried out on the efficient use of energy in the past but little was done so far on the comparative study of energy and exergy for some manufacturing processes.To this effect, in this study, the compilation and analysis of data collected from a cement manufacturing plant in the* North-Central region of Nigeria*for a period spanned from 2010 to 2014were conducted in order to study the variations of energetic and exergetic efficiencies in each unit of theproduction line of the plant. Consequently, the study revealedthat the overall energetic and exergetic efficiencies were estimatedat 56.5% and 42.2% respectively.The discrepancy of which was due to the fact that the exergy analysis efficientlyidentifiedvarious losses due to the irreversiblities in the thermodynamic system of the plant. This however, provided useful information on the degradation of the input energy associated with internal consumptions and emitted gases*.

Keywords: *Energy, energetic efficiency, exergetic efficiency, exergy analysis.*

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I. Introduction

In order to overcome the present challenge of increasing demand of consumers in the cement industry, there is the need to conduct a deep analysis and evaluation of periodical data for cement process.This will definitely improve the efficiency of the plant as some ofknown energy sources have been nearly exhausted.

Energy is the ability to perform work or to produce heat as an input for various industrial processes [1]Therefore, issues related to efficient utilization of energy should be given priority since the industrial growth of any country is dependent of the availability and effective utilization of energy in that country.In thermodynamics analysis, energy can be converted from one form to another and the structure of thermodynamics involves the concept of equilibrium states [2]

1.1Energy and Exergy Concept

Energy analysis is characterized by the old method of assessing the way energy is used in an operation which involves the physical and chemical processing of materials and transfer or conversion of energy. It entails performing energy balances and energy efficiencies which are only based on the First Law of Thermodynamics (FLT). It however, provides no information about the inability of any thermodynamic process to convert heat fully into mechanical work [2] Therefore, energy balanceneither gives details on the energy degradation during a process norquantifies the usefulness of the various energy and material streams flowing through a system and exiting as products and wastes.

On the other hand, exergy analysis is based on the available energy or utilizable energy. Therefore, the exergy analysis is dependent of theFirst and Second Lawsof Thermodynamics (SLT) The results of exergy analysis arerelative to the specified reference environment, which in most applications is modelled after the local environment.[3]Whenever a process involves a temperature change, exergy is always destroyed[4] This destruction is proportional to the entropy increase of the system together with its surroundings. After the system and surroundings reach equilibrium, the exergy is zero[4]Therefore, the limitations of the FLT are overcome by the exergy method of analysis whose concept is based on both the FLT and the SLT as shown in Table 1 below.

Table1. Comparison of Energy and Exergy.

Energy	Exergy
It can only be quantitatively measured.	It can both be measured quantitatively and qualitatively
It can neither be created nor destroyed. It can only be transformed from one form to another	It is only in a reversible process that it can neither be created nor destroyed. However, in any irreversible process, it is either partly or totally destroyed.
It can be in forms of kinetic energy (KE), potential energy (PE), work and heat, and also measured in that form.	It can be in forms of potential exergy, kinetic exergy, work, thermal exergy, and measured on the basis of work or ability to perform work.
It does not depend on the environment properties but is only dependent of properties of a matter or energy flow.	It is dependent of properties of both a matter or energy flow and the environment.
When in equilibrium with the environment, its values are not zero.	When in complete equilibrium with environment, it is always equals to zero (dead state)

1.2 Problem Statement

Many attempts have been made globally to ensure that the consumption of finite resources like energy and material is reduced while increasing the value of industrial output. This makes the role of improving the energy efficiency of industrial processes more important in recent years. However, energy which is based on the First Law of Thermodynamics (Law of Conservation of Energy or Matter) can neither be created nor destroyed[5] though it may change from one form to another. It is therefore, obvious that reduction of energy consumption cannot be efficiently explored based on the First Law of Thermodynamics (FLT) only, since whenever a task is performed in the real process, energy is not consumed, but is only transformed into a less useful form. This useful form of energy is known as quality and related to the potential of energy used to perform work.

Every real or natural process has a tendency to transform higher quality energy into lower quality forms. Therefore to reduce the energy consumption of any process, the quantity of energy as well as the degradation of energy quality must be adequately controlled. However, no indication of this energy degradation is provided by the energy analysis based on the FLT. In order to proffer solution to this limitation of energy analysis a quantity called exergy which is based on both the First Law of Thermodynamics, FLT and the Second Law of Thermodynamics, SLT is needed for comparative purpose as exergy does not only measure the energy transformation quantity but also the quality (the useful part of energy)

1.3 Literature Review

The present work has reviewed some contributions of researchers who have used energy and exergy analyses for some manufacturing processes as follows:

Energy and ExergyAnalyses of Egyptian Cement Kiln Plant was carried out by Laila M. Farag. Energy and exergy balances were conducted in the preheater-precalciner and the rotary kiln; the energy efficiency was estimated at 40% while that of exergy efficiency was 25.7%. It was also observed that the total exergyoutputs was about 49% of exergy input. That is, irreversibility loss was around 51% of total exergy input [6]

Moreso,MarcioMacedo Costa with other researchers in 2001applied energy and exergy analyses to steel production processes in the following stages: conventional integrated, semi-integrated and new integrated with smelt reducing to calculate and compare exergy losses and efficiencies for each case, semi –integrated steelworks were the most efficient in exergetic terms, ψ_1= 67% while for the new integrated steelworks COREX-BOF, ψ_2 = 50% and for the conventional integrated steelworks,ψ_3 = 48% . Compared with the other steelworks, the conventional integrated steelwork was the least exergy- efficient [7]The differences between ψ_2 and ψ_3 indicate the relativeexergy importance of products for a particular kind of steel works

Energy and exergy analyses have been also carried out by some researchers for a vegetable oil refinery in the Southwest of Nigeria. The performance of the plant was estimated by considering energy and exergy losses of each unit operation of the production process. The energy intensity for processing 100 tonnes of palm kennel oil into edible oil was estimated as 487.04 MJ/tonne with electrical energy accounting for 4.65%, thermal energy, 95.23% and manual energy, 0.12% [8]Thishelped the researchers to identify the most energy intensive operation and the most inefficient operation.

Methodology for energy and exergy analyses of industrial steam boilers was also reviewed for this work, in which mass, energy and exergy analyses were used to develop a methodology for evaluating thermodynamic properties,energy and exergy input and output resources in industrial steam boilers[9] It was observed that, chemical exergy of the material streams offered a more comprehensive detail on energy and exergy resource allocation and losses of the processes in a steam boiler

1.4 Research Contribution to knowledge

In this study, Energy and Exergy analysis has been carried out as well as the comparative study of both energy and exergy in order to efficiently identify which analysis gives information on energy degradation and locates various sources of losses in a thermodynamic system using a cement manufacturing plant in the North-Central region of Nigeria as a case study.

1.5 The Research Objectives

The objectives of this study were to determine the energy input/output and exergy input/output in the various manufacturing stages of cement production, and compare the energy efficiency with the exergy efficiency in each unit, hence the overall efficiency of the cement plant based on energy and exergy analysis.

1.6 The Cement Manufacturing Process

Cement manufacturing is an energy intensive process, the study of the energy required and utilized in producing cement is important in order to increase amount of output and reduce the cost of production. Production of cement involves series of stages and in each of the stage energy is utilized and consumed**.**

The raw materials are quarried using chemical explosives or powerful excavators. By usinga special machinery, the major raw material which is limestone is crushed into pieces usually smaller than 30 millimetres in size. The crushed limestone and other raw materials (bauxite, iron oxide, gypsum, etc.,) are stored separately in category, and then conveyed to the mill in carefully set and controlled proportions for mixing. This is called pre-homogenisation. As the mill rotates, the steel spheres in the mill crush the raw materials into granules, which forms what is known as raw meal. The raw meal is then conveyed to special silos where the homogenisation process is completed.

After homogenisation, firing-clinker formation takes place in which the raw meal moves through a system of cyclones called a preheater, undergoing gradual heat treatment at temperatures up to 900°C. Rotary kilns are then used to roast the homogenized material. The kilns are metal cylinders lined with refractory bricks. The raw meal is driven towards the exit at temperature of about 1450°C by the rotary action of the kiln and its angle. The raw meal is transformed into a granular hard substance called clinker as a result of the processes occurred inside the kiln.

Clinker being the principal ingredient of cement, highly determines the quality of the end product as the clinker is finally ground with gypsum and certain additives like pozzolana which give beneficial properties to the finished product (cement) in form of a very fine powder whichwhen mixed with water, it sets and hardens.

II. Study Methodology

The data collected from the selected plant were carefully analysed for the following energy-intensive unit operations.

I. Quarrying
II. Cement Raw Materials' Preparation
III. Pyroprocessing and Finish Grinding

2.1 Input-Output Analysis Method (IOA)

The Input-Output Analysis Method introduced by Leontief (1914) was used for this work. Since the introduction of the method, it has been used to analyze energy and labour intensities.The Input-Output Energy Analysis structure is very useful in the economic Input-Output Analysis for energy and exergy analyses. It aims at calculating energy intensity of an economic sector. It takes different forms: Linear, non-linear, open-closed, or static-dynamic [10]In this study, the Input-Output Analysis Method was used to estimate the energy content of materials.

To evaluate the effective use of energy and thermodynamic efficiency within a process,two kinds of approaches used for the calculation of performance indexes were energetic and exergetic balances.

