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ENERGY CONSUMPTION AND SAVING POTENTIAL IN CEMENT FACTORY: THERMAL ENERGY AUDITING

GEBRESLASSIE, M. G., GEBRELIBANOS, K.G., & BELAY, S.
Ethiopian Institute of Technology-Mekelle,
Mekelle University, P.O Box 231
Mekelle, Tigray, Ethiopia
Email: mulualem.gebregiorgis@mu.edu.et
Phone: +251930284990

ABSTRACT

Energy is one of the major inputs for the economic development of any country, thus lack of efficient and effective utilization of energy is a major concern in high-energy consuming industries such as the cement industries. The objective of this research is therefore to conduct energy auditing in Messobo Cement Factory to quantify the energy losses in the system and to identify potential areas for improvement. On site measurements of the material and energy flows was conducted using Infrared thermometer, Thermocouples and Pitot static probe with manometer. Based on the energy analysis performed, the most energy intensive process is found to be the pyre system (burning). The specific heat consumption has been found to be 844.5 kcal/kg-cl with around 45.83 % system efficiency. The major heat losses for the processes occurred in pre - heater exhaust gases and grate cooler vent air that accounted as 176.7 kcal /kg-cl and 199.3 kcal/kg-cl respectively. Comparison of the specific heat consumption with the standard specific heat consumption of the technology under study (730-780 kcal/kg-cl) showed about 64.5 kcal/kg-cl more energy consumption in the kiln system. This indicates that there is a need to improve the energy consumption by applying proper energy saving techniques.

Key Words – Rotary Kiln; Heat balance; Auditing; Efficiency

INTRODUCTION

The cement industry consumes high energy particularly in the chemical and physical processes reaction. Considerable amount of the total energy consumption of the industrial sector, which is 30–70 % of the total global energy consumption, is attributed to the cement industry (Al-Ghandoor, Al-Hinti, Jaber, & Sawalha, 2008; Al-Mansour, Merse, & Tomsic, 2003; Önüt & Soner, 2007; Saidur, 2010; Saidur, Rahim, Masjuki, et al., 2009; Saidur, Rahim, Ping, et al., 2009; Steenhof, 2006). It is also noted that the dry process of a rotary kiln consumes and leaks large amount of thermal energy. The cement industries consumes approximately 12% of total energy consumption in Malaysia (Madlool, Saidur, Rahim, & Kamalisarvestani, 2013) and 15 % of the total energy consumption in Iran (Avami & Sattari, 2007).

The share of energy cost compared to the total production cost in the cement industries is in the range of 20 to 60% of operational costs, which clearly requires great attention for improving the energy efficiency in the industry (Wang, Dai, & Gao, 2009; Worrell, Kermeli, & Galitsky, 2013). In addition, 5-7 % of CO2 emissions in the world are caused by cement plants with the specific emission being around 900 kg CO2 per ton of cement produced (Ali, Saidur, & Hossain, 2011; Benhelal, Zahedi, Shamsaei, & Bahadori, 2013). Increasing in energy consumption per unit product would have also an impact directly on the profitability, competitive advantage of the company and energy-related environmental emissions. Electrical and thermal energy are commonly utilized in cement factories. Thermal energy is commonly utilized for Clinker production and it is the most energy intensive production stage in cement factory. The basic process of cement production involves Mining, Preparation of raw meal, Formation of clinker, and grinding into cement. The cement manufacturing is an energy intensive process where energy is consumed mainly in the pyro-process in the kiln plant for producing clinker, which accounts for 50 % of the total energy cost. Coal take major share of fuel used in cement industry and the pyro-processing is accompanied with high thermal energy losses and only fraction of the energy obtained from combustion is being effectively used. Thus, considerable attention is being given for cement manufacturing industries worldwide because of high amount of energy consumption and its associated environmental impact.

An energy auditing study conducted by (Engin & Ari, 2005) indicated that with an input heat of 3686 KJ/kg of clinker (KJ/kg-cl) (95.47 %), the energy utilized for clinkering was 1795 kJ/kg-cl with an efficiency of 48.7 % with almost around 40 % of the total input energy being lost through hot flue gas (19.15 %), Cooler stack (5.61 %) and kiln shell (15.11 % convection plus radiation). Based on this, heat recovery system was introduced to capture the heat that would be wasted to the environment to generate electricity and heating water. The heat recovery for power generation was done from the potential areas, which are pre-heater and cooler vent. Around 15.6 % of the total heat input was being used to be recovered, as a result, 4MW energy was harnessed and the electricity generated would offset a portion of the purchased electricity. A similar study by (Tripathy, Roy, & Balasubramanian, 1992) also showed that the efficiency of the clinker production was estimated to be 41.83 %. With a heat recovery system, the study showed that an estimated power of 1.14 MW could be generated with a simple payback period of 48 months. A study on the energy saving potential and reduction of CO2 emission in the cement industry indicated that a maximum of 3.4 GJ/ton and 212.54 kg CO2/ton respectively could be achieved (Madlool et al., 2013).

