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The Effect of Excess Heat Utilization on the Production Cost of Cement

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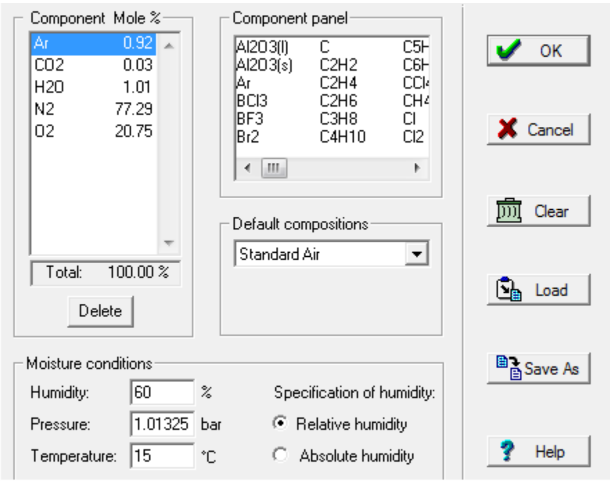

Highlights:

- Studies of excess heat in the typical cement industry have been studied.
- Optimization of production costs in a cement factory is simulated.
- Excess heat can be utilized in pre-heated boilers.
- Savings of more than two billion dollars can be achieved in production costs per year.

Abstract

Industrial excess heat is a largely untapped resource that has the potential for external use that would be beneficial to the cement industry. Therefore, this work studied the excess heat utilization for the optimization of production cost in a cement plant within a period of three years. The study of plant layout in the selected plant in Nigeria (Ewekoro II Cement Plant of 200 tonnes/hour) was carried out to identify areas where excess heat is generated. The temperature and static pressure of precalciner, kiln, and cyclone were taken using a temperature probe, pitot tube, digital manometer, and light-emitting diode temperature reader. These parameters were used to obtain the mass flow rate and heat transfer needed for the heat energy analysis of the system. The kiln was maintained at constant tonnage per hour through a clinker truck weighed using the weighbridge. The result showed that the heat generated from the kiln was 577,640,260 MJ/hr. through excess air draft of 780,000 m^3/hr (89.4%) at 250 °C and induced draft fan of 900,000 m3/hr at 350 °C. The result showed that excess heat can be utilized in pre-heater and air quenched cooler boilers, steam turbines and auxiliaries, and generators. The total estimated heat that could be saved amounted to 344,648,250 MJ with a total annual capacity of 2.25 million tonnes of cement. A saving of over two billion dollars could be achieved in production cost per year.

Keywords: Cement, Production cost, Excess heat utilisation, Energy saving

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1. Introduction

The cement manufacturing process demands large amount of energy, with a large amount of it being lost due to inefficiencies. Most of the energy losses occur in the form of heat and sound, with improvements relating to the combining and reusing of heat for drying and other production purposes within the plant. Cement firms are facing significant problems in the area of energy conservation, since overall energy expenses (thermal and electrical) account for 30 to 40% of total production costs, and cement is a vital component in worldwide housing and infrastructure construction [1].

To trigger the reaction and phase shifts required to generate the complex mineral compounds that give cement its qualities, the cement industry requires extremely high temperatures. The operational stage of pyro-processing in a large rotating kiln supplies the energy and environmental conditions required for the reaction and phase transition [2]. Use of excess heat can provide a way to reduce the use of primary energy and to contribute to global CO_2 mitigation as reported by Broberg and Johansson [3], and SWEP [4]. Portland cement is produced by means of one of the most energy intensive industrial processes with thermal energy consumption from 3100 to 7300 MJ/t, while electric energy consumption is about 147 kWh/t [4-5]. As a result, numerous energy-saving solutions have been proposed, such as recovering sensible heat from the kiln. Kiln operation that is both efficient and steady can minimize energy consumption and maintenance costs while also increasing kiln output and improving overall product quality [6]. To facilitate the production of the clinker stages, the material sinters and partly fuses. Tricalcium silicate, dicalcium silicate, tri'-calcium aluminate, and calcium aluminoferrite are the main phases of cement clinker [7]. With the addition of a few percent of gypsum, the clinker is cooled and pulverized to a fine powder. The end output is what is known as commercial Portland cement.

