ENERGY UTILIZATION, CONSERVATION AND AUDITING IN NIGERIA CEMENT INDUSTRY

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Abstract

Manufacturing of cement is identified as one of the most energy intensive industries in the world. Therefore, there is a need for its effective and efficient utilization and hence conservation. In order to produce clinker, rotary kilns are widely used in cement plants. This study takes a look at the energy source, utilization and conservation in a Cement Company in Nigeria. The company's energy source was determined, utilization pattern investigated and possible areas of energy conservation considered. The rotary kiln of this plant where the large form of energy is consumed has a capacity of 6000 tonnes per day. It was found that about 20% of the total input energy was being lost through hot flue gas (5.09%), cooler stack (12.4%) and kiln shell (2.61% convection and radiation). To recover some of this heat energy loses, a feasible energy management method was introduced and discussed. Findings showed that approximately 4MW of electrical power could be recovered through conservation and proper energy management.

Keywords: Energy Utilization, Auditing, Cement Industries, Thermal energy, Electric Motor

Introduction

Industrial sector energy consumption ranges between 30% and 70% of total energy used in some selected countries (Al-Mansour, Merse, Tomsic, 2003; Onut & Soner 2007; Saidur, 2010). A substantial amount of energy is used up in cement production industries. Therefore, a considerable attention is required for the reduction of energy and energy related environmental emissions locally and globally (Gielen, Taylor, 2009; Sheinabaum, Ozawa, 1998). Based on literatures, the cement industry accounts for about 12% of total energy consumption in Malaysia and 15% of total consumption in Iran (Avami & Sattari, 2007). With the cement industry being an energy intensive industry, this segment of industry typically accounts for 50–60% of total production costs (Singhi & Bhargava, 2010). Typically, electrical energy consumption of a modern cement plant is about 110 – 120kWh per tonne of cement (Mejeoumov, 2007). The bulk of the thermal energy is used during burning process, while electrical energy is used for cement grinding (Junior, 2003). Specific energy consumption in cement production differs with technology used. The dry process uses more electrical but much less thermal energy than the wet process. In industrialised countries, primary energy consumption in a typical cement plant is up to 75% fossil fuel and 25% electrical energy in dry process. Pyro-processing requires the major share of the total thermal energy use. This accounts for about 93-99% of total fuel consumption (Junior, 2003; Khurana, Rangan & Uday, 2002). However, electric energy is mainly used to operate both raw materials handling (33%) and clinker crushing and grinding (38%) equipment. Electrical energy is also required to run the auxiliary equipment such as kiln motors, combustion air blowers and fuel supply, etc (22%) in order to sustain the pyro-process (Engin & Ari, 2005). Consequently, significant amounts of greenhouse gases (GHG) emissions are released to the atmosphere due to burning of fossil fuel used in supplying the energy need of the cement industries (Gielen & Taylor, 2009). With specific thermal energy consumption in cement industries found to be about 4-5GJ/tonne (Ziya, Zuhal, Hikmet, 2010). It has however been made evident that a thermal energy saving potential of 0.25–0.345GJ/t, an electrical energy saving potential of 20–35kWh/t and an emission reduction potential of 4.6–31.66kg CO_2 is feasible in these industry (Singhi & Bhargava, 2010).

Energy audit has emerged as one of the most effective procedures for a successful energy management program (Pahuja, 1996). The main aim of the energy audit is to provide an accurate account of energy consumption and energy use analysis of different components in order to reveal the detailed information needed for determining the possible opportunities for energy conservation. Waste heat recovery from hot gases (Kamal, 1997) and hot kiln surfaces (Engin, 1997) in a kiln system are known as potential ways to improve overall kiln efficiency. However, it is still fairly difficult to find a detailed thermal analysis of a rotary kiln system in the open literature. This paper focuses on the energy audit of a horizontal rotary kiln system which is in use in one of the Cement Plants in Nigeria.

Materials and Methods

Data Sources and Collection

The cement plant under study is one of the largest cement plant in sub-saharan Africa with 13.25 mmtpa capacity across four lines. The data collected are tabulated in Table 1.

Materials

To carry out energy audit of the plant, the required data was obtained from the plant's laboratories where samples were taken each hour. The Central Control Room (CCR) receives feedback of various technical characteristics of electrical and mechanical equipment. Other materials required include measuring tapes for measuring dimensions where dimension is not available from the plant's equipment list and Infra-red thermometer to directly record temperature values where necessary. The data collected covers the following: The energy reading was recorded daily from electrical substations in the plant for each section of production. The fuel (gas) sample analysis, raw material sample analysis, Kiln-feed sample analysis and Clinker sample analysis were done hourly and the feedback to the Robotic laboratory. The temperature values and flow rates were obtained from the CCR based on feedback from instruments installed on equipment. Infra-red thermometer was used to obtain surface temperatures where necessary. The dimensions of equipment, types and other details were obtained from plant manufacturer's document in the company's library. Electric motor rating was obtained from motor plates, running current and power output are recorded from the feedbacks received in the CCR.

Thermal and Electrical Components Analysis

Thermal and electrical components analysis was done to ascertain the energy utilization. The thermodynamic analyse of the kiln system was achieved using the following assumptions: The working conditions was steady state; The change in the ambient temperature is neglected; Cold air leakage into the system is negligible; Raw material compositions do not change; The average kiln surface temperatures do not change; The preheater is modelled as a vertical cylinder; The cooler surface is modelled as a vertical plate. The kiln system considered for the energy audit is schematically shown in Figure 1. The control volume for the system includes the preheater group, rotary kiln and cooler. The analysis of these components is discussed in the next sections.

