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Exergy Analysis of a Cement Manufacturing Plant in Nigeria

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Abstract*:Exergy balances at each stage of the cement productionline of a cement manufacturing plant of installed capacity 10.25 million metric tonneslocated in the North - Central region of Nigeria were carried out in this study. Datafor the period of 2010 – 2014were collected from the plant and the energy-intensive operations considered in the study include quarrying, preparation of raw materials, pyroprocessing and finish grinding. Pyroprocessingwas observed to bethe most energy-intensive unit operationas it required over 50% of the total energy input for the whole plant due to the huge amount of energy needed for drying, preheating, and calciningprocesses. Therefore, fromthe study theefficiency of the plant was estimated between39.3 – 47.8% over the period selected. The variance in the efficiencies was attributed to the degradation of the input energy associated with internal consumptions and exergy losses in combustion, heat transfer and emitted gases during the transportation ofenergy across each boundary of the production line. Consequently, the overall exergeticeffficiency of the plant was estimated at 42.2% for the selected period under review.*

Keyword:*Cement plant, Efficiency, Exergy, Exergy balances,Pyroprocessing*

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I. Introduction

In thermodynamics, the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir[1] That is, the maximum work that can be done by the composite of the system and a specified reference environment. Exergy is therefore, referred to as the energy that is available to be used (utilizable energy)

It is destroyed whenever an irreversible process occurs. It is conserved only when all processes taking place in a system and the environment are reversible. When an exergy analysis is performed on a systemthe thermodynamic imperfections can be quantified as energy destructions. Theseare losses in energy quality. It is important to note that, as energy can be transported across the boundary of a system so exergy does. Therefore, for each type of energy transfer there is a corresponding exergy transfer.

1.1 Statement of Problem

The consumption of finite resources like energy and materials in various energy-intensive manufacturing industries during production for example, in cement production increases at an alarming rate while reducing the value of industrial output. This can be attributed to the type of technology adopted for the production.

Energy analysis is characterized by the old method of assessing the way energy is used in an operation as it 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) The energy balance provides no information on the energy degradation during a process and does not quantify the usefulness or quality of the various energy and material streams flowing through a system and exiting as products and wastes.

Therefore, the limitations of the First Law of Thermodynamics (FLT) are overcome by the exergy method of analysis whose concept is based on both the First Law of Thermodynamics (FLT) and the Second Law of Thermodynamics (FLT)

Exergy is a useful quantity that stems from the Second Law of Thermodynamics (SLT). According to the First Law of Thermodynamics (FLT), energy cannot be destroyed during a process; it changes from one form to another. In contrast, exergy accounts for the irreversibility of a process as a result of increase in entropy according to the Second Law of Thermodynamics. It is destroyed whenever energy loses its quality.It is the part of energy which is useful. Therefore, it has economic value and is worth managing well [2]Exergy analysis involves indicating the locations of energy degradation in a process which leads to improved operation or technology by quantifying the quality of heat in a waste stream. The exergy analysis is the modern thermodynamicmethod used as an advanced tool for engineering processevaluation [3]

1.2 Literature Review

In recent years, the Exergy Analysis has been used as an important tool for understanding complex energy systems in various manufacturing industries. Fromthe search of the literature of the previous works, it was discovered that various researchers have employed the analysis to determine efficiency in the following industrial processes.

1.2.1 Power Plants

Exergy Analysis was employed by Resisted to identify the true nature of losses in power plants. He noted that energy losses arise in the condenser, and therefore offered little prospect of improvement other than by way of a 'bottoming' cycle. However, exergy analysis indicates that Second Law losses (Exergy losses) are associated with combustion processes and with heat exchangers. Making improvements at that end of the cycle will have the 'knock-on' benefit which gives rise to higher First Law Efficiencies (energy efficiencies) [4]

1.2.2 Fruit Juices

Theenergy consumption pattern and inefficiency in exergy expenditure of the Fruit Juices Processing Industry in Nigeria was determined. The quantities ofexergy losses and wastes were determined and located, and ways to address these losses and wastes were suggested [5]From the analysis, the total energy intensity for the fruit juice production was 1.12 MJ/Kg while the major exergy loss took place at the pasteurizer with an inefficiency of over 90%. This was as a result of the use of steam for the heating of the process steam [5]