Several studies [8-10] conducted research on effective use of excess heat in a cement plant, they found clinker cooler, hot gases, and kiln surface as heat recovery sources. Then, other studies were conducted on different ways of saving energy in cement production. Lowering fuel costs, increasing clinker output, lowering electricity usage, and lowering greenhouse gas emissions are all benefits of successful waste heat recirculation. Meyer and Lambert [11] discovered a reduction in energy usage by modifying the coal mill operation using pre-heater exhaust gas for high volatile coal and using 14% fuel for the pyro-system. Diener *et al.* [12] also reported that by using waste heat at precalciner, excess moisture will be eliminated which would reduce energy consumption in clinker production. Huge amount of heat is used in the production of clinker and with a slight reduction in temperature, the heat has been flared out together with some percentage of clinker dust which can also be converted to a useful product. This practice increases production costs by using high energy and it pollutes the environment. International Financial Corporation [13] reported no waste heat recovery was installed in Nigeria's cement plant as of 2012. Therefore, this work studied the effect of excess heat utilization on the production cost of cement.

2. Materials and Method

In this work, the materials involved the raw meal, clinker, gypsum, cement, coal, air, water, and steam. The method employed involved preliminary plant layout study, temperature and pressure measurements, truck weighing, waste heat recovery and reuse, exergy and energy analyses for the cement plant, mass analysis in the rotary burner (RB), heat losses by conduction and radiation, and determination of energy efficiency, and waste heat utilization in steam turbine using cycle tempo software.

2.1. Preliminary study of plant layout

A study of the record of kiln burner inlet and outlet temperatures was done. Clinker cooler, suspended preheater, cooling tower, and bypass lines were included in the preliminary study. System audits and heat inputs calculations were carried out. Complete analysis of fuels for burning, sensible enthalpy, kiln feed, and the air was undertaken. Coal drying and cement grinding temperatures were measured.

2.2. Temperature and pressure measurements

The LED reader and thermocouple probe were employed for the temperature measurement according to earlier investigators [14-15]. The digital manometer using the air hose and the pitot tube inserted into the cyclone were used to measure the static pressure readings. Several readings were taken by varying the position of the tube in the duct to obtain enough representative static pressure values as possible.

2.3. Clinker trucks weighing in and out

Kiln was maintained at a constant tonnage per hour (TPH) for 24 hours with the dust at down comer returned to the kiln. The clinker was then diverted to off-specification silo (which was completely emptied before the activity). The time of the diversion was noted and recorded. The trucks were weighed empty and with clinker loaded; values were recorded for each transfer from the off-specification clinker silo to the dump site.

2.4. Waste heat recovery and reuse

Using Organic Rankine cycle principle, excess heat was recovered at the pre-heater and Air Quenched Cooler (AQC). Through the Pre-Heater (PH) heat recovery boiler and the AQC heat recovery boiler, the feed water recovered the heat energy wasted by the 5000 t/d cement clinker production plant and converted it into superheated steam, which was then delivered into the steam turbine through the steam pipe. Heat energy was turned into kinetic energy in the steam turbine, which powered the turbine to create electricity. The flue gas after AQC boiler flew through the kiln Bag filter for de-dusting and then vented to the atmosphere. The flue gas after PH boiler was extracted to dry raw materials.

3. Theory and Calculation

3.1. Exergy and energy analyses for the cement plant

For a general steady state, steady-flow process, the following equations are applied to find the work and heat interactions, the rate of exergy decrease, the rate of irreversibility, the energy and exergy efficiencies. These are given in Eqs. (1) to (14).
The mass balance equation can be expressed in the rate form as

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (1)$$

where ṁ is the mass flow rate in Kg/s, and the subscript 'in' stands for inlet and 'out' for outlet.
The general energy balance can be expressed as:

$$\sum \dot{E}_{in} = \sum \dot{E}_{out} \quad (2)$$

$$\dot{Q} + \sum \dot{m}_{in} h_{in} = W + \sum \dot{m}_{out} h_{out} \quad (3)$$

where $\dot{E}_{in}$is the rate of net energy transfer in (J/s) , $\dot{E}_{out\,out}$ is the rate of net energy transfer out by heat, work and mass, $\dot{Q} = \dot{Q}_{net,in} = \dot{Q}_{in} - \dot{Q}_{out}$ is the rate of net heat input, $\dot{W} = \dot{W}_{net,out} = \dot{W}_{out} - \dot{W}_{in}$ is the rate of net work output, and h is the enthalpy.