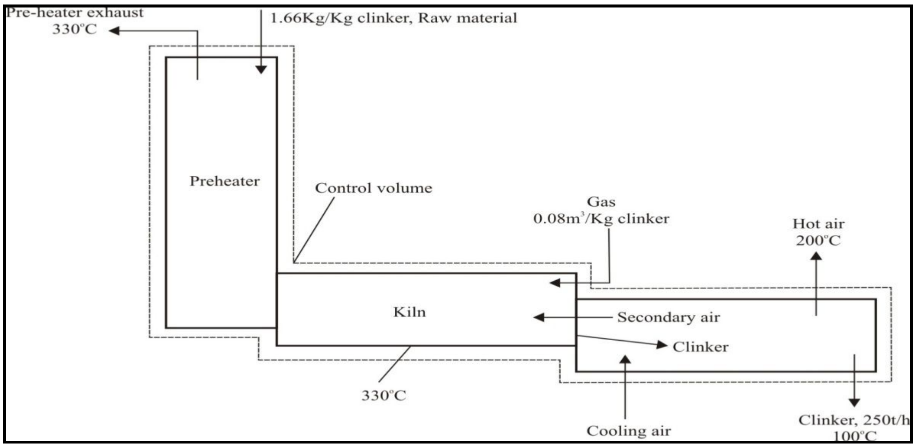

Figure 1: Control volume, various streams and components for kiln system

Thermal Energy Balance Analysis

The thermal energy balance was performed on the fourth line of the plant. The information about several parameters such as temperature, dimension and energy consumption of the utility equipment were obtained. The data were gathered from existing factory laboratories and feedbacks from monitoring instruments installed on each of the equipment. The data required for this case study is outlined in Table 1

Table 1: Information required for Heat Balance Calculation

Parameter	Value
A_{ch} (m^2)	11.32
A_{Kiln} (m^2)	402.96
Cl_{SiO_2} (wt)	21.55
$Cl_{Al_2O_3}$ (wt)	5.42
$Cl_{Fe_2O_3}$ (wt)	3.42
Cl_{CaO} (wt)	65.71
Cl_{M_gO} (wt)	1.25
Cl_{SO_3} (wt)	0.41
Cl_{Ig} (wt)	1.0264
D_{Ig} (wt)	9.7
D_{cooler} (m)	5.6
$D_{preheater}$ (m)	5.6
F_{CO_2} (vol.%)	0.01
F_{H_2} (vol.%)	0.01
F_{CH_4} (vol.%)	93.25
$F_{C_2H_6}$ (vol.%)	5.14
$F_{C_3H_8}$ (vol.%)	0.01
$F_{C_4H_{10}}$ (vol.%)	1.02
$F_{C_5H_{12}}$ (vol.%)	0.09
F_{HV} (KJ/m^3)	37,472
G_{CO_2} (wt)	3.6
G_{O_2} (wt)	0
G_{CO} (wt)	29.3
G_{N_2} (wt)	67.1
KF_{SiO_2} (wt)	14.06

Parameter	Value
$KF_{Al_2O_3}$ (wt)	3.55
$KF_{Fe_2O_3}$ (wt)	2.38
KF_{CaO} (wt)	43.01
KF_{M_gO} (wt)	0.79
KF_{N_2O} (wt)	0.02
KF_{K_2O} (wt)	0.33
KF_{SO_3} (wt)	0.11
KF_{Ig} (wt)	35.02
KF_M (wt)	0.5
L_1 (m)	74
L_2 (m)	5.2
L_3 (m)	19.63
L_4 (Mm)	22
L_5 (Mm)	50
L_6 (deg)	2.3
L_{cooler} (M)	275
$L_{preheater}$ (M)	16.25
P_h (mm H_2O)	0.6
T_{amb} (°C)	31
T_C (°C)	50
T_{Pa} (°C)	65
T_{Sa} (°C)	1000
T_{Be} (°C)	330
T_{St} (°C)	200
T_F (°C)	100
T_{Z1} (°C)	37

Parameter	Value
T_{Z2} (°C)	250
T_{Z3} (°C)	350
T(°C)	200
T_{Cooler} (°C)	40
T_{Kiln} (°C)	75
$T_{Preheater}$ (°C)	80
V_{Pa} (m^3/s)	346.4
V_{Ex} (m^3/s)	113.8
V_{Co} (m^3/s)	208.6
V_{Be} (m^3/s)	145.3
W_{Cl} (Kg/h)	250,000
W_{dF} (Kg/Kg Clinker)	1.66
W_A (m^3/Kg Clinker)	0.08
c_{jfuel} (KJ/m^3°C)	17.27
c_{jCO_2} (KJ/ Kg°C)	0.80
c_{jH_2O} (KJ/ Kg°C)	1.00
c_{jSO_3} (KJ/ Kg°C)	0.70
c_{jN_2} (KJ/ Kg°C)	0.90
$c_{jair_{31°C}}$ (KJ/ Kg°C)	0.95
$c_{jair_{200°C}}$ (KJ/ Kg°C)	1.01
$c_{jair_{330°C}}$ (KJ/ Kg°C)	1.98
φ_{j1} (KJ/hm²°C)	75
φ_{j2} (KJ/hm²°C)	96
φ_{j3} (KJ/hm²°C)	65

Total heat input and output of the kiln system

The equations for the total heat input and output of the kiln system are presented in equations (1) to (13) as tabulated in Tables 2 and 3.