Referring to the generalized economic sector j shown in figure 1 below, the general principles of the Input-Output Energy/Exergy can be shown as follows:

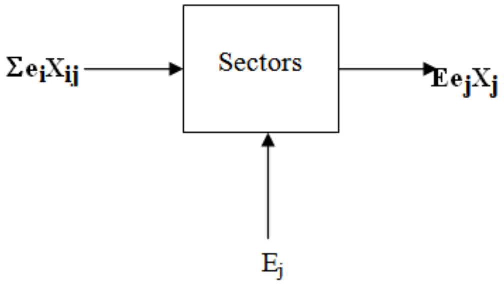

Figure1. Energy/Exergy balance for producing sectors

If the fraction of the total output of unit j derived from inputs from unit i is given as$\boldsymbol{A_{ij}}$

$$\boldsymbol{A_{ij}} = \frac{X_{ij}}{X_j} \qquad (1)$$

$$\boldsymbol{e_j X_j} = \sum \boldsymbol{E e_i A_{ij}\, X_{ij}} + \boldsymbol{E_j} \qquad (2)$$

Where,
$\boldsymbol{A_{ij}}$=the fraction of the total output of unit j derived from inputs from unit i
$\sum \boldsymbol{e_i A_{ij}\, X_{ij}}$=the sum of all energy/exergy inputs from the other units
$\boldsymbol{E e_j X_j}$= the total energy/exergy embodied in an output

In matrix notation, the energy/exergy balance is:

$$\boldsymbol{eA + E = eX} \qquad (3)$$

TwoInput/Output (I/O) Tables were used. They are, the I/O Table for the material transfer/production and the I/O Table for both energy and exergy transactions. Therefore, the matrix equation for the embodied energy/exergy is given as follows:

$$E_e = \partial^T (\mathrm{I} - \mathrm{A})^{-1} \qquad (4)$$

Where,
$E_e$is the embodied energy/exergy and $\boldsymbol{\partial}^{\mathrm{T}}$ is the direct energy/exergy intensity vector given as:

$$\boldsymbol{\partial}^{\mathbf{T}} = \frac{\textbf{Total energy/exergy used in the sector}}{\textbf{Total quantity produced in the sector}} \qquad (5)$$

Where,
$\boldsymbol{X_{ij}}$is the transaction from unit i to unit j
$\boldsymbol{X_j}$is the unit j total output
$\boldsymbol{e_j}$is the embodied energy/exergy intensity per unit of $\boldsymbol{X_j}$, this is the sum of all the energy consumed by all the processes involved to deliver one unit of product to the factory gate of unit j
$\boldsymbol{E_j}$= is the energy extracted from the earth which is non-zero for primary energy unit.

Where,
X is a diagonalized matrix of unit outputs. For the n unknowns, this set of n equations can be solved as follows:

In the IOA, the direct and indirect requirements are usually determined by using matrix operations. For two production sectors, the levels of production can be represented by 2 by 1 Matrix (a column vector) X as follows:

$$X = \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \qquad (6)$$

Similarly, the levels of net output required to be met are known as Final Demands f_1, and f_2 which can be represented as a column vector (2X1 matrix)F

$$F = \begin{pmatrix} f_1 \\ f_2 \end{pmatrix} \quad (7)$$

The direct requirements per units of output for the processing units can be represented as 2X2 matrix A as follows:

$$A = \begin{pmatrix} A_{1,1} & A_{1,2} \\ A_{2,1} & A_{2,2} \end{pmatrix} \quad (8)$$

The amounts of production used up in producing x_1 and x_2 are equal to

$$A_{1,1}x_1 + A_{1,2}x_2 \quad (9a)$$

$$A_{2,1}x_1 + A_{2,2}x_2 \quad (9b)$$

It can be seen that this is the product of the matrix A and matrix X. That is,

AX

Since the levels of production are given by X the net production after the amount used up are deducted are as follows:

$$X - AX \quad (10)$$

This equals the final demand(the required levels) which can be satisfied in matrix form as follows:

$$F = X - AX \quad (11)$$

Using a special type of square matrix known as identity matrix I in order to factorize F

$$I = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \quad (12)$$

Therefore,

$$IX = X \quad (13)$$

We have, $F = IX - AX$ (14)

The matrix equation to be satisfied,

$$F = (\mathrm{I} - \mathrm{A})\mathrm{X} \quad (15)$$

The form of equation now is,

$$C = BX \quad (16)$$

To solve for X, the inverse of B is carried out. That is,

$$X = B^{-1}C \quad (17)$$

This should be checked if matrix B exists that is if det B≠0, otherwise B^{-1} cannot be carried out.