Assuming that there are no changes in kinetic and potential energies due to heat or work transfers, the energy balance provided in Eq. (3) may be reduced to flow enthalpies as shown in Eq. (4):

$$\sum \dot{m}_{in} h_{in} = \sum \dot{m}_{out} h_{out} \quad (4)$$

The general exergy balance can be expressed in the rate form as:

$$\sum \dot{E}x_{in} - \dot{E}x_{out} = \sum \dot{E}x_{dest} \text{ ; or}$$
$$\sum \left(1 - \frac{T_0}{T_k}\right)\dot{Q}_k - \dot{W} + \sum \dot{m}_{in}\varphi_{in} - \sum \dot{m}_{out}\varphi_{out} = \dot{E}x_{dest} \quad (5)$$

where T_0 is outside temperature (K), T_k is Kelvin temperature (K), $\dot{Q}_k$ is heat flow rate (kW) through the boundary, $\dot{W}$ is rate of work done(kW), φ is free energy (J), and $\dot{E}x_{dest}$ is energy destroyed, with:

$$\varphi = (h - h_0) - T_0(S - S_0) \quad (6)$$

where φ is the free energy function (J), h is enthalpy (kJ/kg), h_0 is enthalpy outside, T_0 is temperature outside (K), S is entropy (J/K) while S_0 is outside entropy. The amount of thermal exergy transfer associated with heat transfer Q_r across a system boundary *r* at constant.

$$ex^Q = [1 - \left({T_0}/{T_r}\right)]Q_r \quad (7)$$

The exergy of an incompressible substance may be written as follows:

$$ex_{ic} = C(T - T_0 - T_0 ln\frac{T}{T_0}) \quad (8)$$

where C is the specific heat (J/Kg·K) while ex_{ic} is the net exergy (J) input during the charging period. All exergy intake is expressed as utilized exergy, and all exergy output is expressed as utilised exergy. Therefore, the exergy efficiency ε_1 becomes.

$$\varepsilon_1 = \frac{\dot{E}x_{out}}{\dot{E}x_{in}} \quad (9)$$

Often there is a part of the output exergy that is unused, that is in an exergy wasted, $\dot{E}x_{waste}$ to the environment. In this case, exergy efficiency can be written as follows:

$$\varepsilon_2 = \frac{\dot{E}x_{out} - \dot{E}x_{waste}}{\dot{E}x_{in}} \quad (10)$$

The rational efficiency is defined as the ratio of the desired exergy ouput to exergy used, namely:

$$\varepsilon_3 = \frac{\dot{E}x_{desied\ output}}{\dot{E}x_{used}} \quad (11a)$$

where $\dot{E}x_{desired\ output}$ is all exergy transfer rate from the system, which must be regarded as constituting the desired output, plus any by product that is produced by the system while $\dot{E}x_{used}$ is the required exergy input rate for the process to be performed. The exergy efficiency given in Eq. (11a) may also be expressed as follows:

$$\varepsilon_3 = \frac{Desired\ exergetic\ effect}{exergy\ used\ to\ drive\ the\ process} = \frac{product}{fuel} \quad (11b)$$

The product reflects the system's desired result (power, steam, or some mix of power and steam), which is compatible with the reason for acquiring and operating the system. The fuel signifies the resource used to create the product and not needs to be an actual fuel such as natural gas, oil, or coal. According to Murray and Peace [16], both the product and the fuel are expressed in terms of exergy. The maximum improvement in the exergy efficiency for a process or system is obviously achieved when the exergy loss or irreversibility $(\dot{E}x_{in} - \dot{E}x_{out})$ is minimised. Consequently, he suggested that it is useful to employ the concept of an exergetic "improvement potential" when analsing different processes or sectors of the economy. Campadi [17] gave the improvement potential in a rate form denoted IP.

$$\text{IP} = (1 - \varepsilon)(\dot{E}x_{in} - \dot{E}x_{out}) \quad (12)$$

where $E_{in}$is the rate of net energy transfer in, E_{out} is the rate of net energy transfer out by heat, work, and mass. $\dot{Q} = \dot{Q}_{net,in} = \dot{Q}_{in} - \dot{Q}_{out}$ is the rate of net heat input, then

$$\dot{W} = \dot{W}_{net,out} = \dot{W}_{out} - \dot{W}_{in} \quad (13)$$

where $\dot{W}$is the rate of net work done.