1.2.3 Steel Plants

In 2001, MarcioMacedo Costa with other researchers applied the analysis for 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.Many other authors have also provided energy-exergy analysis of steel production. For instance, a more complete exergy life cycle inventory analysis was applied to the UK iron and steel industry using input–output Analysis.Lenzen and Dey calculated an energy content of 40GJ /t steel for the Australian steel industry [6]

1.3 Contribution to Knowledge

In this study,exergy analysis has been used in the estimation of the efficiency of a majorcement manufacturing plant in the North-Central region of Nigeria.

1.4 The Research Objectives

The objectives of the study were to determine the exergy input/output, the exergy losses, the locations and the causes of the exergylosses, the exergy efficiency in each manufacturing stage of the selected cement production and hence the overall exergetic efficiency of the plant.

1.5 The Cement Manufacturing Process

The basic inputs into cement manufacture include, limestone, red alluvium, shale and gypsum[7]Other raw materials are, clay, iron ore and sand. These materials are primarily quarried from local rock and in some cases from sources such as shell.Dust is the major emission from the extraction of raw materials which is, PM10 particulate matter with a size of 10μm or less.

Raw materials are heated to around 900°C in the preheater in counterflow heat exchange resulting in the decarbonation of calcium carbonate in the raw mix. In the rotary kiln, raw materials are further heated to 1450°C. The raw materials are then turned into clinker at this temperature as clinker production requires high temperature which is generated by the combustion of fossil and other fuels. Alternative fuels can be used in the kiln in order to reduce the consumption of fossil fuels thereby reducing emissions to atmosphere. Alternative fuels include wastes or by-products previously destined for landfill such as used tires,used engine oil and pent solvents. The clinker is rapidly cooled in the clinker cooler to enhance the desired mineralogy in the final product. Heat recovered from the kiln and cooler is recycled in the process to reduce fuel requirements. For finish grinding, clinker is ground with gypsum and supplementary cementitious materials and mineral additions to form the final cement product. Such supplementary materials include limestone, granulated slags and power station fly ash.These materials reduce the requirement for clinker in the cement and hence reduce the use of natural materials and the emission of CO_2 from clinker production.