If det B≠0, the following matrix is obtained,

$$(\mathrm{I} - \mathrm{A})^{-1} \quad (18)$$

Then X is obtained by multiplying this matrix by the vector of final demands F

2.2Development of Equations for Estimating Energy in the Plant.

Equations for estimating energy can be derived from the First Law of Thermodynamics applied to combustion parts of the production system of the cement plant as the First Law of Thermodynamics can be applied to varioussystems[11]The non-flow and steady flow energy equations deduced from this law is applicable to systems undergoing combustion processes or explosion reactions as we have in the production line of cement.

Two concepts were developed for this purpose sequentially namely, internal energy of combustion and enthalpy of combustion. In order to develop these concepts, a hypothetical sequence of processes undergone by a stoichiometric mixture of the fuel and air through the chemical reactions were considered.

2.2.1 Internal Energy of Combustion ΔU.

Considering a combustion process starting with a stoichiometric mixture of the fuel and in an arbitrary state (P_1 , T_1) and ending with the products in another arbitrary state (P_2, T_2). The equation can be written as

$$U_{P2} - U_{R1}) = (U_{P2} - U_{PO}) + (U_{PO} - U_{RO}) + (U_{RO} - U_{R1}) \quad (19)$$

Where subscripts R and P refer to reactants and products respectively, and subscripts 1 and 2 refer to the initial and final states.

The standard pressure $P_O$agreed by international convention is P^{θ} = 1 bar. The corresponding difference in internal energy is denoted by

$$\Delta U_O^{\theta} = U_{PO}^{\theta} - U_{RO}^{\theta} \quad (20)$$

Where the superscript ‘θ’ refers to P^{θ} and the subscript ‘o’ to the standard temperature T_o. By international convention. T_o is chosen to be 298.15K = 25°C

Therefore, using known U or $C_p$data the following equations were used to estimate the energy E based on the law of conservation.

$$E= U_{P2} - U_{PO} = \sum m_i(u_{i2} - u_{i0}) = \sum m_i C_p(T_2 - T_1) \quad (21)$$

Where m_i= mass of constituent i per kmol of fuel reacting

C_p= specific heat capacity.

2.2.2 Enthalpy of combustion and its relation to internal energy

The change of enthalpy between reactants in state 1 and products in state 2 is similar in relation to internal energy as shown above.

$$H_{P2} - H_{R1} = (H_{P2} - H_{PO}) + \Delta h^{\theta} + (H_{RO} - H_{R1}) \quad (22)$$

The equation stated above is equivalent to (19).

The standard temperature T_o is as before, 298.15K = 25°C. The first and third terms were calculated from the equation below,

$$H_{P2} - H_{PO} = \sum m_i(h_{i2} - h_{i0}) = \sum m_i C_p(T_2 - T_0) \quad (22a)$$

Alternatively,

$$H_{R2} - H_{R1} = \sum m_i(h_{i0} - h_{i1}) = \sum m_i C_p(T_0 - T_1) \quad (22b)$$

The choice depending upon what data are available.

It can be observed that the set of (22a) and (22b) are equivalent to that of (21)

Natural gas reforming equation is as follows:

$CH_4+2H_2O \rightarrow 4H_2+CO-165KJ$

The reaction is driven by high temperature heat, which is supplied by another flow of methane being combusted according to:

$CH_4+O_2 \rightarrow CO_2+2H_2O+802.6KJ$ (23)

2.3Performance Criteria

There is a direct relation between the exergy flowing from a process, $B_{OUT}$to that flowing into the process, B_{IN}. This is the ratio of the exergy transfer rate associated to the plant (or plant component) output exergy to the exergy transfer rate associated to the corresponding input exergy. The rational efficiency is a criterion of performance which can be formulated for the plant.
It is given by subtracting the transiting term from the incoming and outgoing exergy terms.It is given as:

$$\psi = \frac{\sum \Delta B_{OUT}}{\sum \Delta B_{IN}} \qquad (24)$$

The concept of exergy incorporates a measure of the potential work obtainable from a system or flow. Other thermodynamic potentials, such as Gibb's freeenergy, Helmhohz's free energy, available work and availability, define potential work for specified constraints.The maximum work that can be obtained from the system in its interaction towards equilibrium with the environment is measured by exergy. We use the function exergy B [12] defined as:

$$B=U+P_oV-T_oS-\sum \mu_i n_i \qquad (25)$$

Where U is Internal Energy
P is Pressure
T is Temperature
S is Entropy
$\mu_i$is Chemical potential of eachcomponent
n_i is number of moles of each component
The subscript "o" denotes the system when it is in equilibrium with its environment.