3.2. Mass analysis in the rotary burner

The mass balance of the RB, which is performed according to the chemical reactions of the components are based on the law of conservation of mass in Eqs. (14a) and (14b).

$$\sum m_{in} = \sum m_{ex} \quad (14)$$

where,

$$\sum m_{in} = m_{coal} + m_{air} \quad (14a)$$

and

$$\sum m_{ex} = m_{clinker} + m_{Dust} + m_{s\text{-}gases} \quad (14b)$$

3.3. Energy analysis in the rotary burner

3.3.1. Energy analysis

The kiln's energy analysis is based on the law of conservation of energy. The following equation may be written when this law is applied to a system including chemical processes [18]:

$$Qcv + \sum_{in} m_{in}\left(h_f^o + \Delta h + \frac{V_{in}^2}{2} + {}^{gG}zin\right) = Wcv + \sum_{ex} m_{ex}\left(h_f^o + \Delta h + \frac{V_{in}^2}{2} + {}^{gG}zex\right) + Q_L \quad (15)$$

where Qcv is the heat energy of conservation (J), m_{in} is the mass (kg) inside, h_f^o is the enthalpy of formation (kJ/kg), Δh is change in enthalpy, v_{in} is velocity of gas inside (m/s), ^{gG}z is acceleration due to gravity (ms^{-2}) of gas zone (in for internal, ex for external), Wcv is work done (J) in energy conservation while Q_L is heat energy (J) left or in liquid form. The followings are assumed for the energy analysis:

- Heat (Q_{cv}) is not given out of the system.
- Electrical energy (W_{cv}) used for the kiln to rotate is not included.
- Kinetic and potential energies of materials going into and leaving the system are neglected.

Eq. (15) can be written as Eq. (16) when the assumptions above are taken into consideration.

$$\sum_{in} m_{in} h_{T,P} = \sum_{ex} m_{ex} h_{T,P} + \sum QL \tag{16}$$

where,

$$h_{T,P} = h_f^0 + \Delta h \tag{17}$$

$$\Delta h = \int_{298}^{T} c_p dT \tag{18}$$

$$c_p = a + bT + cT^{-2} \tag{19}$$

The a, b and c coefficients in Eq. (19) change with material types.

3.3.2. Heat loss by conduction from the surface of the RB

Heat loss by conduction from the surface of the RB as shown in **Figure 1** is given by the following Eq. (20) [13]:

$$Q_{cond} = \frac{T_{in1} - T_{sur1}}{\frac{\ln(r_2/r_1)}{2\pi k_{202} l_1} + \frac{\ln(r_3/r_2)}{2\pi k_{br-Al2O3} l_1} + \frac{\ln(r_4/r_3)}{2\pi k_{s2s} l_1}} + \frac{T_{in2} - T_{sur2}}{\frac{\ln(r_2/r_1)}{2\pi k_{202} l_2} + \frac{\ln(r_3/r_2)}{2\pi k_{br-MgO} l_2} + \frac{\ln(r_4/r_3)}{2\pi k_{s2s} l_2}} + \frac{T_{in3} - T_{sur3}}{\frac{\ln(r_2/r_1)}{2\pi k_{202} l_3} + \frac{\ln(r_3/r_2)}{2\pi k_{br-Al2O3} l_3} + \frac{\ln(r_4/r_3)}{2\pi k_{s2s} l_3}} \tag{20}$$

where r_1 is the internal radius kiln entry, r_2 is the external radius of kiln entry, r_3 is the internal radius of kiln exit while r_4 is the external radius of kiln exit. T_{in1} is the internal temperature of kiln entry (K) while T_{sur1} is the surface temperature of kiln entry (K). T_{in2} and T_{sur2} represent temperature of internal and external pre-calcining zone of the kiln respectively. Tin_3 and $Tsur_3$ represent the internal and external temperatures of calcining zone of the kiln respectively. K represent the radius of clinker at different lenghts of the kiln from l_1 to l_3. Al_2O_3 is alumina and MgO is magnesia are components of kiln feeds.