A complete energy auditing in another plant showed that 1720 kJ/kg-cl (50.4 % efficiency) was utilized for clinker production whereas actual energy supplied is 2286 kJ/kg of clinker with difference of 566 kJ/kg-cl. This indicated a potential of energy saving up to 12 % of its losses by applying different approaches such as optimize fuel and air, minimizing losses through the wall of kiln, and using high grade fuel. A study on dry process cement factory by (Kabir, Abubakar, & El-Nafaty, 2010) showed that the plant operates at 41 % efficiency, which is below the expected efficiency of modern plants that is in the range of 50-54 %. With the use of waste heat recovery steam generator,4.4 MW power could be generated in a plant which has a heat loss of about 35 % of the energy input. This power could save around 30 % of the company's electricity demand (Khurana, Banerjee, & Gaitonde, 2002).

According to the study of energy consumption of dry cement manufacturing process at Keman cement plant in Iran, efficiency of the system was found to be 46.6\%, which is low also lower compared to the expected efficiency. For this reason, a waste hear recovery steam generator was recommended to harness the heat loss through the exhaust gas from the kiln that has an average temperature of 315 ^{0}C and the temperature of the air discharged from the Cooler stack that has an average temperature of 215 ^{0}C. It was estimated that this waste heat recovery can generate about 500 kW with a payback period of 11.28 months (Gholipour Khajeh, Iranmanesh, & Keynia, 2014).

All those researches showed that there is huge heat loss in the kiln system of cement production. For this reason, appreciable amounts of heat energy could be saved or conserved by preventing leakage of heat and making heat recovery in the kiln, pre-heater and grate cooler by modifying the equipment and create awareness towards energy conservation throughout the manufacturing processes. These thermal energy can be easily recovered using heat exchangers for different applications (Campana et al., 2013).

Study by (Ayu, Hailu, Hagos, & Atnaw, 2015) on the rotary kiln process of the same industry where this study is conducted also showed that the efficiency of the system was 46.22 %. However, this study did not consider all the input energy sources that have been utilized at that time, which include furnace oil and coal. Coal was considered as the only energy input while furnace oil was excluded, which will not provide accurate efficiency of the system. The plant is currently using a combination of coal and husk excluding furnace oil in order to reduce the cost, as husk is abundant resource in the region. In addition, the data was collected for two months and the analysis was conducted based on those data and data from the operating manual. The study was also conducted while the plant was under commissioning with a capacity of 3000 ton/d. With all those limitations, it is crucial to conduct more study that is comprehensive by measuring all the input and output energy and materials from the actual process for longer period of time with the plant under full operation with a capacity of 3500 ton/d.

Industrial energy audit is therefore the key to quantify all the energy streams in the facility and quantifying energy usage according to its discrete function. In short, the audit is designed to determine where, when, why and how energy is being used. It allows a better assessment of the heat consumption and the potential for improvement by identifying opportunities to improve efficiency, decrease energy costs and reduce greenhouse gas emissions that contribute to climate change.

As the huge amount of CO2 emissions cause environmental problems, the efficient and effective utilization of energy is a major concern in Messebo Cement Factory. Therefore, a state-of-the-art review on the energy use and savings is necessary to identify energy wastage so that necessary measures could be implemented to reduce energy consumption in this sub-sector.

Therefore, the main goal of this study is to quantify the energy consumption of the kiln system and identify the potential areas for introducing heat recovery systems to improve the overall energy efficiency. The outputs of the study will have significant importance in terms of economical aspect and minimization of environmental impacts by the implementation of recommended energy conservation measures.

PROCESS DESCRIPTION

The basic process of cement production in Messobo Cement Factory involves the following sections as shown in Figure 1.

- Mining
- Preparation of raw meal,
- Formation of clinker,
- Grinding into cement
- Packing unit