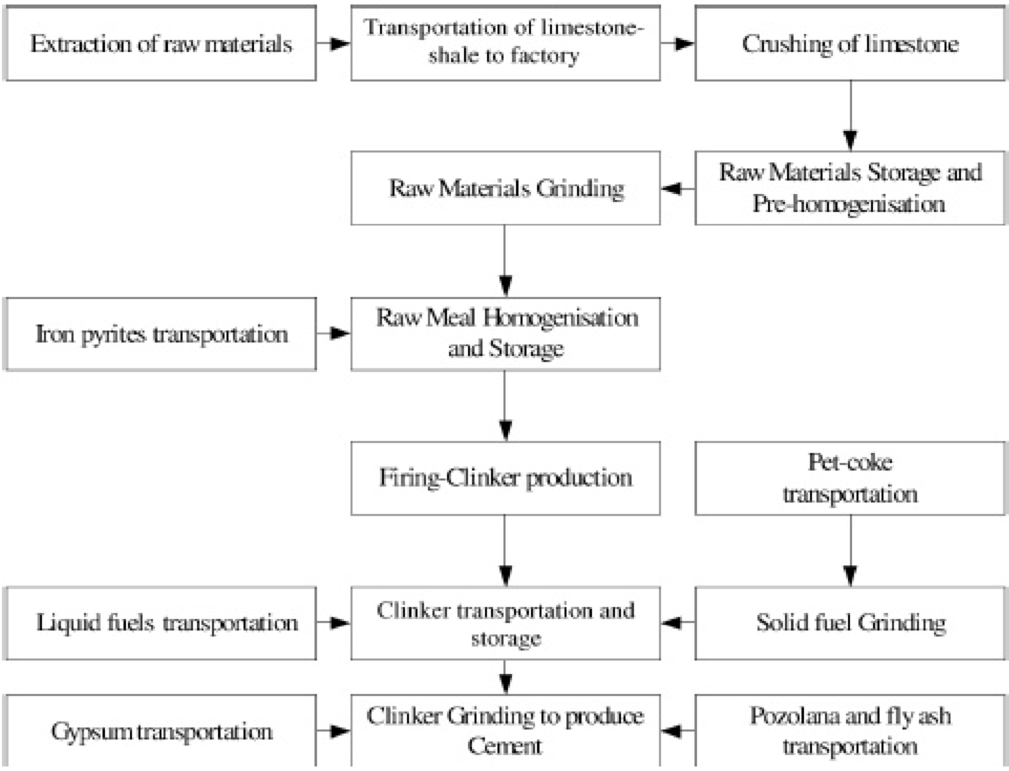

Figure 1. Cement production stages

2Study Methodology

Input-Output Analysis (IOA) was used in this study. IOA is a matrix of different parts of an entire economy and uses economic factors to calculate the exergy use [8] This is based on an economic input/output table in which different sectors of an economy are shown. The production values for a certain output can be calculated by combining all connections between the producing units under definite conditions. Therefore, using the economic input/output table, inventory results can be calculated. By knowing emission factors for each economic sector, emission coefficients can be deduced. Multiplying the production required in different units with the corresponding emission coefficients results in the emissions for the whole production process [9]

To carry out IOA, there are two I/O Tables required. They are,

(i) The I/O Table for the material transfer/production

(ii) The I/O Table for the exergy transaction

The matrix equation for the embodied exergy is given as follows:

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

Where,

E_e is the embodied exergy

$\boldsymbol{\partial}^{\mathrm{T}}$ is the direct exergy intensity vector given as:

$$\boldsymbol{\partial}^{\mathbf{T}} = \frac{\textbf{Total exergy used in the sector}}{\textbf{Total quantity produced in the sector}} \quad (2)$$

A is the technological matrix

I is the identity matrix

The general principles of the Input-Output Energy Analysis can be illustrated by referring to the generalized economic sector j as follows

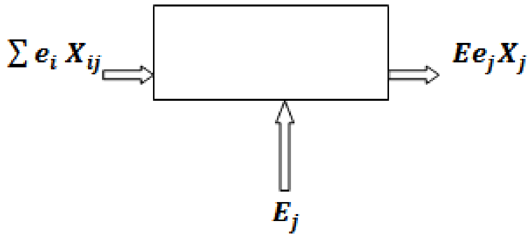

Figure 2. Generalized economic sector

Where,
X_{ij} is the transaction from unit i to unit j
X_j is the unit j total output
$e_j$is the embodied energy intensity per unit of 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

E_j= is the energy extracted from the earth which is non-zero for primary energy unit.

Therefore,

$$A_{ij} = \frac{X_{ij}}{X_j} \qquad (3)$$

$$e_j X_j = \sum E e_i A_{ij} X_{ij} + E_j \qquad (4)$$

Where,
A_{ij}=the fraction of the total output of unit j derived from inputs from unit i
$\sum e_i A_{ij} X_{ij}$=the sum of all energy inputs from the other units
$Ee_j X_j$= the total energy embodied in an output
In matrix notation, the energy balance is:

$$eA + E = eX \qquad (5)$$

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

2.1 DataAcquisition

The data used for the analysis were obtained from the cement manufacturing plant selected for the study.The plantwas split into three energy – intensive unit operations for the purpose of analysis as shown in table 1

Table 1. The Process Units of the Cement Manufacturing Plant

UNIT	PROCESS
1	Quarrying
2	Preparation of Raw Materials (Limestone Crushing and Raw Milling)
3	Clinker Formation andFinish Grinding

2.2 Performance Criteria

Performance indexes were calculated using exergetic balances in order to evaluate the effective use of energy within the process.This provides much more valuable information as the underlying idea of quality of energy is taken into consideration.