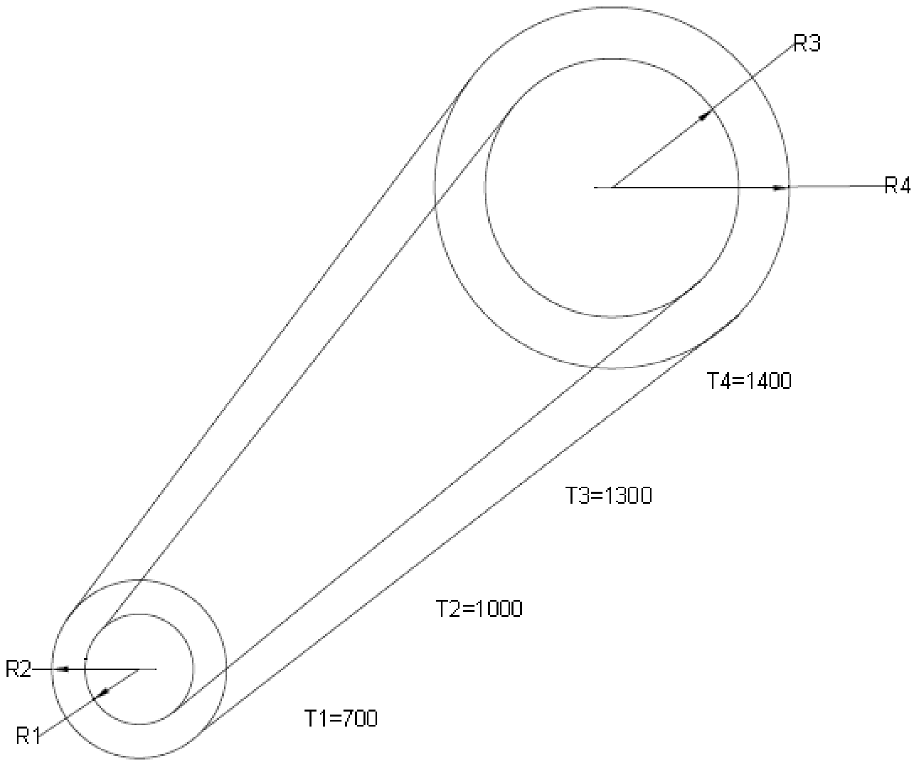

Figure 1. Shemantic diagram of Rotary Burning Kiln with shown temperatures in °C

3.3.3. Heat loss by radiation from inlet of RB, by convection from surface of RB

Heat loss from the left and right ends of the RB intake can be determined using Eq. (21), heat loss from the surface can be computed using Eq. (22) and total heat loss may be calculated using Eq. (23):

$$\dot{Q}_{rad} = \sigma\varepsilon(T_{in}^4 - T_0^4)A \quad (21)$$

$$\dot{Q}_{conv} = hA(T_{sur} - T_0) \quad (22)$$

$$\sum \dot{Q}_L = \dot{Q}_{cond} + \dot{Q}_{rad} + \dot{Q}_{conv} \quad (23)$$

3.4. Energy efficiency

The ratio of energies leaving the RB to energies entering the RB is used to calculate energy efficiency. Consequently, Eq. (24) may be used to express the energy efficiency and its outcome:

$$\eta = \left|\sum m_{ex} \cdot (h_{T,P})\right| / \left|\sum m_{in} \cdot (h_{T,P})\right| \quad (24)$$

3.5. Waste heat utilization in steam turbine

The optimization of the excess heat for the operation of gas turbine was carried out using cycle tempo software. The result obtained is contained in section 4.3

4. Results

The plant layout of the cement production system with potential of reusing waste heat is given in **Error! Reference source not found.**. The readings obtained from temperature and p ressure measurements of pre-calciner, preheater, rotary kiln, coolers and generator are contained in **Table 1**, **Table 2**, **Table 3**, and **Table 4**.