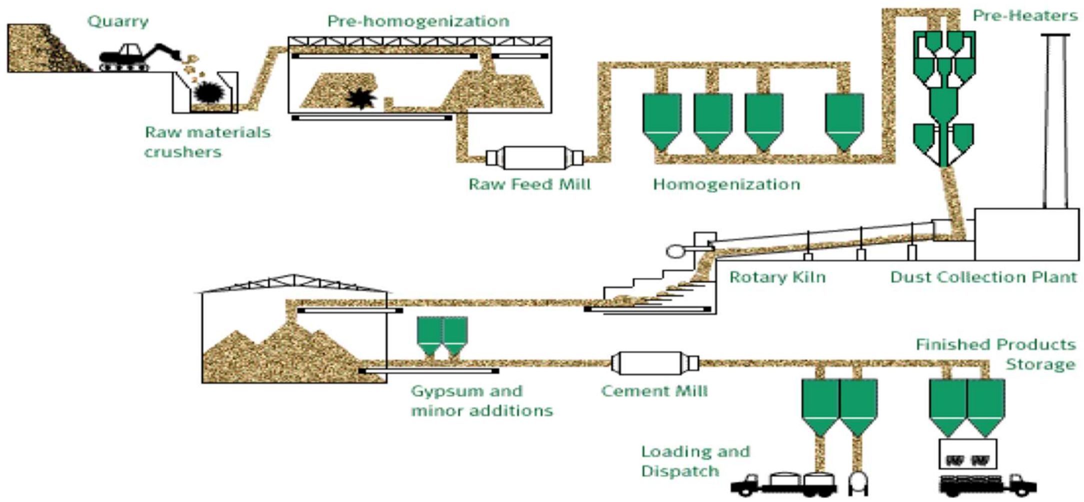

Figure 1: Plant layout of Messobo Cement Factory/cite {Manual 2010 energy}

Mining

Limestone and shale are the main raw materials and are found at a distance of 0.7 km from the factory. This place has its own mining facility. The limestone and shale is crushed into small size for convenient transportation, with the help of primary and secondary crusher in the area itself and the other material is brought from other near place by truck. Through conveyor belt, the crushed material is transported to the plant for further grinding.

Preparation of Raw Meal

In the raw milling process, homogenizing and grinding actions are performed. In the homogenizing system the main material that are limestone and shale are mixed together with additives (Iron ore and Sand) to obtain the correct chemical configuration, and grinding them by the vertical raw mill (VRM) to achieve the proper particle size to have optimization of fuel in the clinkering process. The ground material is stored, as raw meal in storage silos, which has a capacity of 14400 tons. The moisture in the material is removed by making full contact with hot gases that comes from the pre- heater in order to have the required level of moisture.

Coal Mill and Conveying

From the pre-homogenizing system for coal, the raw coal is sent to raw bin for storage by belt conveyor with storage capacity of 140 tons. The raw coal is fed to the vertical mill by avoiding iron objects using metal detector for grinding by airlock roll or vertical mill (L42RM1) with capacity of 40 ton/h. Three metering scales are installed below the pulverized coal silo with feeding capacity of 1.1-11 ton/h to kiln head and the pre-calciner based on 40 to 60 % respectively.

Byre Process (Pre-Heating, Pre-Calcining and Firing)

From the meal silo of the raw meal the feed comes and enter into the cyclones (six stage pre- heater) from the top of pre- heater, and heated by the hot air comes from burner then hot meal goes toward the pre- calcining for calcining process. It is then transferred for burning (sintering process) or fusion zone to be heated to 1450 ^{0}C, which produces hot clinker.

Grate Cooler

A clinker with high temperature comes down to the horizontally driven Grate cooler with capacity of 3500 ton/d and pushed to the back end through reciprocating movement the grate bed for cooling the clinker by cold air with help of cooling blowers. At last, any particle greater than 25 mm in size is blocked and crushed by the hammer crusher. Temperature of the clinker outlet is 65 ^{0}C.

Cement Grinding Process

Clinker grinding is the end process in the Cement manufacturing. It involves adding of additives like gypsum, fly ash, blast furnace slag to the clinker depending on the types of cement and grinding of the material using double cement mill. The output or fine material is sent to silo by bucket elevator for final storage. Finally, the cement is sent to cement packing unit.

Packing Unit

In the packing unit the cement stored in the silo is packed. There are three packing sections, which are loading in the wagon or bulk quantity in jumbo bag (big bag) and packed in 50 kg bags. Details of the processes and their material and energy inputs are given in Figure 2.

SCOPE OF THE STUDY

Due to the nature and the complexity of the processes and sites, a comprehensive audit can take too much time and special equipment to complete it. This study focused in the Byre process (pre-heating, pre-calcining and firing) and the grate cooler, which are found within the burning process shown in Figure 2.