To calculate the thermodynamic efficiency of a process, there is a direct relation between the exergy flowing from the process, E_{OUT}, to that flowing into the process, E_{IN}. Therational efficiency is given by:

$$\psi = \frac{\sum \Delta E_{OUT}}{\sum \Delta E_{IN}} \qquad (6)$$

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 was formulated for the plant.

The concept of exergyalso incorporates a measure of the potential work obtainable from a system. Other thermodynamic potentials, such as Gibb's free energy, Helmhohz's free energy, available work and availability, define potential work for specified constraints. We use the function exergy B defined by [10]as follows:

$$B=U+P_oV-T_oS-\sum\mu_in_i \quad (7)$$

Where,

U is Internal Energy

P is Pressure

T is Temperature

S is Entropy

$\mu_i$is Chemical potential of each component

n_i is number of moles of each component.

The subscript "o" denotes the system when it is in equilibrium with its environment.

2.3 Exergy Model Equations

Exergy B for a closed system may be defined mathematically [11] as:

$$B = V(P - P_0) - S(T - T_0) - \sum n_i(\mu_i - \mu_{io}) \quad (8)$$

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

$$E_x = (H - H_o) - T_o(S - S_o) - \sum\mu_i(n_i - n_{io}) \quad (9)$$

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.

2.4 Exergy Balances

Given the physical and chemical exergies B of energy and material carriers for each step of a given production process, exergy losses can be calculated according to the following exergy balance shown in the figure 2 below.

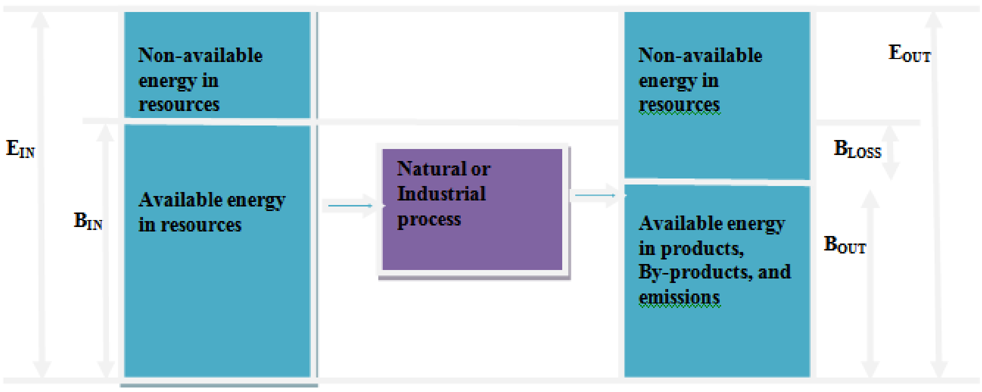

Figure3. Energy and exergy analyses

Exergy accounting for a process step in the production route of a cement product:

$$\boldsymbol{B_{inputs}} = \boldsymbol{B_{products}} + \boldsymbol{B_{losses}} + \boldsymbol{B_{wastes}} \quad (10)$$

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}denotes exergy 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:

$$B_{losses} = B_{inputs} - B_{products} - B_{wastes} \quad (11)$$

Some proper exergy efficiencies ψ can now be defined as:

$$\Psi_1 = \frac{B_{product} + B_{waste}}{B_{input}} \quad (12)$$

The performance index ψ_1 complement (i.e, 1 - ψ_1) indicates the input exergy that was lost. For instance, if ψ = 0.75, it means that 25% of the exergy inputs were lost with the exergy of wastes excluded:

$$\Psi_2 = \frac{B_{product}}{B_{input}} \quad (13)$$

The performance index ψ_2 indicates the useful exergy (exergy embodied in the main product and in the by- products) obtained from the exergy inputs:

$$\Psi_3 = \frac{B_{main\ product}}{B_{input}} \quad (14)$$

The performance index ψ_3 is related only to the exergy of the main product.For the perspective assumed in this study, ψ_2 is the most appropriate efficiency indicator to allow comparisons between different cement production routes as it considers products and by products as useful outputs and deducts the exergy embodied in wastes.