Table 2: Total heat input of the kiln system

Heat Inputs	Formulation	equ
Combustion of fuel	$W_A \times F_{HV}$	(1)
Sensible heat in fuel	$W_A \times c_{jfuel} \times T_F$	(2)
Sensible heat in kiln feed	$\left(W_{dF} \times c_{jfuel} \times T_C\right) + \left(\left(WGF_{H_2O\ free} + WGF_{H_2O\ chem}\right) \times T_C \times 4.184\right)$ $WGF_{H_2O\ free} = \frac{100 \times W_{dF}}{100 - KF_M} - W_{dF}$ $WGF_{H_2O\ chem} = (1 + dl) \times \left(0.00075 \times KF_{SiO_2} + 0.0035 \times KF_{Al_2O_3}\right)$ $dl = \frac{(W_{dF} - FR)}{W_{dF}}$ $FR = [(0.01784 \times KF_{CaO}) + (0.0209 \times KF_{MgO}) + (0.0135 \times KF_{Al_2O_3}) + (0.01075 \times K + (0.01 \times KF_{Fe_2O_3})] \times \left(\frac{100 - Cl_{Ig}}{100}\right)$	(3)
Cooler air sensible heat	$\frac{CAB_{CO} \times c_{jair} \times T_{amb}}{W_{Cl}}$, where $CAB_{CO} = 4654.44 \times V_{CO}$	(4)
Primary air sensible heat	$\frac{CAB_{Pa} \times c_{jair} \times T_{amb}}{W_{Cl}}$, where $CAB_{Pa} = 4654.44 \times V_{Pa}$	(5)
Infiltrated air sensible heat	$\frac{AIH \times c_{jair} \times T}{W_{Cl}}$, where $AIH = 11{,}720.3 \times A_{ch} \times (1.157 \times P_h)^{0.5}$	(6)

Table 3: Total heat output of the kiln system

Heat Outputs	Formulation	
Clinker formation	$\left(4.11 \times Cl_{Al_2O_3}\right) + \left(6.48 \times Cl_{MgO}\right) + \left(7.646 \times Cl_{CaO}\right) - \left(5.116 \times Cl_{SiO_2}\right) - \left(0.59 \times Cl_{Fe_2O_3}\right)$	(7)
Kiln exit gas	$(W_{CO_2} \times c_{jCO_2} \times T_{Be}) + (W_{H_2O} \times c_{jH_2O} \times T_{Be}) + (W_{SO_3} \times c_{jSO_3} \times T_{Be}) + (W_{N_2} \times c_{jN_2} \times T_{Be}) + (\text{Excess air} \times c_{jair} \times T_{Be})$ Where, $W_{CO_2} = CP_{CO_2} + WGF_{CO_2}$ $W_{H_2O} = CP_{H_2O} + WGF_{H_2Ofree} + WGF_{H_2Ochem}$ $W_{SO_3} = 0.5 \times CP_{SO_3}$ $W_{N_2} = CP_{N_2}$,	(8)

	$\text{Excess air} = \left(\frac{EA}{100}\right)\left[\left(CP_{CO_2} + CP_{H_2O} + CP_{N_2}\right)\right]$	
	$CP_{CO_2} = W_A\left[\left(1.97 \times F_{CH_4}\right) + \left(3.94 \times F_{C_2H_6}\right) + \left(5.9 \times F \ldots + \left(9.64 \times F_{C_5H_{12}}\right) + \left(1.97 \times F_{CO_2}\right)\right]$	
	$WGF_{CO_2} = \left(1 + \frac{dl}{2}\right)\left[\left(0.0078 \times KF_{CaO}\right) + \left(0.0109 \times KF_{MgO}\right)\right]$	
	$CP_{H_2O} = W_A\left[\left(1.6 \times F_{CH_4}\right) + \left(2.4 \times F_{C_2H_6}\right) + \left(3.14 \times F_{C_3H} \ldots + \left(5.05 \times F_{C_5H_{12}}\right)\right]$	
	$CP_{N_2} = W_A\left[\left(9.55 \times F_{CH_4}\right) + \left(16.70 \times F_{C_2H_6}\right) + \left(23.86 \ldots + \left(38.19 \times F_{C_5H_{12}}\right) + \left(1.25 \times F_{H_2}\right)\right]$	
	$EA = \frac{189 \times \left[\left(2.0 \times G_{O_2}\right) - G_{CO}\right]}{\left[G_{N_2} - \left(1.89\left(\left(2.0 \times G_{O_2}\right) - G_{CO}\right)\right)\right]}$	
Moisture in feed or slurry	$\left(WGF_{H_2Ofree} + WGF_{H_2Ochem}\right) \times 2500.8$	(9)
Dust in the kiln exit gas	$\left(Dl \times c_{jDust} \times T_{Be}\right) = \left(W_{dF} - FR\right) \times c_{jDust} \times T_{Be}$	(10)
Clinker at cooler discharge	$c_{jClinker} \times T_{Cl}$	(11)
Cooler stack	$\frac{CAB_{Ex} \times c_{jair} \times T_{St}}{W_{Cl}}, \; CAB_{Ex} = 4654.44 \times V_{Ex}$	(12)
Radiation on kiln shell	$\frac{A_{Kiln}}{3} \times \frac{\left(\left(q_{j1} \times \left(T_{z1} - T\right)\right) + \left(q_{j2} \times \left(T_{z2} - T\right)\right) + \left(q_{j3} \times \left(T_{z3} - T\right)\right)\right.}{3}$	
Calcination wasted in kiln dust	$\dot{q} \times TC_{Dust} \times 1{,}592.5$ $\dot{q} = \frac{KF_{Ig} - D_{Ig}}{KF_{Ig}}$ $TC_{Dust} = \frac{\left(\left(0.01784 \times KF_{Cao}\right) + \left(0.0209 \times KF_{MgO}\right) \times W_{dF} \times dl\right)}{FR}$	(13)

Electrical Energy Balance Analysis

The need for electrical energy audit is clear when average electrical energy consumption values for Cement plant is compared with world best practice as presented Figure 2. It is observed that in almost all cases, the average energy consumption values are significantly higher than the best practice value, indicating a strong potential for energy efficiency improvement.