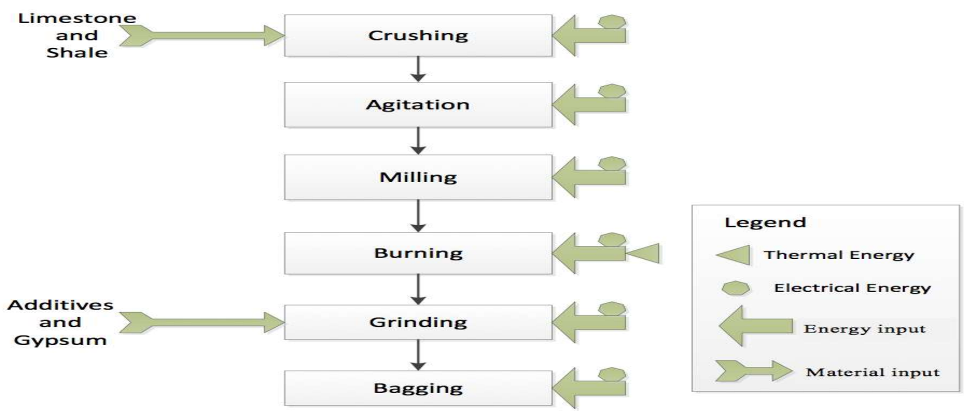

Figure 2: Material and energy flow diagram for dry process of cement factory

The cement manufacturing is an energy intensive process where energy is consumed mainly in the pyro-process in the kiln plant for producing clinker, which accounts for 50 % of the total energy cost. Coal take major share of fuel used in the cement industry and the pyro-processing is accompanied with high thermal energy losses and only fraction of the energy obtained from combustion is being effectively used. This is why the focus of this study was in this energy intensive process to quantify the actual energy consumption and losses in the process. The study focused on heat energy and most of the energy auditing and analysis was focused on the heat inputs and heat outputs within the selected energy intensive process.

METHODS AND MATERIALS

This study used quantitative and qualitative data collected as primary and secondary data from different resources. The following methods have been employed to achieve the objectives of this project.

Data Collection

Primary and secondary data was collected using the following methods for a period of one year:

- Primary data was collected through field measurements in the process within the company
- Secondary data was collected from existing measurements and data recorded from the central control room (CCR)
- Secondary data of all monthly utility bills and invoices for delivered fuel was collected from the company

The collected data from the CCR was compared with past data and by referring to the original design of the plant to make sure that it is a real data (Gholipour Khajeh et al., 2014).

The various input and output gas volume at different locations was measured with Pitot tube with manometer assembly. The kiln, pre-heater and cooler surface temperatures were measured with radiation pyrometer. The material input and output temperature are measured by using a Thermocouple. The temperatures of inlet and outlet gas were continuously measured by the on-line temperature probes, which are installed on the system.

Data Processing and Analysis

A detailed heat and material balance were conducted for the pyro-process of the system including the pre-heaters, kiln and grate cooler making quantitative analysis based on the collected data to get:

- Total heat input in to the system
- Heat output from the system
- Identified energy used for clinkerazation
- Estimated total heat losses from the system
- Specific heat consumption
- System performance

To find the heat input to the system we first identified the energy sources. In the company, the energy sources are electrical, coal and stalk and the heating value of coal and husk is 6000 kcl/kg of coal and 3968 kcl/kg of Husk respectively. All the total energy consumption was weighted based on the production of one kg clinker (kg-cl) by collecting the data for one year and taking averaged whenever necessary (Hefei, 2010). The equation utilized to estimate the total energy input is given as:

$$Q_{in} = Q_{Fuel} \times H_{Value} \quad (1)$$

Where: Q_{in} is heat input, Q_{Fuel} is fuel input, H_{Value} is the heating value of the fuel.

To calculate the heat output, first we calculate the useful or used heat by using the composition for one kilogram of fuel using the standard equation. Then after evaluating all losses such as pre-heater gases, cooler exhaust gas, heat with the hot exiting clinker from the grate cooler, the radiation and convective losses and other will be sum up to the total heat input. Therefore, the specific energy consumption is calculated by summing up the total energy input divided to the clinker or material production as:

$$\text{SHC} = \frac{\text{Total heat}}{total\ clinker(\ kg)} \quad (2)$$

Where: SHC is the specific heat consumption

Equipment

The measuring equipment utilized in this research are:

- Infrared thermometer
- Thermocouples
- Pitot static probe with manometer

RESULTS AND DISCUSSIONS

1.1. Operations data of the kiln system

The control volume for the study includes the pre-heaters, rotary kiln and cooler. The streams into the system are the raw meal, the air into the cooler and coal fired in the kiln. The streams leaving the system are clinker out from the cooler, the exhaust gas from the pre-heater and hot gases from the cooler. The various input and output gas volume at different locations are measured with Pitot tube with manometer assembly. The kiln, pre-heater and cooler surface temperature were measured with radiation pyrometer. The material input and output temperature is measured by using a Thermocouple. The temperatures of inlet and outlet gas are continuously measured by the on-line temperature probes, which are installed on the system.

In order to conduct the heat energy and material balance, it is necessary to know the operating parameters of the kiln system and all the operating parameters measured are provided in table 1 and Figure 3. These data were the basis for the energy and material balance analysis. They also show capacity of the kiln system of the cement factory. The average clinker production is 145.4 ton/h, the average coal consumption 18.15 ton/h, and the ambient air temperature is 27 ^{0}C as shown in Figure 3

Table 1: Operation Data of Kiln System

Components	Value
Ambient temperature	27 ^{0}C
Production capacity	3500 t/d
Kiln feed	232.6 t/h
Clinker production	145.4 t/h
Coal consumption	18.15 t/h
Temperature of feed	80 ^{0}C
Temperature of coal	80 ^{0}C
Pre-heater exhaust gas temperature	320 ^{0}C
Temperature of primary air	70 ^{0}C
Excess air	10 %
Clinker discharge temperature	92 ^{0}C
Temperature of hot air from cooler	400 ^{0}C
Dust concentration in Pre-heater exhaust gas	100 g/m^3
Dust concentration in cooler exhaust gas	80 g/m3
Surface temperature of kiln	275 ^{0}C (0-22 m), 318 ^{0}C (22-46 m), 345 ^{0}C (46-70 m)
Surface temperature of pre-heater	
Surface temperature of cooler	95 ^{0}C
Primary air flow rate	11700 m^3/h