In any real engineering system (which is irreversible), exergy is degraded and the exergyefficiency is consequently less than unity.
Thus, an exergy efficiency, ψ can be defined as:

$$\psi = B_{OUTPUT}/B_{INPUT} = 1 - B_{OUTPUT}/B_{INPUT} < 1 \quad (15)$$

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

$$B_{losses} = B_{inputs} - B_{output} > 0 \quad (16)$$

2.5 Exergy of Electricity

Electricity may be regarded as an energy having a high quality that is, highexergy [12]
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. Consequently, he suggested that, it is useful to employ the concept of an exergetic improvement potential; IP, when analyzing different processes. It is given by:

$$IP = (1 - \psi)(B_{input} - B_{output}) \quad (17)$$

The exergy analysis provides an indication of the thermodynamic quality of an energy carrier. This is defined by the ratio of exergyto enthalpy in the floor Stream [13] as:

$$\Theta = \frac{B}{H} \quad (18)$$

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

2.6 Exergetic Potential of Process Heat

For process heat:

$$\Theta = \mathbf{1} - \frac{T_o}{T_p} \tag{19}$$

Where T_o/T_p = the process temperature ratio

The exergy:

$$(\Delta B) = m_i C_p\{(T_o - T_1) - T_o ln\, {}^{T_o}/_{T_o}\} \tag{20}$$

Standard temperature and pressure (T_o = 298.15K (25^oC) and P_0= 1 atrn) was employed for this analysis [12]

2.7 Estimation of Exergy at Quarrying Unit Operation
There are three forms of energy utilized in this unit namely,
1. Chemical Explosive Energy: There are two types. They are
Ammonium Nitrate Fuel Oil (ANFO) $C_{0.37}H_{4.7}N_2O_3$ - Low chemical explosive
Nitroglycerin $C_3H_5(NO_3)_3$ - High chemical explosive

For the estimation of chemical explosive exergy$B_{explosive}$, the work potential of the explosives was determined by following these steps:
(a) Deriving a chemical equation from the explosive reaction.
(b) Obtaining the heat of formation which is the energy released during the process.
(c) Obtaining the work potential of the explosives (the exergy input by the explosives) using steps (a) and (b)

The reaction products from the detonation of ANFO is given in the balance equation given below:

$$C_{0.37}H_{4.71}N_2O_3 \rightarrow 0.37CO + 2.36H_2O + N_2 + 0.14O_2 \tag{21}$$
(products of reaction from the ANFO detonation)

The reaction products from the deflagration of Nitroglycerin is given in the balance equation given below:

$$C_3H_5(NO_3)_3 \rightarrow 3CO_2 + 2.5H_2O + 1.5N_2 + 0.25O_2 \tag{22}$$

Therefore, exergy input is obtained using the following equation:

$$Q_{ev} = Q_{ep} + W \tag{23}$$

From(23) above, the conversion of energy to work in the constant pressure state can be expressed as follows:
Where Q_{ep} = Total heat given off by 1mole of explosive at 15°C for constant pressure (atm)
W = Work energy expended during an explosion for pushing the surrounding air.
Here Q_{ev} = Work potential (exergy input by the explosive)

2.7.1Exergy Losses
Exergy losses in the quarrying unit operation can be considered in two stages namely,

(i) Exergy loss with the use of ANFO
The general equation given below was used for the estimation of the physical exergy loss:

$$\boldsymbol{B_{ph} = m_i C_p\{(T_1 - T_o) - T_o\left(ln\, {}^{T_1}/_{T_o} - Rln\, {}^{P_1}/_{P_o}\right)\}} \tag{24}$$

Pressure component is eliminated since it is at constant pressure and the equation is reduced to:

$$\boldsymbol{B_{ph} = m_i C_p\{(T_1 - T_o) - T_o ln\, {}^{T_1}/_{T_o}\}} \tag{25}$$

T_o = 273.15K + 25^{0}C

C_p = specific heat capacity

This equation was used to estimate the lost physical exergy due to the emission of carbon monoxide (CO), water vapour(H_2O), Oxygen (O_2) and Nitrogen (N_2)

(ii) Exergy Loss with the use of Nitroglycerin:
To determine the lost physicalexergy due to the emission of gases at the nitroglycerin detonation, (25) was also applied. The temperature of explosion is 218^0C.
T_o = 273.15K + 25°C
T_1 = 218°C + 273.15K
C_p = specific heat capacity.