2.4 Exergy Model Equations

Exergy B for a closed system may be defined mathematically according to [13]

$$B = V (P - P_0) - S (T - T_0) - \sum n_i (\mu_i - \mu_{io}) \qquad (26)$$

The exergy of a flow crossing the system boundaries of an open system can be written as

$$B = (H - H_o) - T_o (S - S_o) - \sum \mu_i (n_i - n_{io}) \qquad (27)$$

Where $H = U + P_oV$
The extensive quantity, U denotes the internal energy,
S the entropy
H the enthalpy
V the Volume
n_i the number of moles of substance, i
Intensive quantity, T the temperature
P the pressure
μ_i the chemical potential of the substance i
The subscript 'o' denotes the conditions of the reference environment.

2.5 Exergy Balances

Given the physical and chemical exergies B and material carriers for each step of a given production process, exergy losses were calculated according to the following exergy balance.

$$B_{inputs} = B_{products} + B_{losses} + B_{wastes} \qquad (28)$$

B_{inputs} denotes the sum of exergies of the energy and material resources.
$B_{products}$ includes the main product and by products exergies
B_{Wastes}denotesexergy embodied in air emissions, water effluents and solid wastes.
B_{losses} includes irreversibilities and part of the exergy output that is not used.

Therefore, for the exergy losses, the exergy balance gives:

$$B_{losses} = B_{inputs} - B_{products} - B_{wastes} \qquad (29)$$

Some proper exergy efficiencies ψ can now be defined as

$$\Psi_{1s} = \frac{B_{product} + B_{waste}}{B_{input}} \qquad (30)$$

The performance index ψ_1 complement (i.e, 1 - ψ_1) indicates the input exergy that was lost. For instance, if $\psi_1 = 0.80$, it means that 20% of the exergy inputs were lost (with the exergy of wastes excluded).However, the performance index ψ indicates the useful exergy (exergy embodied in the main product and in the by products) obtained from the exergy inputs. This is given by

$$\Psi = \frac{B_{main\ product}}{B_{input}} \qquad (31)$$

The performance index ψ is related only to the exergy of the main product.For the perspective assumed in this study, ψ is the most appropriate efficiency indicator to allow comparisons between different cement production routes, because it considers products and by products as useful outputs and deducts the exergy embodied in wastes.

In any real engineering system (which is irreversible), energy is degraded and theefficiency is consequently less than unity.

An exergy efficiency, ψ can be defined as

0

$$\psi = {B_{OUTPUT}}/{B_{INPUT}} = 1 - {B_{OUTPUT}}/{B_{INPUT}} < 1 \qquad (32)$$

Thus, theexergy loss or irreversibility rate of the system is given by

$$B\_(losses) = B\_(inputs) - B\_output > 0 \qquad (33)$$

2.6Exergy of Electricity

The concept of an exergetic improvement IP, Potato Van Cool noted that the maximum improvement in the exergy efficiency for a process or system is obviously achieved when exergy loss B_{losses} is minimized. Electricity may be regarded as an energy having a high quality, or exergy [14]

It is useful to use the concept of an exergetic improvement potential; IP, when analyzing different processes:

$$IP = (1 - \psi)(B_{input} - B_{output}) \qquad (34)$$

Defined by Van Cool as the ratio of exergy to enthalpy in the floor Stream, theexergy analysis provides an indication of the thermodynamic quality of an energy carrier.

$$\Theta = \frac{B}{H} \qquad (35)$$

Where Θ = exergetic potential (Van Cool's thermodynamic quality) and for electricity, (H) = 1

2.7Exergetic Potential of Process Heat

For process heat: $\Theta = 1 - \frac{T_o}{T_p}$

(36)

Where T_o/T_p = the process temperature ratio

$$(\Delta B) = m_i C_p\{(T_o - T_1) - T_o ln \, {}^{T_o}/_{T_o}\} \qquad (37)$$

Standard temperature and pressure (T_o = 298.15K (25°C) and P_0= 1 atrn) was used for this analysis [14]

III. Results and Discussion

The plant utilizes chemical, thermal and electrical energy for production. For simplicity, the production process was divided into three most energy intensive unit operations.The parameters for evaluating energy and exergy in each unit operation of cement processing were collected from the production unit.

3.1 Quarrying

The energy efficiency increased by 6% between 2010 and 2011 butdecreased by 11.3% between 2011 and 2012as depicted in Fig. 2 below. The energy efficiency declined further between 2012 and 2013 by 8.5%. This was due to the largeemission of gases like water vapour, carbondioxide, oxygen and nitrogen. The efficiency was however, increased by 34% between 2013 and 2014which resulted in small amount of energy losses.