The average temperature of the pre-heater exhaust gas is 320 ^{0}C, while the study by (Ayu et al., 2015) shows around 323.44 ^{0}C. Similarly the average temperature of hot air from the cooler is 400 ^{0}C, while the study by (Ayu et al., 2015) showed around 285.85 ^{0}C. The difference is mainly because the data taken by (Ayu et al., 2015) are during frequent interruptions and commissioning of the process and within a short period. This has a consequence in choosing heat recovery systems if the actual exhaust temperatures are not properly measured.

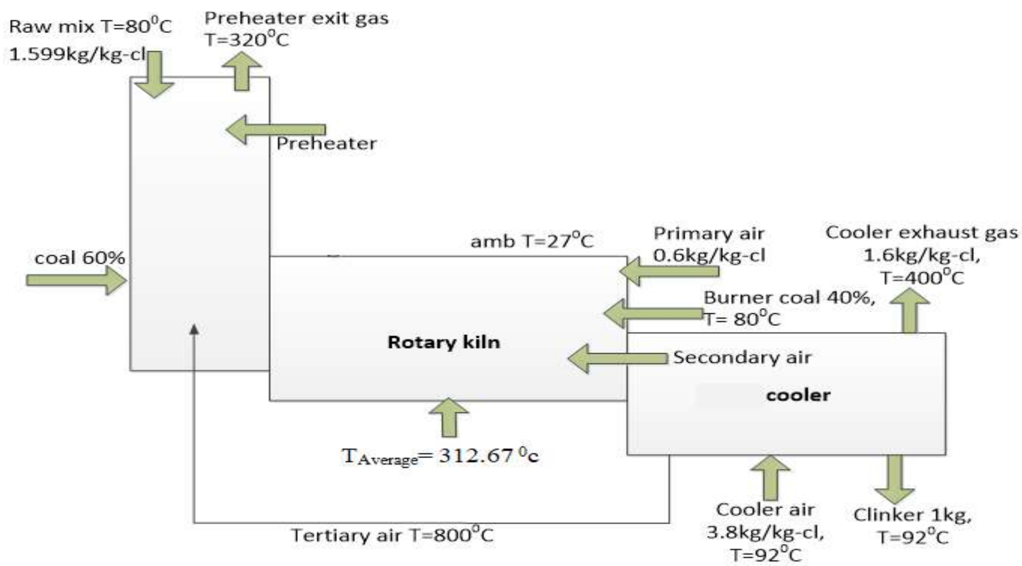

Figure 3: Byre process Diagram

The energy auditing has been performed based on the data collected from control volume of the kiln, pre-heater and grate cooler system for a one-year period. All the input and output parameters are converted per kilogram of clinker and the material balance is done accordingly. In order to analyses the kiln system thermodynamically, the following assumption are made for mass and the heat balance of the preheated, rotary kiln and grate cooler.

- Steady state working conditions
- The change in the ambient temperature is neglected
- Raw material compositions do not change
- The average kiln surface temperatures do not change
- The pre-heater is modeled as a vertical cylinder
- The cooler surface is modeled as a vertical plate

1.2. Materials Balance

Calculating the mass balance is important to identify the thermal energy consumption easily. Based on the data obtained from the CCR or the company the mass input and mass output is estimated as shown in Table 2.

Table 2: Material Input and Output summary

Material in	Mass in (kg/kg-cl)	Material out	Mass out (kg/kg-cl)
Raw material (Feed)	1.599	Clinker	1
Coal	0.139		
Husk	0.0023		
Total air to the system	5.30	Hot air from the cooler	1.67
		Dust from the cooler	0.3
		Pre-heater exhaust gas	2.01
		Dust from pre-heater	0.0000743
		Excess hot air	1.10 constant
		Losses due to leakage	0.96
Total	**7.04**		**7.04**

1.3. Thermal Energy Balance

The total heat input to the kiln system is given in table Table 3. These include the total heat of the coal, the sensible heat of coal, raw material, and air. The total heat input from a combination of these input materials and coal fuel is 915.09 Kcal/kg-clinker. This total heat input will serve as the bases to understand the heat losses in the system and the actual heat consumption for clinker formation. Whereas the output energy or calculated is 876.94 kcal/kg of clinker (95.83 %) and the left or uncounted losses was 38.15 kcal/kg-clinker or 4.17 %. The specific thermal energy consumption of the line is 915.09 kcal/kg of clinker. The fuel (coal and husk) consumption of the kiln system is however, 92.3 % of the total heat input with the remaining coming from the sensible heat of the input materials.