Lost exergy due to fuel that is,exergy loss due to fuel is estimated as follows:

$$B_{\text{fuel (loss)}} = C_f W \tag{26}$$

Where,
C_{fuel}= the calorific value of the fuel
W = Quantity of the fuel used

Therefore, the total exergy loss due to explosives and fuel:

$$B_{\text{(Total losses)}} = B_{\text{loss (explosives)}} + B_{\text{loss (fuel)}} \tag{27}$$

(ii) Thermal Energy: This is derived from the fossil fuel (diesel) to run the internal combustion engine of the truck conveying the limestone.

Exergy from fossil fuel was assigned to this unit operation according to its level of consumption. The total quantity of exergy consumed from fossil fuel was estimated by multiplying the quantity of fuel consumed by the corresponding calorific value (lower heating value) of the fuel used [14]Exergy input for fuel (MJ) can be obtained using (26) above.

(iii) Electrical Energy

In this unit, the exergy content is as large as the energy content. Therefore, the exergy input from electricity is equivalent to the energy content of the total electricity consumed.

$B_{\text{input (electricity)}}$ = the electricity consumed.

2.8 Estimation of Exergy at Raw Materials Preparation Unit
The input sources of energy in this unit are as follows,
The thermal energy of the fuel combustion process

Exergy input for diesel:
Thermal exergy from fossil fuel was estimated by multiplying the quantity of fuel consumed by its lower heating valueusing (26) above.

Electrical Exergy:
The exergy content is as large as the energy content. Therefore, the exergy input from electricity is the same value as the energy content of the total electricity consumed.
The conversion factor used: 3.6MJ = 1KWh

2.9 Estimation of Exergy(Clinker Formation andFinish Grinding)
Pyroprocessing is the most technical and energy intensive operation from quarrying to cement production. The 1870°C flame heats up the mixture to about 1450°C.The extreme heat triggers a series of chemical reactions. The raw material breaks down(calcine), becomes partially molten, and fuse together into nodules called clinker.
Calcination of the calcium carbonate ($CaCO_3$) to calcium oxide (CaO) with the evolution of carbon dioxide (CO_2) at about 900°C takes place during pyroprocessing.
Clinker is formed as the material approaches the exit of the kiln at temperature of approximately 1,500°C.

Energy transaction of the process is in three stages. These are,

(i) Preheating Stage:
The exergy input due to the preheating process can be determined by using the following equation:

$$B_{input} = mC_p \; [T_1\text{-}T_o - T_o \ln T_1/T_o] \tag{28}$$

Where m= mass of the natural gas used

C_p= Specific heat capacity
T_o= 273.15K + 25°C = 298.15K
T_1= 273.15 + 900°C = 1173.15K

(ii) Calcination Stage:
The decomposition of the limestone (calcination) took place in the system. Determining the chemical composition of the limestone and shale, the resulting calcination energy required by clinker is given by the following equation:00000

$$\left[\frac{CaO\%}{100-CO_2\%}\times\frac{\Delta H_1^0}{MW_{(CaO)}}\right]+\left[\frac{MgO\%}{100-CO_{2\%}}\times\frac{\Delta H_2^0}{MW_{(MgO)}}\right] \tag{29}$$

(iii) Burning exergy at sintering stage
Exergy input due to the chemical exergy of the fuel (natural gas) can be calculated as follows:

$$\varphi = \frac{B^o_{Na}}{NCV} \tag{30}$$

NCV = net caloric value of natural gas
$B^o_{Na} = \varphi \;\; X \;\; NCV$

The chemical of the heavy fuel φ by mass is calculated from using the following equation:

$$\varphi = 1.0401 + 0.1728\,{}^H/_C + 0.0432\,{}^O/_C + 0.2169\,{}^S/_C[1-2.0628\,{}^H/_C] \tag{31}$$

where
C = Carbon
H = Hydrogen
O = Oxygen
S =Sulphur

2.9.2 Exergy losses during burning and cooling
Exergy losses in the clinker production can be considered in two stages namely,
(i) Clinker Coolers
During the clinker production process, this is the first point of exergy loss. That is, from the clinker coolers where the preheater exhaust and the hot air are ejected. This is due to the cooling of the hot clinker to a lower temperature and this was estimated using the following exergy of heat equation:

$$\mathbf{B_{HEAT}} = \left(\mathbf{1} - \frac{\boldsymbol{T_O}}{\boldsymbol{T}}\right) \times \boldsymbol{Q} \tag{32}$$