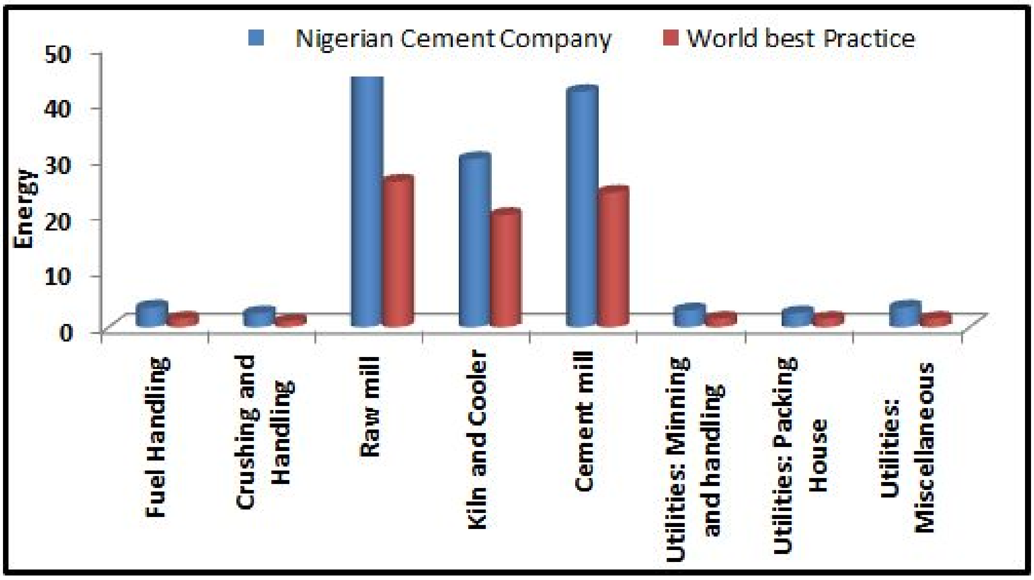

Figure 2: Energy consumption values for cement plant by process

The mathematical model of Garcia (Garcia, 2003) used for estimating the motor load has presented a correlation coefficient of 99.3% with real motor curves (Sola & Xavier, 2007). From the real measured current (I_R), nominal current (I_N) given by the manufacturer, and no load current (I_0), measured or given by the manufacturer. The real load (γ) is then determined from the relation;

$$\gamma = 1 + \frac{1}{\alpha}\ln\frac{I_R}{I_N} \qquad (14)$$

Where the load current parameter is calculated by:

$$\alpha = -\ln\frac{I_0}{I_N} \qquad (15)$$

The efficiency is the relation between output power and input power including energy losses (Kosow , 1972. Thus, the real efficiency is given by:

$$\eta_L = \frac{P_{out}}{P_{in}} = \frac{P_N}{P_R}\gamma \qquad (16)$$

Where, P_N is the nominal output power, P_R is the real input power, γ is the rated load percentage and η_L is the low efficiency.

Improving Energy efficiency in an Industrial Motor System

The industrial motors used for this study are those operating at 690 V and 415 V. Motors nominal data were collected and electric current and power measurements were recorded straight from digital meters attached to each motor and others from the CCR. The motor data are shown in Table 3 and 4 for 690 V and 415 V respectively.

Table 3: Efficiency data from motors at 690V

Motors	Name of motor	P_N	P_R	I_N	I_R	I_0	γ	η_L
56RK01.MO1	Rotary Kiln	900	454	900	454	360	25.32	50.19
84SR01.MO1	Cement Separator (Classifier)	800	398	780	388	312	23.79	47.83

Table 4: Efficiency data from motors at 415V

Motors	Name of motor	P_N	P_R	I_N	I_R	I_0	γ	η_L
22BC01.MO1	Raw material Handling (Belt Conveyour)	110	64	196	114	78	40.86	70.25
22ST01.MO5	R/material Handling (R/Material Stacker)	90	43	164	78	66	18.89	39.73
22BC04.MO1	Raw material Handling (Belt Conveyour)	250	122	418	204	167	21.71	44.48
35BC04.MO1	Raw material Handling (Belt Conveyour)	132	77	234	136	94	40.78	70.16
52BE01.MO1	Kiln feed Handling (Bucket elevator)	250	122	405	198	162	21.90	44.80
66DP01.MO1	Clinker Handling (Deep pan conveyour)	110	62	194	109	78	37.08	66.00
78RE01.MO1	Clinker Handling (Additive Reclaimer)	132	64	238	116	95	21.57	44.25
83BC05.MO1	High grade Handling (Belt Conveyour)	90	44	154	76	62	22.93	46.46

The improvement in energy efficiency (IEE) indicates the percent of energy saved after the replacement of a low efficiency motor (η_L) with a high efficiency motor(η), and is calculated as follows:

$$IEE = \left(1 - \frac{\eta_L}{\eta}\right) \times 100 \qquad (17)$$

The real low efficiency (η_L) and the real rated load (γ) were obtained using equations (14) to (16). The real high efficiency was determined from the performance curve of the motor given by the manufacturer, considering the high efficiency (η). The improvement in energy efficiency (IEE) is determined by equation (17).

The real high efficiency is not necessarily the nominal efficiency of new motors, because this depends on rated load, which varies as a function of the electric current. The quantity of Energy Saved (QES) can be calculated as follows (McCoy & Douglas, 2000):

$$QES = P_N \gamma t\left({}^{1}/_{\eta_L} - {}^{1}/_{\eta}\right) \qquad (18)$$

Where, t is the operating time (h/yr). By the calculation of QES and considering the energy cost per kilowatt-hour (C), the Energy Saved Value (ESV) is derived by the following formula [20].

$$ESV = QES.C \qquad (19)$$

Considering the Motor Investment Value (MIV) and the calculated ESV, the Simple Payback (SPB) is given by:

$$SPB = \frac{MIV}{ESV} \qquad (20)$$

Results and Discussions

Thermal Energy Balance

Thermal Input of Kiln System: The thermal heat input and output balances obtained from equation (1) to (13) are shown in Table 5 and 6. From Table 5, the fuel combustion is the major heat input into the kiln system with a value of 2997.8kJ/kg which represents 86.9% of the total heat input. Sensible heat added from primary air is next to the sensible heat from fuel with a value of 189.9 kJ/kg (5.5%). The cooler air added 114.35 kJ/kg representing (3.3%) of total heat input energy. The other heat input energy into the kiln system include sensible heat from fuel that is burned (natural gas) with a value of 51.10 kJ/kg (1.5%), sensible heat added from the kiln feed is 79.85kJ/kg (2.3%), and sensible heat in infiltrated air is 16.8 kJ/kg (0.5%).