Table 3: Heat input summary

Specific heat of material in	Equation	kcal/kg-cl	Heat (%)
Coal combustion	$Mc*H_c+M_h*H_h$	844.5	92.3
Sensible heat of coal & Husk	$M_c*cp_c+M_h*cp_h(T_1-T_{amb})$	2.24	0.25
Sensible heat of raw material	$M_R*cp_R(T_2-T_{amb})$	17.8	1.95
Sensible heat of combustible air	$M_{ar}*cp_{ar}(T_3-T_{amb})$	50.55	5.51
Total		**915.09**	**100**

With the total heat input to the system, the total heat consumption for clinkering and heat losses through various exit points across the kiln system was calculated and all these outputs are given in Table 4. The heat balance shows that more than 95.83 % is accounted through the different exit points with the remaining 4.17 % of the heat input unaccounted. However, the critical issue here is that the actual energy consumption for clinker formation is around 419.4 Kcal/kg-cl, which is nearly 45.83 % of the heat input to the system.

As indicated in Table 4, the highest heat losses from the system happens in the hot air from cooler and pre-heater exhaust gas with more than 21.78 % and 19.31 % of the total heat input respectively. Those are the potential areas for improvement by introducing additional heat recovery systems. The heat losses through radiation and convection from the kiln system are 3.3 % and 0.80 % respectively. This is relatively low compared to the losses through the hot air from cooler and pre-heater exhaust gas.

Table 4: Heat Output Summary

S/No	Specific heat of material out	Equation	kcal/kg-cl	Heat (%)
1	Clinker formation		419.4	45.83
2	Clinker discharge	$M_c * cp_{cl} * (T_4 - T_{am})$	19.5	2.13
3	Pre-heater exhaust gas	$M_{pg} * cp_{pg} * (T_8 - T_{am})$	176.7	19.31
4	Moisture on coal	$M_{H2O} * (T_7 - T_{co})$ + heat of evaporation	9.75	1.07
5	Moisture on raw mix	$M_{H2OR} * (T_7 - T_R)$ +heat of evaporation	7.9	0.86
6	Hot air from cooler	$M_{co} * cp_{co} * (T_9 - T_{amb})$	199.3	21.78
7	Heat loss by dust in preheat	$M_{dp} * cp_{dp} * (T_6 - T_{amb})$	0.0038	0.0004
8	Heat loss by dust in cooler	$M_{dc} * cp_{dc} * (T_5 - T_{amb})$	9.1	0.99
9	Radiation from Kiln surface (0-25 m)	$\frac{\sigma\varepsilon k A_k (T^4{}_{10} - T^4 amb)}{1000 * \dot{m} - cl}$	11	1.20
10	Radiation from kiln surface (25-53)	$\frac{\sigma\varepsilon A_{k2} (T^4{}_{11} - T^4{}_{amb})}{1000 * \dot{m} - cl}$	8.8	0.96
11	Radiation from kiln surface (53-70 m)	$\frac{\sigma\varepsilon A_{k3} (T^4{}_{12} - T^4{}_{amb})}{1000 * \dot{m} - cl}$	9.2	1.00
12	Convection from kiln surface (0-25)	$\frac{hcA_{k1} (T_{10} - T_{amb})}{1000 * \dot{m} - cl}$	2.6	0.28
13	convection from kiln surface	$\frac{hcA_{k2} (T_{11} - T_{amb})}{1000 * \dot{m} - cl}$	2.5	0.27
14	Convection from kiln surface	$\frac{hcA_{k3} (T_{12} - T_{amb})}{1000 * \dot{m} - cl}$	1.94	0.21
15	Radiation from-pre-heater surface (1-3 cyclones)	$\frac{\sigma\varepsilon A_{p1} (T^4{}_{13} - T^4{}_{amb})}{1000 * \dot{m} - cl}$	0.4	0.04
16	Radiation from pre-heater surface (4-6)	$\frac{\sigma\varepsilon A_{p2} (T^4{}_{14} - T^4{}_{amb})}{1000 * \dot{m} - cl}$	0.64	0.07
17	Convection from pre-heater surface (1-3)	$\frac{hcA_{p1} (T_{13} - T_{amb})}{1000 * \dot{m} - cl}$	0.14	0.015
18	Convection from pre-heater surface (4-6)	$\frac{hcA_{p2} (T_{14} - T_{amb})}{1000 * \dot{m} - cl}$	0.24	0.026
19	Radiation from cooler surface	$\frac{\sigma\varepsilon A_{p2} (T^4{}_{15} - T^4{}_{amb})}{1000 * \dot{m} - cl}$	0.25	0.027
20	Convection from cooler surface	$\frac{hcA_{p2} (T_{15} - T_{amb})}{1000 * \dot{m} - cl}$	0.075	0.008
21	unaccounted losses		38.15	4.17
22	**Total**		**915.09**	**100**