As regards exergy,theexergetic efficiencykept on declining from 2011till 2013 as shown in Fig 3. This was due to the fact that input sources of exergy in this unitoperation were chemical explosives, diesel (AGO) and electricity. The blasted limestone wasproduced from the heat of formation of the explosives (ANFO and Nitroglycerin) while the sources of exergy losses were from the emitted gases such as water vapour,carbonmonoxide,carbondioxide, oxygen and nitrogen. The major source of exergy loss in this unit wasthrough the emitted water vapour during the explosion. As the input energy was being transferred into this same unit from time to time it was being degraded which resulted inexergy losses associated with the emitted gases.The performance however, increased in 2014 as the losses were reduced by7% due to modernization. The exergy performanceof this unit for the selectedperiod was averagely estimated at 30.7% which was as a result of the overallexergy lossesoccurred during the period.

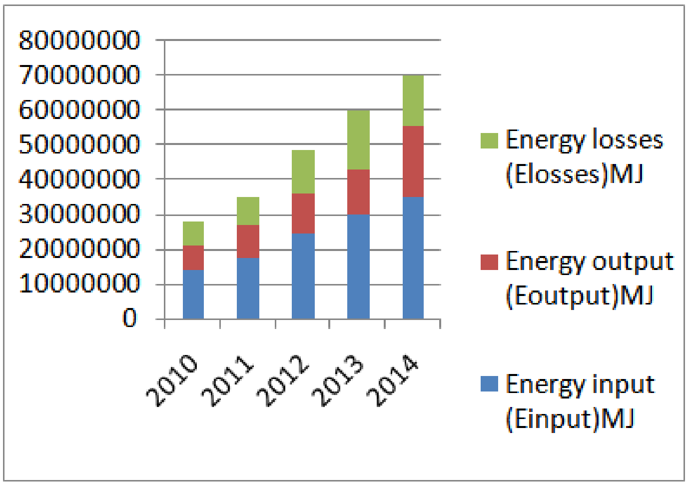

Figure2. Energy quantities at quarrying unit operation

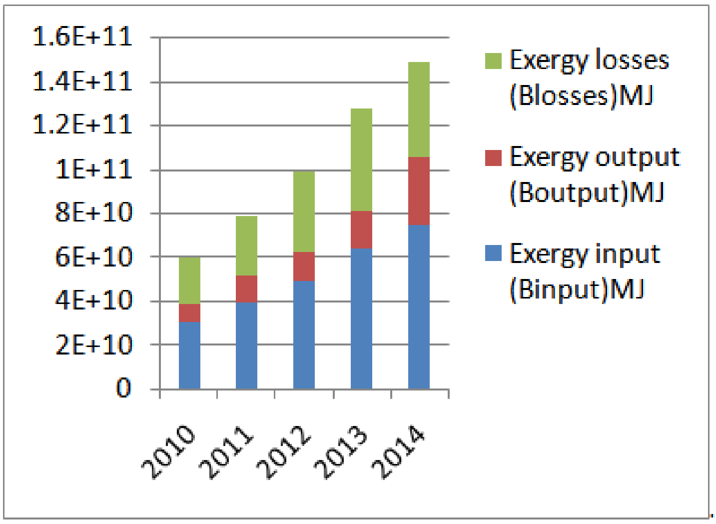

Figure3. Exergy quantities at quarrying unit operation

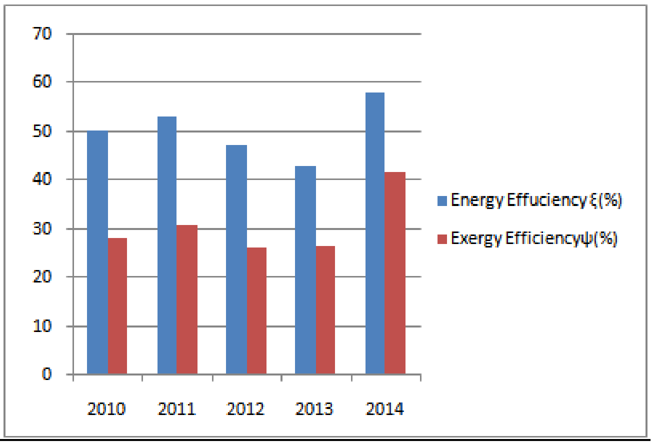

Figure4. Energy efficiencies versus exergy efficiencies at quarrying unit operation

3.2 Raw Materials' Preparation

In this section, the blasted limestone is fed into the crushers to produce crushed limestone. After which other raw materials are added for grinding operation. This unit is majorly powered by electricity.

This unit was found to be relatively efficient as the average energy losses over the selected period were minimal compared to other units as depicted in Fig. 5 below.The only major energy losses were the thermal losses from the fuel combustion process.

Therefore, thefairly high performance (63.2%) averagely estimated for this unit was as a result of large consumption of electrical energy which is an energy carrier of high quality.

As shown in Fig. 6 the exergy losses were also minimal over the period underconsideration which led to thefairly high exergetic efficiency of 52.6% asthe unit is majorly powered by electricity. This is also an indication of thermodynamic quality of electrical energy carrier.