Table 5: Summary of Heat Input of Kiln System

S/No	Parameter	Value (kJ/kg)	Percent (%)
1	Combustion of fuel	2997.8	86.9
2	Sensible heat in fuel	51.10	1.5
3	Sensible heat in Kiln feed	79.85	2.3
4	Sensible heat in Cooler air	114.35	3.3
5	Sensible heat in primary air	189.9	5.5
6	Sensible heat in infiltrated air	16.8	0.5
	Total	3449.8	100%

Thermal Output of Kiln System: Based on the result in Table 6 above, it is observed that the heat energy input and output of the kiln system is in agreement with the law of conservation of energy. Table 6 shows that a large amount of the input energy is used up in the formation of clinker which is the main essence of the input heat energy. Heat used up in clinkerisation is 1759.5 kJ/kg representing 51%. The percentage does not only depict the fraction of the total input heat energy used up in the kiln system for clinker formation but also establish the efficiency of the kiln system. Other heat usage within the kiln is drying of kiln feed prior to burning 101.3 (2.94%). Much of the input energy 601.1 kJ/kg (17.42%) is wasted during calcinations; an important chemical process for clinkerisation. Some of heat escapes with dusts associated with kiln exit gases 188.3 kJ/kg (5.46). About 20% is lost to the atmosphere, this includes losses in kiln exit gas of 175.5 kJ/kg (5.09%), losses in cooler exit gas of 427.6 (12.40%) and radiation losses on kiln shell of 90.1 kJ/kg (2.61%).

Table 6: Summary of Heat Output of Kiln System

S/No	Parameter	Value (kJ/kg)	Percent (%)
1	Clinker formation	1759.5	51.00
2	Losses in kiln exit gas	175.5	5.09
3	Evaporation of moisture in feed	101.3	2.94
4	Dust in kiln exit gas	188.3	5.46
5	Clinker at cooler discharge	77.0	2.23
6	Cooler stack losses	427.6	12.40
7	Radiation losses in kiln shell	90.1	2.61
8	Calcinations wasted in kiln dust	601.1	17.42
9.	Uncountable losses	29.4	0.85
	Total	3449.8	100%

The Sankey diagram in Figure 3 is a specific type of flow diagram in which the width of the arrows is shown proportionally to the flow quantity shows the input and output of the kiln system. It was clear that the bulk of the input energy comes from fuel combustion gas. The thermal energy in the considered line of production is 3449.8KJ/Kg of clinker produced. The efficiency of the system is equal to 51% which is relatively low.

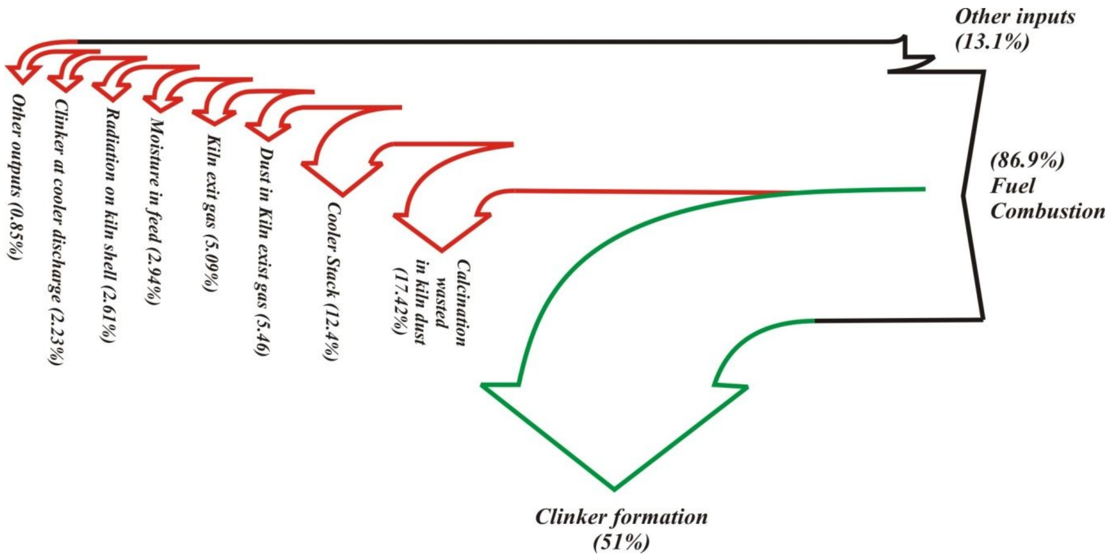

Figure 3: Sankey diagram showing the flow of thermal energy in the plant

Heat Recovery from the Kiln System: The kiln system efficiency (51%), which is relatively low, can be improved by recovering some of the heat losses. The recovered energy can be used to generate electricity, hot water preparation and fuel heating. Some of the major heat loss source that would be considered for heat recovery include; heat losses by the kiln exhaust gas (5.09%) and hot air leaving the cooler stack pipe (11.15%). Since the plant is running on captive power plant, it will be wise to capture the waste heat to the environment and utilize it to generate electricity thereby reducing the fuelling cost of the captive power plants and also their total dependency, it will also extend their life span as their loads reduces. The most feasible and in turn the most cost effective waste heat losses available for such purpose are the clinker cooler discharge and the kiln exhaust gas stack. The kiln exhaust gas temperature is 330^{o}C on the average and the temperature of the discharge air from the cooler stack is 200^{o}C. Both streams would be directed through a Waste Heat Recovery Steam Generator (WHRSG) and the available energy is transferred to the water via the WHRSG. The waste heat recovery system with generator is shown in Figure 4.