The consumption of energy for clinker formation has increased to 419.4 Kcal/kg of clinker compared to the study by (Ayu et al., 2015), which was 402.66 kcal/ kg of clinker. In addition, the operation manual of the Kiln system recommends energy consumption of 179.14 kcal/kg of clinker for clinker formation (Ohunakin, Leramo, Abidakun, Odunfa, & Bafuwa, 2013). This shows there is high energy consumption compared to the operating manual. In addition, though the study by (Ayu et al., 2015)has limitations as mentioned in the aforementioned sections, there is clear indication that as the rotary Kiln system gets older, the energy consumption for clinker formation has increased in this study. This requires great attention in order to sustain the energy efficiency of the process. A summary of the energy and material input and output of the Kiln system is given in Figure 4.

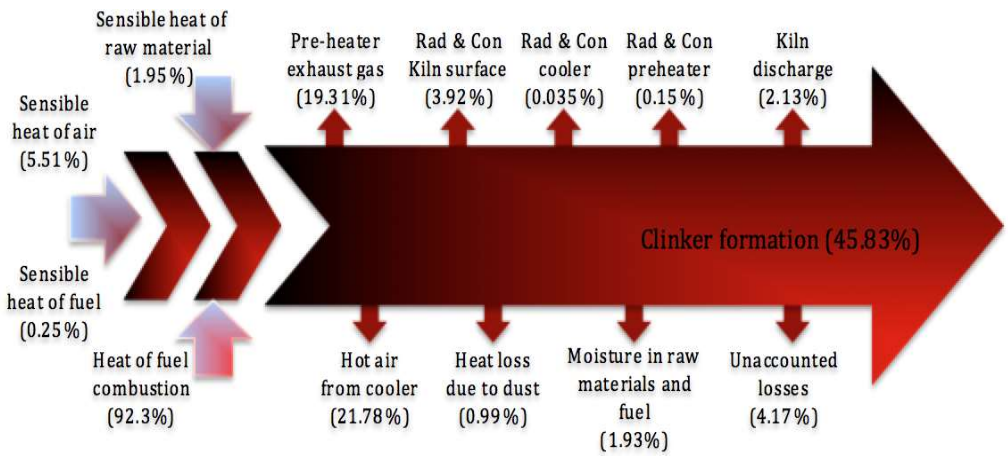

Figure 4: Sankey Diagram of the energy balance of the Kiln system

The specific heat input to the kiln system is nearly 844.5 %, which is higher than the standard heat input range to the system for a 6-stage cyclone system as shown in Table 5. As indicated in the introduction, the standard heat input to the system as a fuel is in the range of 730-780 kcal/kg of clinker for this technology. This shows the fuel input in Messobo Cement Factory (844.5 kcal/kg clinker) is much higher than the range. This is a clear indication that there are huge heat losses through the kiln system.

Table 5: Actual energy consumption per standard

Energy type	Actual energy consumption /unit	Acceptable (standard)[13]	Remark
Thermal energy	844.5 kcal /kg clinker	730-780 kcal/kg of clinker	6-stage pre-heater cyclones

SYSTEM EFFICIENCY

With the consumption of heat energy for the clinker formation being 419.4 kcal/kg-cl and the total heat input to the system being 915.09 kcal/kg-cl,the overall system efficiency 45.83 %. This is considered relatively low. Some modern kiln systems operating at full capacity would have an efficiency of 50-54 % based on the same dry process methodology (Kabir et al., 2010). Therefore, the efficiency of the system can be improved by recovering some of the heat losses. The recovered heat energy can be used for different applications such as electricity generation, hot water. This kind of recovered energy would offset a portion of the purchased electricity, thereby reducing the electrical demand.

RECOMMENDATION FOR SYSTEM EFFICIENCY IMPROVEMENT

The heat recovery system has been recommended by making detailed evaluation to see whether it is economically effective or not, by getting the actual heat, total power generated, investment cost and saving cost, and payback period. One of those thermal energy saving methods is the waste heat recovery, currently in the line the energy used can be reduced to optimum value by installing waste heat recovery (WHRSG) without affecting the production rate and the quality of the clinker.

Among those heat loss sources or potential areas identified in the energy balance in the kiln system that can be easily recovered are the hot air from cooler stack, which accounted to 176.7 kcal/kg of clinker (19.31 %) and the pre - heater exhaust gas around 199.3 kcal/kg (21.78 %). In this case hot air from cooler stack and pre-heater exhaust gases has been considered as potential for the heat recovery.