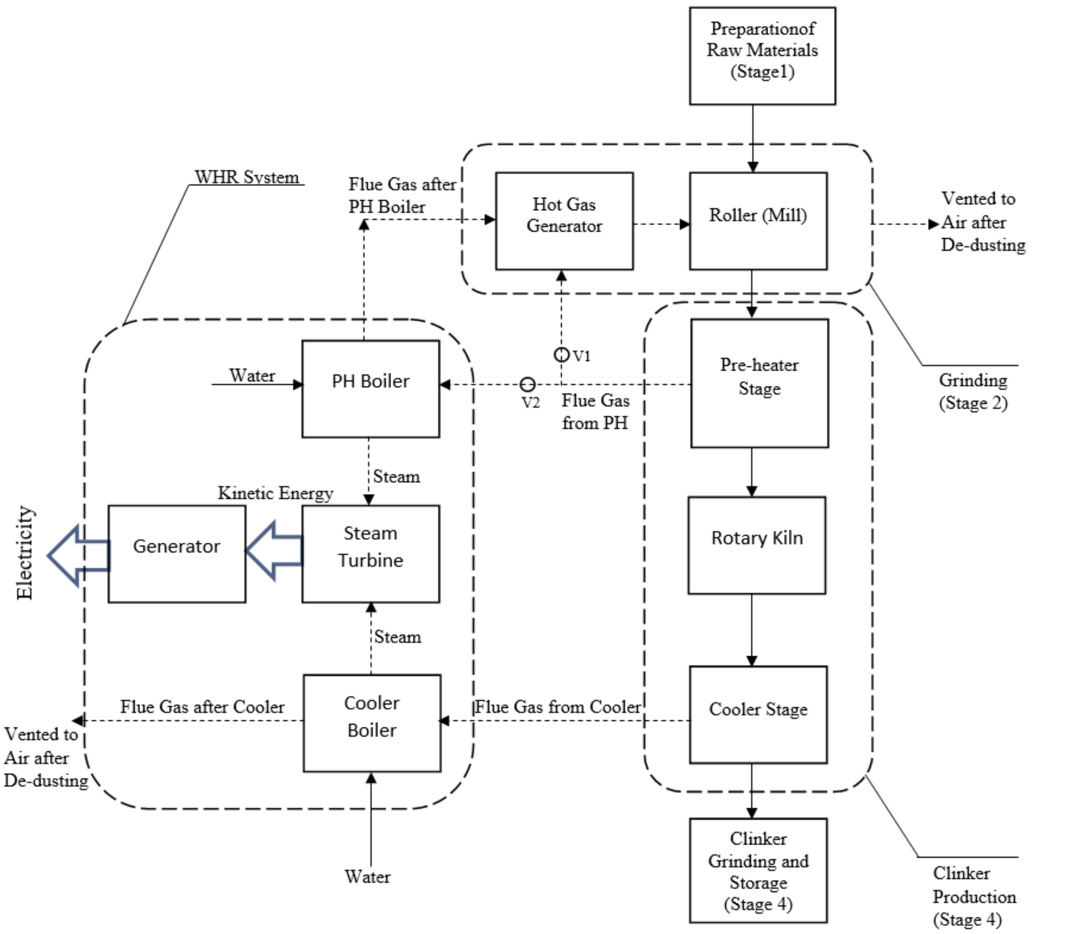

Figure 2. Flowchart of new dry process clinker production with WHR system [9]

Table 1. Pre-heater temperature and pressure measurements

Cyclones		A	B
Cyclone 1	Temp. (°C)	225	266
	Pressure (mbar)	-53	-53
	Material temp (°C)	260	268
Cyclone 2	Temp. (°C)	309	364
	Pressure (mbar)	-48	-48
	Material temp (°C)	425	410
Cyclone 3	Temp. (°C)	577	558
	Pressure (mbar)	-38	-41
	Material temp (°C)	556	560
Cyclone 4	Temp. (°C)	688	710
	Pressure (mbar)	-34	-34
	Material temp (°C)	682	689
Cyclone 5	Temp. (°C)	840	856
	Pressure (mbar)	-29	-29
	Material temp (°C)		
Kiln inlet temperature (°C)		1,236	
Kiln feed material temperature (°C)		75.3	

Table 2. Cooling fans air flow readings for the air quenched cooler (AQC)

Tag	A Flow (m³/hr.)	B Flow (m³/hr.)
117FA31	24,105.94	24,098.81
117FA33	26,719.85	27,471.00
117FA35	52,522.43	52,492.75
117FA37	40,269.29	41,294.50
117FA39	6335.65	58,906.40
17FA41	66,866.00	62,400.31
117FA43	70,059.63	68,923.93
117FA45	72,986.39	72,219.17

Table 3. Air Quenched Cooler Exhaust Measurement

Time	Flow (m³/hr.)	Temperature (°C)
14h30	597,267.62	345
14h42	647,755.42	340

Table 4. Raw meal and clinker weight reading

Item	Weight (tons)
Raw meal consumed	2843
Clinker produced	1728
Calculated factor (Raw meal/Clinker)	1.645

4.1. Analysis of excess heat generated in the plant

Table 5 gives summary of heat obtained at various sections. Excess air Draft is given as 780,000 m³/hr (design) at 250 °C while ID fan Draft is 900,000 m³/hr at 350 °C. Assuming atmospheric temperature basis of 30 °C. Quantity of heat taken out by the Excess Air fan;

$$Q = mc\Delta\theta \qquad (25)$$

$$Mass \;=\; \rho \, x \, V \qquad (26)$$

$$Q = \rho V c \Delta\theta \qquad (27)$$

Where ρ = density of air,
V = volume,
c = specific heat capacity,
$\Delta\vartheta$ = change in temperature.