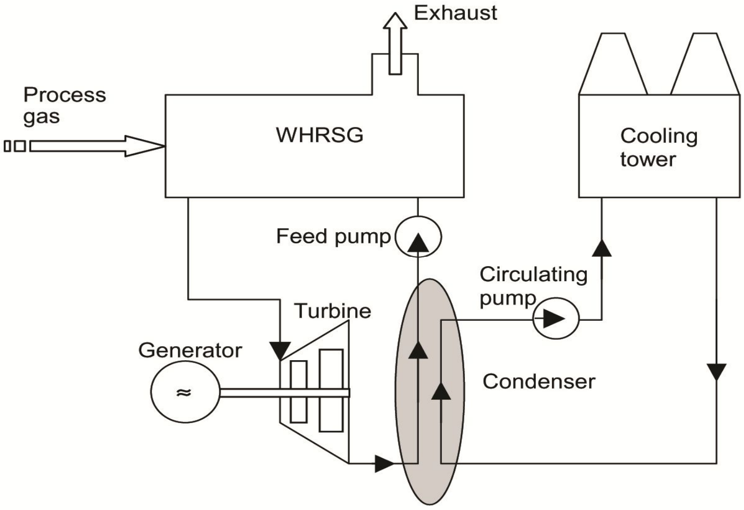

Figure 4: Illustration of waste heat recovery system with generator (Kamal, 1997)

The available waster energy is such that stream would be generated. This stream would then be used to power a steam turbine-driven electrical generator. The electricity generated would offset a portion of the electricity generated from the captive power plant running on gas, thereby reducing electricity demand.

In order to determine the size of the generator, the available energy from the gas streams must be found. Once this is determined, an approximation of the streaming rate for a specified pressure can be found. Having the streaming rate and pressure, the size of the generator can be determined. The following calculation was used to determine the size of the generator.

$$Q_{WHRSG} = Q_{available} \times \eta \quad (21)$$

Where η is the WHRSG efficiency.

Because of various losses and inefficiencies inherent in the transfer of energy from the gas stream to the circulating water within the WHRSG, not all of the available energy will be transferred. A reasonable estimate of the efficiency of the WHRSG must be made. Therefore, the efficiency of 85% is assumed for this steam generator. As the gas passes through the WHRSG, energy will be transferred and the gas temperature will drop. Approximation for the streaming rate is 5 kg/s, and a pressure of 800 Pa with a temperature of 40°C flowing through it, being heated from two sources. The control volume should have a single inlet and exit flow with two heat transfer rates coming from reservoirs different to the ambient surroundings. The characteristics of the exit water are 800 Pa and 170°C. The reversible work is obtained from the following equation [22].

$$W_{rev} = T_o(S_e - S_i) - (h_e - h_i) + q_1\left(1 - \frac{T_o}{T_1}\right) + q_2\left(1 - \frac{T_1}{T_2}\right) \quad (22)$$

Where, T_o, T_1 and T_2 is the ambient Kiln, exhaust stack and cooler exhaust stack temperatures respectively. The values of h_i , h_e, S_i, S_e, T_o, T_1 and T_2 were contained from periodic table. Mass flow rate of hot air stream in both kiln and cooler stack is 41.66 kg/s. Therefore q_1 and q_2 is 7,311.33 W and 17,813.82 W respectively. From the above equations, the values of W_{rev}, $Q_{available}$ and Q_{WHSRG} are calculated as 1892.58 kJ/Kg, 9462.9 kW and 8043.465 kW respectively.

Thermal Energy Cost Savings: The next step is to find a steam turbine generator that can utilize this energy. Since a turbine is a rotating piece of machinery, if properly maintained and supplied with a clean supply of dry steam, the turbine should last for a significant period of time. Considering a turbine pressure of 8bars and a condenser pressure of 10 kPa, it can be shown that the net power which could be obtained from the turbine is almost 4000 kW. Assume that the useful power generated is 4000kW, then the anticipated savings will be based on the load reduction of 4000kW. Assuming a running hours of 8000 h per year, the energy saved can be obtained from the relation;

$$Energy\ saved = energy\ x\ time \quad (23)$$

The total energy saved is 3.2 x 10^6 kWh/yr. The anticipated cost savings is calculated from;

$$Cost\ savings = Energy\ saved\ x\ Unit\ cost \quad (24)$$

Considering the average unit price of electricity in Nigeria as published by the National Energy Council for industries is ₦22.04 per kWh excluding fixed charges [22]. The cost savings is ₦705,280,000 per year.

Simple Payback Period: Assume that labour and maintenance costs average out to ₦4,000,000 annually, the saved amount becomes ₦701,280,000 per year. The cost associated with the implementation of this additional system would be the purchase price of the necessary equipment and its installation. An additional cost would be the required maintenance of the power generation unit. For the whole system, estimated cost of shipping and installation is ₦1,230,000,000. Hence the simple payback period can be calculated as follows;

$$\text{Simple payback period} = \frac{\text{Total Annual Savings}}{\text{Total Investment Cost}} \qquad (25)$$

The simple payback period is approximately 21 months. The energy savings made through using a WHSRG system would also result in an improvement in the overall system efficiency. It should be noted that these calculations reflect a rough estimation and may vary depending upon plant conditions and other economic factors.