The exhaust gas from the pre-heater has an average temperature of 320 ^{0}C and the average temperature of the hot air discharged from the cooler vent is 400 ^{0}C. Thus, the temperature of hot air that exit from the cooler vent and pre-heater that passes through the heat exchanger should be less than 200 ^{0}C before it enters the bag filter for safety purpose. The measured temperature from the cooler vent is higher than the temperature used by (Ayu et al., 2015), which affects the use of technology for the waste heat recovery.
The total available heat that can be recovered from the two largest heat losses can be made by considering output of the pre-heater (PH) exhaust (320 ^{0}C) as an input to waste heat recovery system and it leaves the system with a temperature of 160 ^{0}C. Similarly, the inlet air temperature to the waste heat recovery from the cooler vent is 400 ^{0}C and the outlet temperature from the waste heat recovery is assumed to be 170 ^{0}C. A simple steam turbine power system shown in
Figure ***5*** can be utilized to generate power from the heat losses.

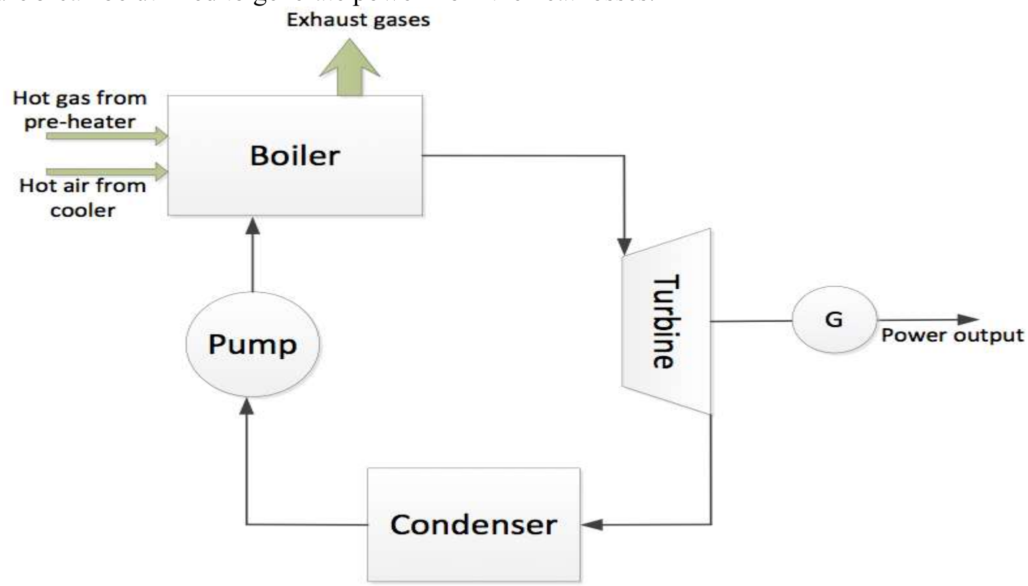

Figure 5: Schematic representation of a steam turbine power generation system

With these considerations, the total theoretical power that can be harnessed from the pre-heater exhaust gas and the cooler vent is 14048.3 KW and 16172 kW respectively. This could easily help to improve the efficiency of the system. With the implementation of the WHRSG considering the available energy from the losses, the economic analysis is tabulated below.

Table 6: Summary of investment and saving

Description	Value
Saving in power	9609.1 kW
Annual saving cost	1,202,617.07 USD
Investment cost	7,120,343.1 USD
simple payback	6 year

Based on the economic analysis, the simple payback of installing WHRSG is 6 year as shown in

Table ***6***, which is feasible and attractive for the company.

There are other opportunities that can be implemented within the process to improve the overall efficiency of the clinkering by capturing the energy that would be wasted in terms of thermal energy. Some of these possible energy saving systems are described below.

- Installation of high efficiency separator. Separator is used in material grinding to separate the fine material from the course material and improve the mill performance by avoiding the over grinding of the material and thereby reduce the power consumption.
- Utilization of alternative fuel especially waste fuel which have a high calorific value like tire chips, paint sludge
- Avoid air leakage from the pyro processing system
- By pass gas from kiln inlet must be used for heating as the exhaust gas
- Using the exhaust gas from pre-heater after drying the coal and feed that is send out where the pressure gets high by safety valve, which can be used for heating water in boiler
- Minimizing excess air in the rotary kiln
- Replacement of worn out bricks

CONCLUSION

The energy auditing in Messobo Cement Factory was conducted to quantify the energy losses in the system and to identify potential areas for improvement. Based on the energy analysis performed in this plant, the most energy intensive process is found to be the pyre system (burning) since it uses high thermal energy for clinkering. The specific heat consumption has been found to be 844.5 kcal/kg of clinker and with the system efficiency value of 45.83 %. The major heat losses for the processes were identified as the pre - heater exhaust gases and grate cooler vent air that accounted as 176.7 kcal /kg of clinker and 199.3 kcal/kg of clinker respectively.

Comparison of the specific heat consumption of the system (844.5 kcal/kg of clinker) with the standard specific heat consumption (730-780 kcal/kg of clinker) showed that there are huge energy losses in the kiln system. This indicates that there is a need to improve the energy consumption by applying proper operational control, optimization of air in kiln and cooler, changing worn out bricks to protect the losses though convection and radiation from the kiln surface and other energy saving techniques.

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