Table 5. Excess heat generated

S/N	Section	Temperature °C	Amount
1	Total heat taken by ID fan	350	2,356,196.8 MJ/h
2	Heat required for grinding	100	30,635.400 MJ/h
3	Heat taken from kiln to cement mills	350	577,648.260 MJ/h
4	Heat supplied by gas generators	350	61,270.8 MJ/h
5	Heat saved per ton of cement @400 ton/h	100	153.177 MJ/ton
6	Heat saved annually for 2.25 million ton capacity	30	344,648.28 GJ

4.2. Cement production cost Implication

Thus, the amount of heat to be saved per ton $=\left(\frac{61{,}270{,}800KJ/hr}{400t/hr}\right)$ = = 153,177kJ/ton of cement. Consequently, in a plant of 2.25 million ton capacity, the quantity of heat that can be saved annually amounts to 153,177 x 2.25 million tons (= 344,648.25GJ). Then, the cost analysis result based on excess heat utilization is contained in **Table 6**.

Table 6. Cost saving analysis

S/N	Type	Cost ($)
1	Heat generation	6.5/GJ
2	Heat saved	0.987/ton of cement
3	Annual capacity saving	2,240,212
4	Fuel	9/ton
5	Power	8.052/ton
6	Energy	17.06/ton
7	Clinker	48.327/ton
8	Cement	55.107/ton
9	New fuel cost based on saving	8.013/ton
10	New cement cost based on saving	54.120/ton
11	Percentage saving	1.79%

4.3. Cycle Tempo software simulation

The power generating cycle (rankine cycle) was simulated with Cycle Tempo software package with the result in **Figure 3**. The cycle combines two (2) heat streams and one (1) rankine cycle. Simply it comprises:

1) Waste heat recovery system
2) The cooling system
3) Power generating cycle (rankine).

4.3.1. Waste heat recovery source

The waste heat recovery source comprises of two components which are source and sink. The source is modelled with the heat recovered pyro processing a dry air in the pyro which has been heated up, directing the air into the heat exchanger transfer heat to the fluid which is used to drive the turbine. The other stream is the water stream for the cycle. The maximum temperature and pressure from the pyro processing are 350°C and 2.9 bar respectively. Not all the heat from pyro can be transferred to work in the turbine, there are energy loss due to system losses and irreversibilities.

4.3.2. The cooling system

The cooling system comprises of cooling water source and sink.it is modelled at atmospheric temperature and pressure of 32°C and 1 bar respectively. Water at atmospheric temperature is the source of coolant, it transfers heat away from the working fluid for the cycle to continue. The heat transferred to the cooling water by working fluid is discharged to the atmosphere at normal condition.it is assumed that the water is pumped to the cooling system.

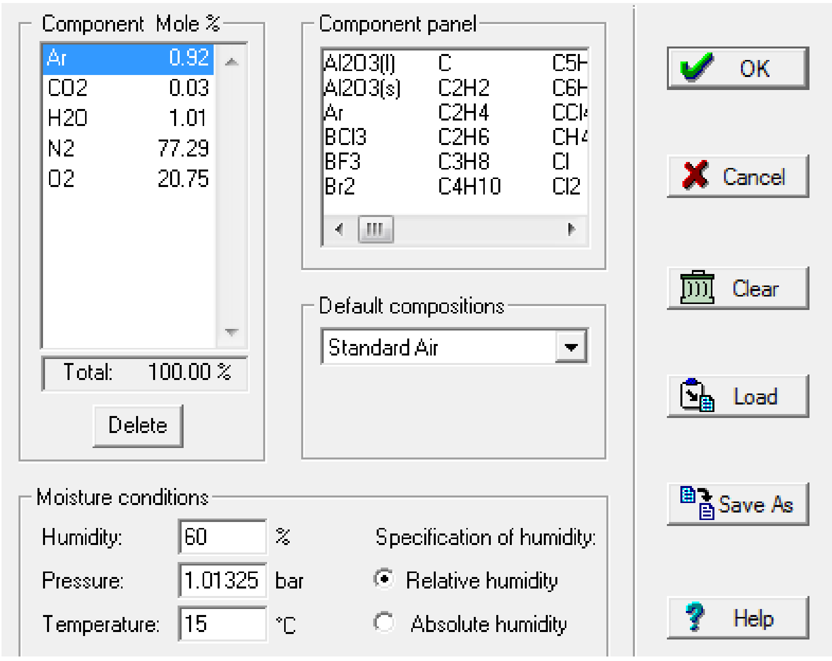

Figure 3. Gas mixture compositions captured from cycle tempo

4.3.3. Power generation cycle

This is a complete cycle that comprises four major component which are heating utilities (heat exchanger and condense), turbine and pump. The working fluid changes states as it enters the evaporator from water to team which in turn enters the turbine and convert its kinetic energy stored by heat absorption to rotate it. The following assumptions are adopted for the modelling of the system:

- Each component is considered as an open system in steady-state operation;
- Friction and heat losses as well as kinetic and potential energies are neglected;
- The specific heat of the source and sink are assumed to be constant;
- At the exit from the condenser the working fluid is saturated liquid;
- The specific volume of the working fluid remains constant during pumping; and
- The efficiency of the turbine and pump is assumed to be constant for all.

Modelling heat exchangers means providing the models that describe the heat transfer from hot to cold fluids. All the considered heat exchangers are of counter current flow type.

- $T_{hot\ in}$ is inlet temperature of the hot fluid;
- $T_{hot\ out}$ is outlet temperature of the hot fluid;
- $T_{cold\ in}$ is inlet temperature of the cold fluid; and
- $T_{cold\ out}$ is outlet temperature of the cold fluid

4.3.4. Power generation analysis

Power generation from turbine work on the rankine cycle principle. Assuming constant pressure fluid expansion, the turbine work output can be calculated using:

$$\dot{W} = \dot{m} * (h_3 - h_4) \quad (28)$$

where;
$\dot{W}$ = work done by the working fluid in the expander (kJ/kg)
$\dot{m}$ = mass flow rate of the working fluid(kg/s) = 13
h_3 = working fluid enthalpy at the exit of evaporator (kJ/kg) = 2890.63
h_4 = working fluid enthalpy at the exit of evaporator (kJ/kg) = 2327.5

Work done by the turbine = 13*(2890.63 -2327.52) =563.11*13= 7320.43kw=7.32MW. This result is confirmed by the thermograph simulation and calculation for the turbine output analysis. Then, the cycle thermal efficiency is calculated by Eq. (29).

$$\mu_{th} = 1 - \frac{(h_4 - h_1)}{(h_3 - h_2)} \quad (29)$$

$$\mu_{th} = 1 - \frac{(2327.52 - 352.746)}{(890.63 - 356.101)} = 0.2208$$

Finally, yhe thermal efficiency (μ_{th}) of the rankine cycle is 22.08%

5. Discussion

From the results obtained from this study, the heat generated from the kiln was 477,648 MJ/hr. while the heat required by two cement mills was 61,271 MJ/hr as contained in **Table 5**. The amount of heat to be saved per ton of cement was 153,177 kg. The total amount of heat to be saved was 344,648.25 GJ based on plant of 2.25 million tonnes cement capacity. The cost of heat generated was $6.5 /GJ thus total annual saving of $2,240,212 as given in **Table 6**. Further saving of 7.2 MW could be achieved in power generation based on cycle tempo software. Part of this heat generated from the kiln can be used to run the two cement mills, PH and Air Quenched Cooler boilers, steam turbine and auxiliaries, and generators. The result of cycle tempo simulation gave the analysis of air composition which indicated CO_2 and trace gases to be 0.03%. This result was also confirmed by Madlool *et al.*, 2011. Other results obtained in this research work conformed to the findings of Broberg and Johansson, 2014, Dienner *et al.*, 2012, and Adetunji, *et al.*, 2019 wherein maintenance best practices reduced production cost [3],[12],[20].

The result of mathematical modelling on energy and exergy analyses confirmed that the maximum improvement in the exergy efficiency for cement process is achieved when the exergy loss is minimized. The energy efficiency is enhanced when the excess heat from kiln is utilized in other areas like cement mill, boiler and power plants. These findings tallied with researches conducted earlier [21-27].

6. Conclusion

The following conclusions are drawn having carried out the study on effect of excess heat utilization on the production cost of cement.

- The heat from the kiln is presently in excess of the required heat for finished processing of cement product. The excess heat constitutes a cost burden on the company, and can be reused in other purposes, thereby reducing the cost of production.
- Effective utilization of the excess heat in cement plant at Ewekoro will enable the company to save about 1.79% ($2 m) of the present cost in producing a ton of cement in the company. This will result in a huge efficiency with the present 200 tons/hour capacity of the plant.
- Energy saving of 7.2 MW could be achieved in power generation based on cycle tempo software.
- Energy and Exergy efficiencies would be enhanced by wastage reduction and excess heat utilization.

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Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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