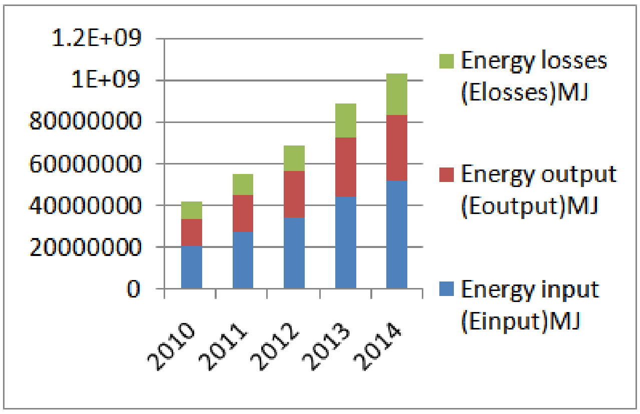

Figure5. Energy quantities at raw materials' preparation unit operation

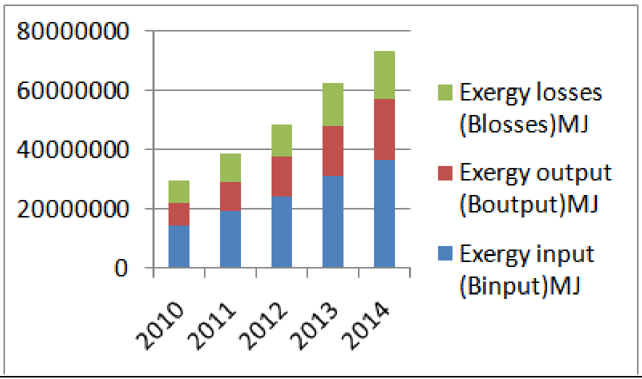

Figure6. Exergy quantities at raw materials' preparation unit operation

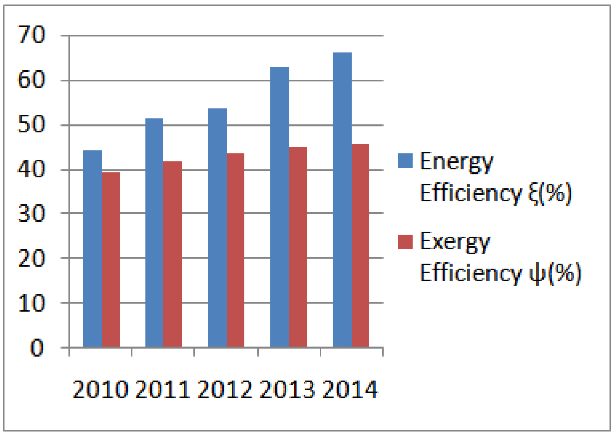

Figure7. Energy efficiencies versus exergy efficiencies atraw materials’ preparation unit operation

3.3 Pyroprocessing and Finish Grinding

Pyroproprocessing is the most energy-intensive operation in the production line of cement. This is where clinker is formed. The study showed that in this section, natural gas was utilized as the major thermal energy source for sintering the raw and turning it into clinker.

As shown in Fig. 8, due to the large amount of energy needed for drying and pre-heating process, the average energy input required for the operation was over 50% of the total energy input forthe plant. It can be further deduced for instance, that the energy loss in 2014 was 22.6% of the total energy losses for the selected period. This huge loss was as a result of the temperature associated with heat generation during the preheating and burning processes.

As regards exergy as it is depicted in Figure 9, the lower thermodynamic performance that occurred especially in 2014 was principally as a result of exergy losses in combustion and heat transfer processes.