Where:
T_o = Exiting temperature of clinker from coolers
T = Temperature of clinker before entering the cooler
Q = Total heat transfer rate(KW)

(ii) Process Emission of Gases
Another source of exergy losses in the production of clinker is the process emission of carondioxide (CO_2), oxygen (O_2) etc. from the kiln into the atmosphere. These are emitted into the atmosphere at temperature range of 900°C to 980°C.

The specific exergy of the emitted can be estimated at the sintering stage:

$$B = C_p [T_1 - T_o \ln T_1/T_o] \quad (33)$$

Cp = Specific heat capacity of gas
T_o = initial temperature
T_1 = exit temperature

For the finish grinding of the cooled clinker, electrical energy is mainly used. Here again the exergy content is as large as the energy content. Therefore, the exergy input from electricity is equivalent to the energy content of the total electricity consumed.

2.10 The Overall Efficiency of the Cement Plant

This was estimated by considering the average efficiency of all the operation units based on exergy for each year. Then the average of the values obtained was taken as the exergy efficiency of the whole plant for the period selected.

II. Results and Discussion

The parameters for evaluating exergy in each unit operation of cement processing were collected from the production unit of the plant.

As shown in Fig. 4, the exergetic efficiency kept on declining from 2011 to 2013. This was due to the fact that input sources of exergy in this unit operation were majorly chemical explosives and diesel (AGO). The blasted limestone was produced 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, carbon monoxide, carbon dioxide, oxygen and nitrogen, and the major source of exergy loss in this unit was through 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 2013 when theexergy losses were greatly reduced due to some modernization on the plant. The exergy performance of this unit for the selected period was estimated at 28% which can be attributed to the overallexergy loss experienced the period.

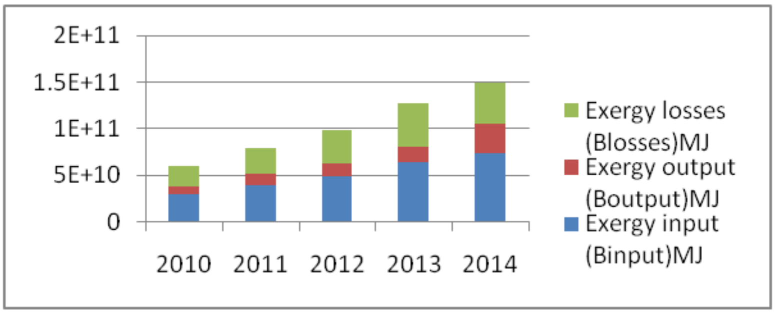

Figure4. Exergy quantities (Quarrying)

As shown in Fig. 5below the exergy losses were minimal over the period under consideration which led to the high exergetic efficiency of 52.6% as the unit is majorly powered by electricity and the exergy analysis provides anindication ofthermodynamic quality of electrical energy carrier.

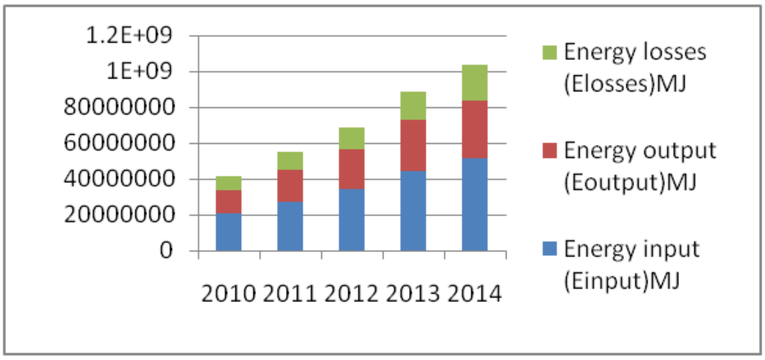

Figure 5. Exergyquantities (Raw materials' preparation)

From the Fig. 6 below, it was deduced that thelow thermodynamic performance that occurred in this unit operation during the period selected especially in 2010 was principally as a result of exergy losses in combustion and heat transfer processes.