Electrical Energy Balance

The result of electrical energy utilization and efficiency improvement carried out mainly on electric motors showed that 10 out of a total of 46 motors selected for the study in the technical areas (production and maintenance) are operating below the expected specified efficiencies. Eight (8) of these motors are operating at 415 V (Table 7) while two others are operating at 690 V (Table 8). The results obtained from equations (14) to (20) for electric motor operating at 690V and 415 V are tabulated in Tables 7 and 8 respectively. The tables show that there is improvement in energy efficiency (IEE), motor investment value (MIV), quantity of energy saved (QES), the energy saved value (ESV) and the simple payback time (SPB) if a new motor is purchased to replace the ones with low efficiency. Although, from the Table 8, it is apparent that the motor investment value (MIV) for these motors operating at 690V, the simple payback time for the two (2) motors if replaced is less than 2 months.

Table 7: Result of Improvement from Motors at 415V

Motor Tag No.	IEE	MIV	QES	ESV	SPB
22BC01.MO1	25.67	320567.6	143777.60	862665.5814	0.39
22ST01.MO5	56.68	220347.4	212422.03	1274532.152	0.17
22BC04.MO1	52.93	580453.5	565418.38	3392510.277	0.17
35BC04.MO1	25.76	402345.5	173030.23	1038181.376	0.39
52BE01.MO1	52.60	580453.5	562878.07	3377268.399	0.17
66DP01.MO1	30.16	386765.7	163209.19	979255.1252	0.39
78RE01.MO1	53.18	402345.5	299558.01	1797348.084	0.22
83BC05.MO1	49.34	220347.4	191881.77	1151290.632	0.19

Table 8: Result of Improvement from Motors at 690V

Motor Tag No.	IEE	MIV	QES	ESV	SPB
56RK01.MO1	46.89	1568432	1863883.14	11183298.83	0.12
84SR01.MO1	32.03	1385359	1243683.94	7462103.624	0.17

Figure 5 shows that the efficiency of new motors is higher than that of old motors. In all, the motors with improved efficiencies and operating at 415 V, the maximum payback time is 4 months and the new efficiency can reach 94.5%. The cause of the low efficiencies in the motors was found to be due to depreciation in motor windings over time.

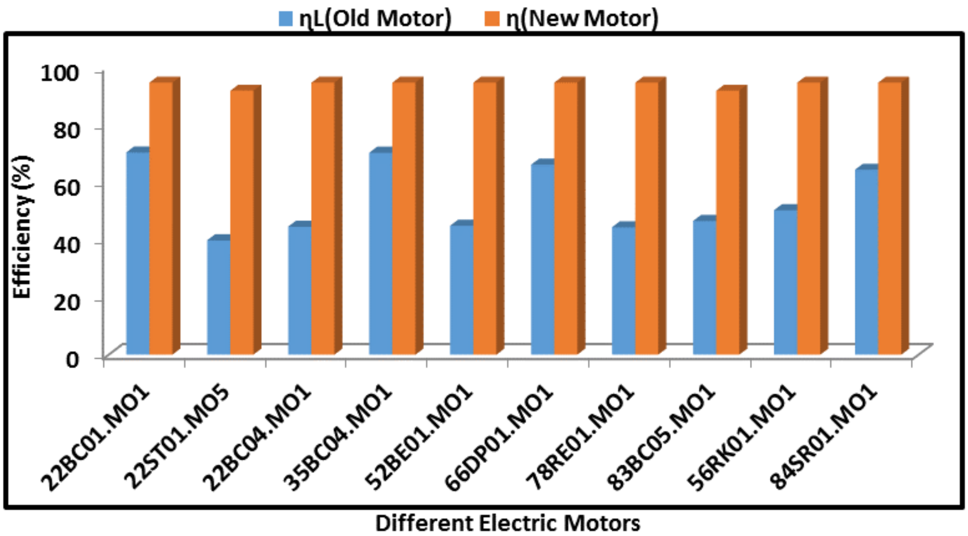

Figure 5: Comparison of old and new Motors operating at 690V 415V

Conclusions

A detailed energy audit analysis which can be directly applied to any dry kiln system has been carried out for the Cement Plant in Nigeria. The distribution of the input heat energy to the system components showed a good agreement between the total input and output energy and gave significant insights about the reasons for the low overall system efficiency. According to the results obtained, the system efficiency is calculated to be 51%. The major heat lose sources have been determined as kiln exhaust (5.09% of total input) and cooler exhaust (12.4% of total input). For these losses, a convention WHRSG system is proposed. Evaluations of energy auditing showed that 4 MW of energy could be recovered. The payback period for the system is expected to be less than 2 years (24 months). There is a significant improvement in the efficiencies of a new motor when compared to the old motors.

References

Al-Mansour, F., Merse, S. & Tomsic, M. (2003). Comparison of energy efficiency strategies in the industrial sector of Slovenia. *Energy*, 28, 421 - 40.

Avami, A. & Sattari, S. (2007). Energy conservation and opportunities: cement industry in Iran. *International Journal of Energy*, 1(3), 65 - 71.

Engin, T. (1997). *Thermal analysis of rotary kilns used in cement plants.* First Mechanical Engineering Congress (MAMKON'97), Istanbul Technical University, TURKIYE, 4-6 June; 29-35.

Engin, T. & Ari, V. (2005). Energy auditing and recovery for dry type cement rotary kiln systems. *Energy conversion and Management*, 46.

Garcia, A. (2003). *The impact of the energy efficiency law on industrial electrical motors' energy savings potentials.* M.Sc. Thesis of Energy Planning, COPPE/UFRJ, rio de janeiro.

Gielen, D. & Taylor, P. (2009). Indicators for industrial energy efficiency in India. *Energy*, 34.

Junior, L. M. (2003). *Sustainable development and the cement and concrete industries*.

Kamal, K. (1997). *Energy efficiency improvement in the cement industry.* Seminar on energy efficiency organised by ASSOCHAM-India and RMA-USA.