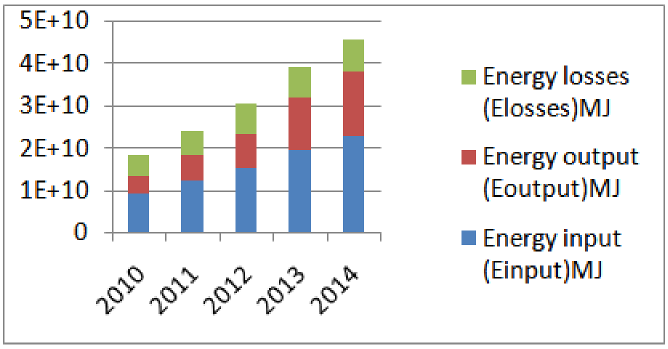

Figure8. Energy quantities at pyroprocessing and finish grinding unit operation

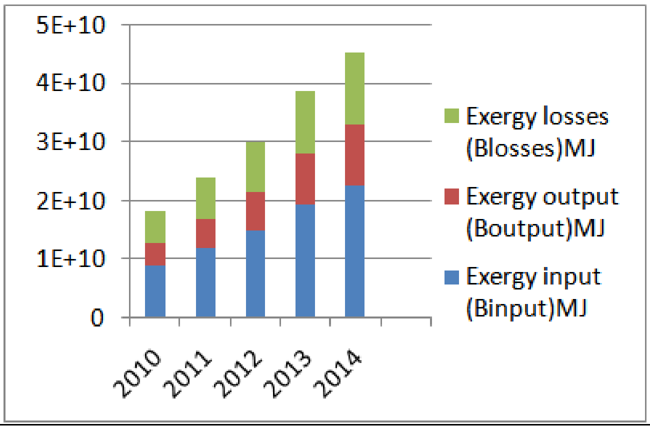

Figure9. Exergy quantities at pyroprocessing and finish grinding unit operation

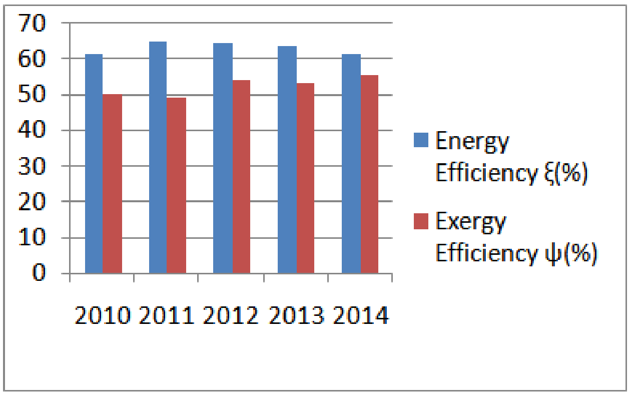

Figure10. Energy efficiencies versus exergy efficiencies atpyroprocessing and finish grinding unit operation

3.4 The Overall Efficiency of the Cement Plant

The values of the First and Second Law Efficiencies weredetermined and compared for the overall cement plant as presented in Fig. 11 below. That is, energy and exergy efficiencies were estimated for the plant performance analysis and improvement. The overall exergy-efficiency (42.2%) was found to be significantly lower than the corresponding energy-efficiency (56.5%).

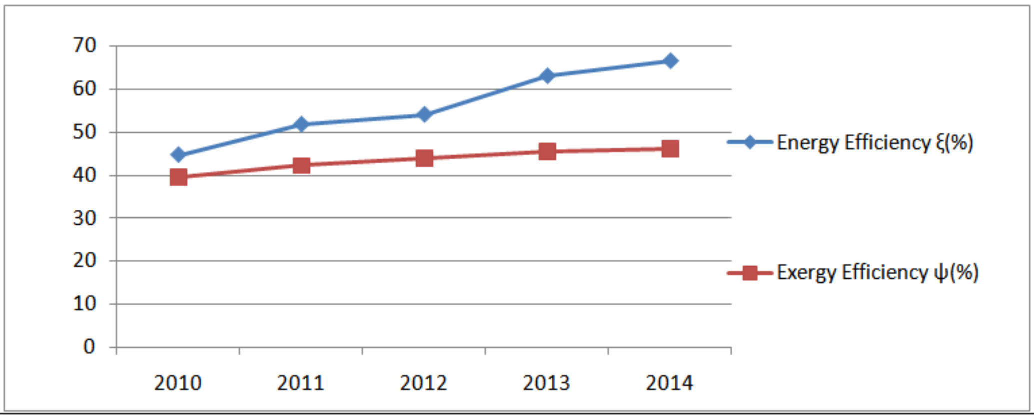

Figure11. Energy efficiency versus exergy efficiency of the overall plant.

IV. Conclusion and Recommendation

The study has been able to compare energy analysis and exergy analysis and it was discovered that exergy analysis demonstrated as a better effective tool for analyzing and comparing the true performance of various sources of energy by providing a clearer, more meaningful and useful accounting of efficiencies and losses in the thermodynamic system of the cement manufacturing plant selected.

From the study, clinker formation (pyroprocessing) was observed as the most energy-intensive unit operation in the production line of the plant as it required for drying and preheating processes over 50% of the total energy input for the whole plant.

It was also deduced from the results that there was discrepancy in the `efficiencies within the period selected for the study. This could be attributed to the degradation of the input energy associated with the internal consumptions, combustion processes, heat transfer processes and emission of gases during the production process, and operational factors such as age of the equipment installed, cost of energy, type of fuel available etc.

For future research, this work should be improved upon as the energy-exergy analysis is limited in some areas; environmental impacts are not dealt with. I therefore, recommend that the analysis be integrated with an effective environmental tool such as Life Cycle Analysis (LCA) as this will assess environmental impacts by estimating various emissions related to energy and material flows. Moreso, this recommended method should as well be applied to other manufacturing processes.

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