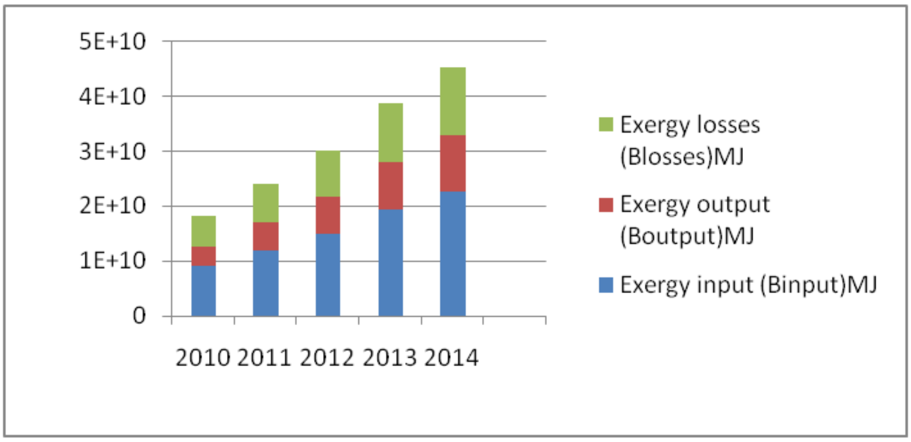

Figure 6: Exergy quantities (Clinker formation and grinding)

As shownin Fig.7 below, the overall exergy efficiency was estimated by considering the exergy efficiencies of all the unit operations ofthe plant for the period between 2010 and 2014 and found to be 42.2% .

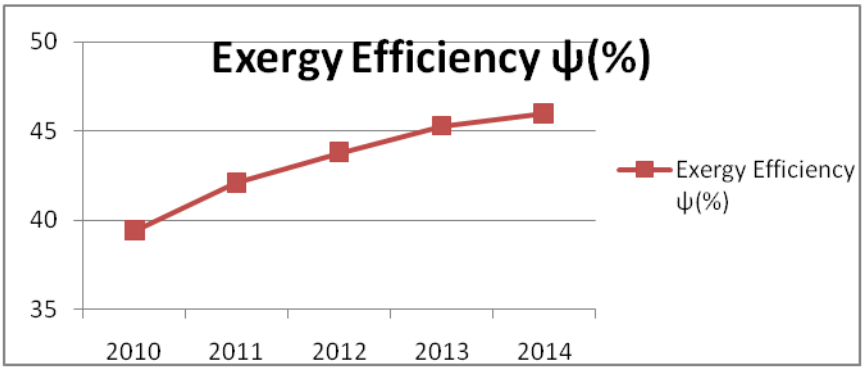

Figure 7: Overallexergy efficiency ψ(%)

III. Conclusion

Exergy analysis has been employed as an effective tool to determine the energy quality or work potential for assessing the thermodynamic efficiency of the selected industrial processas shown from the study. From the result, the performance of the cement plant was generally improved as the exergetic efficiency of the plant increased over the period due to some modernization.However, the analysis ignored the impact of emissions, this limitation can be overcome by applying the extension of exergy analysis which is Exergetic Life Cycle Analysis. This is integrating both Life Cycle Analysis and exergy analysis to a manufacturing process in order to give a better insight to each processing unit not only in terms of evaluating environmental impacts but also identifying the inefficient units or products based on exergy. Another benefit of complementing both tools is that the effort put into inventory is reduced while simultaneously improving the quality of data and obtaining faster development of treatment data. To consider the exergy consumed simultaneously with associated environmental impacts in all processes that transform resources into economic products,Exergetic Life Cycle Analysis is hereby recommended for future research.

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