Khurana, S., Rangan, B. & Uday, G. (2002). Energy balance and cogeneration for a cement plant. *Applied Thermal Engineering,* 22, 485 - 94.

Kosow, I. L. (1972). *Electric machinery and transformers*: Prentice-Hall.

McCoy, G. & Douglas, J. G. (2000). *Energy management of motor driven systems.* Department of Energy Motor Challenge Programme.

Mejeoumov, G. G. (2007). Improved cement quality and grinding efficiency by means of closed mill circuit modelling.

NERC, (2015). *Newly approved electricity tariff.* Available from http://www.nerc/2015/new-electricity-tariff-cost-phcn-abuja.html.

Onut, S. & Soner, S. (2007). Analysis of energy use and efficiency in Turkish manufacturing sector SMEs. *Energy Conversion and Management*, 48, 384 - 394.

Pahuja, A. (1996). Energy and monitoring in the cment industry. Energy Conservation and Environmental Control in cement industry, vol. 2, published by Akademia books International, 670-94.

Saidur, R. A. (2010). Review on electrical motors energy use and energy savings. *Renewable and Sustainable Energy Reviews,* 14(3), 877 - 898.

Sheinabaum, C. & Ozawa, L. (1998). *Energy use and CO_2 emissions for Mexico's cement industry. Energy,* 23(9),725 - 732.

Singhi, M. K. & Bhargava, R. (2010). Sustainable Indian cement industry. In: Workshop on International comparison of industrial Energy Efficiency.

Sola, A. V. H. (2007). Xavier AADP. Organizational human factors as barriers to energy efficiency in electrical motors systems in industry. *Energy Policy,* 3(5), 5784-94.

Sonntag, R. E., Borgnakke, C., Van Wylen, G. J. & Van Wyk, S. (1998). *Fundamentals of Thermodynamics.* New York: Wiley.

Vetiva, A. (2010). *The emergence of a Titan: Dangote Cement Plc – Initiation of coverage.* Published by Capital Management Limited, p. 2.

Ziya, S., Zuhal, O., & Hikmet, K. (2010). Mathematical modelling of heat recovery from a rotary kiln. *Applied Thermal Engineering*, 30, 817 - 825.

NOMENCLATURE

Symbol	Description
A	Surface area, m^2
A_{ch}	Total effective area of cooler hood, m^2
AIH	Air infiltrated at hood
C	Energy cost per kilowatt-hour
CAB_{Pa}	Primary air at cooler, kg/h
CAB_{Ex}	Excess air vented at cooler stack, kg/h
CAB_{CO}	Total air flow into cooler, kg/h
Cl	Percent of a specific type of molecule in clinker
CP	A specific type of molecule from fuel combustion
c_j	Mean specific heat, kJ/kg.°C
D_{Cooler}	Cooler width, m
D_{Ig}	Percentage ignition loss in kiln dust (hot meal)
$D_{preheater}$	Preheater diameter, m
Dl	Amount of feed wasted as dust, kg/kg clinker
Dl	Percent dust loss
EA	Excess air percent in the kiln
F	Percent of specific type of molecule in natural gas
F_{HV}	The heat value of natural gas, kJ/m^3
FR	Theoretical amount of feed required to produce 1kg of clinker, kg/kg clinker
G	Percentage specific type of molecule in kiln exit gas
H	Convection heat transfer coefficient

Symbol	Description
I	Current (A)
I_o	No load current (A)
KF	Percentage of specific type of molecule in kiln feed
L_1	Kiln length, m^2
L_2	Kiln diameter, m
L_3	Effective burner tip orifice area, m^2
L_4	Refractory thickness, mm
L_5	Kiln shell thickness, mm
L_6	kiln slope, degrees
L_{cooler}	Cooler length, m
$L_{preheater}$	Preheater height, m
P_h	Hood draft, mm H_2O
P	Electrical power, kW
Q	Heat energy, kJ
φ_j	Heat Transfer Coefficient, kJ/m^2.°C
$\dot{q}$	Percent calcinations of kiln dust
T	Operation time, h/yr
T_{amb}	Ambient air temperature, °C
T_C	Feed entering kiln temperature, °C
T_{Pa}	Primary air temperature, °C
T_{Sa}	Secondary air temperature, °C
T_{Be}	Kiln exit gas temperature, °C
T_{St}	Cooler stack temperature, °C
T_{Cl}	Clinker temperature at cooler exit, °C
T_F	Fuel temperature, °C
T_{Z1}	Average temperature of shell, lower third, °C
T_{Z2}	Average temperature of shell, middle third, °C

Symbol	Description
T_{Z3}	Average temperature of shell, upper third, °C
T	Kiln room temperature, °C
T_{Cooler}	Surface temperature of cooler, °C
T_{Kiln}	Surface temperature of kiln, °C
$T_{Preheater}$	Surface temperature of preheater, °C
TC_{Dust}	Total carbonates in the kiln dust, kg
V_{Be}	Air volume of kiln exit gas, m^3/s
V_{CO}	Air volume of total air into the cooler, m^3/s
V_{Ex}	Air volume of cooler vent stack, m^3/s
V_{Pa}	Air volume of primary air flow, m^3/s
W_A	Fuel rate, m^3/kg of clinker
W_{Cl}	Kiln output, kg/h
W_{dF}	Dry feed rate, kg/kg clinker
WGF_{CO_2}	CO_2 from feed, kg/kg clinker
$WGF_{H_2O\ f}$	H_2O_{free} from feed, kg/kg clinker
$WGF_{H_2O\ c}$	H_2O_{chem} from feed, kg/kg clinker
W	Total weight of a specific type of molecule in kiln exit gas, kg/kg clinker
w_{rev}	Reversible work, kJ/kg
ε	Emissivity
γ	Rated load
α	Load current parameter
η	Efficiency