Recoverable Quantity of Waste Heat from Kiln and Preheater Systems and Economic Analysis (Case of Messebo Cement Factory)

Halefom Kidane¹  Birhane Fisha²  Haftom Asmelash³  Dawit Tafesse¹
1. Hawassa university Institute of Technology, Hawassa Ethiopia  
2. Ethiopian Metal Engineering Corporation  
3. Ethiopian Institute of Technology Mekelle, Mekelle Ethiopia

Abstract
This project entitled “Recoverable quantity of waste heat at Messebo cement factory” has tried to quantify the amount of heat loss, the amount of energy and cost saved from the waste heat. Here both primary and secondary data collection methods were included to carry out the study. So, the projects present starts by identifying the main source of waste (which part of cement have high loss), following calculated heat lost from the identified places or machines and final calculating the possible money saved if the waste heat changed to use full form or if it recovered. Successful recovery waste heat contributes to lower fuel cost, lower electricity consumption. Kiln surface zones, Preheater cyclone 4 and 5 are the main areas in which high waste was occur. From Kiln surface zones (959.13 kJ), Preheater cyclone 4 and 5 (587.199 kJ) amount of heat is lost. From this lost we can recover around 62 kW power is recovered, 44155kwhr/month energy and 26492birr/month could be saved. It recommended the energy management department should invite and support others participation and to study on the heat recovery from the loosing of energy and to study on the alternative energy sources of the company.

Keywords: Waste heat, waste heat recovery system, Preheater, Kiln, energy,

DOI: 10.7176/JETP/9-9-03

1. INTRODUCTION
There are more than 10 cements factories in Ethiopia. Mesebo cement factory is among the largest and former plants which provides cement for the African largest dam which is known as great Ethiopian renaissance dam which has the capacity to produce 6050 mega Watt. In the country majority of cement factories their main source of power is electricity from of utility grid and imported fossil fuels like coal. Thus, they consume a lot of powers to perform their daily activity. As stated in [1 and 2] cement factories are among sector’s which consumes high energy especially the clinker calcination process.

Due to the increase of human population and their demand of electricity increases parallelly. So, peoples are search an alternative option to meet their energy demand. Thus, they do either by introducing renewable source of energy, by hybridization different energy mixes or by optimization and increasing the efficiency of energy materials and equipment’s. Besides these methods peoples are also started recovering the waste heat to generate power for different purposes. A model example of countries which are successfully produced power from waste of cement plants as indicated in [1] are India, China and South-east Asia countries.

As written in [3] the first heat recovery system was established in Japan in 1980 by Kawasaki Heavy Industry KHI at Sumitomo Osaka Cement. Then after, a key project with 15 MW capacity has been released in Kumagaya plant (Taiheiyo Cement). After almost two decades later as stated in [4] China was plant installed its first system in 1998 in partnership with a Japanese manufacturer. So, after many obstacles and modification we have reached in technology of waste heat recovery system to generate power from the flue gases. As described [5] some new generation of heat recovery installations in cement kilns producing up to 45 kWh per ton of clinker currently worldwide.

Messebo cement factory utilize a large quantity of fuel and electricity that ultimately produce heat for a process and generates large amounts of exhaust heat during these manufacturing processes, as much as of the energy consumed is ultimately lost via waste heat, that simply passes out through the gas tubes (chimneys) into the atmosphere or into the surrounding without any recovery.

1.1 waste heat
A lot of authors and researches define in different ways. for examples as defined in [3] Waste heat is heat generated in a process by way of fuel combustion or chemical reaction and then goes into the environment without using it. Reference [4] also define waste heat as the extra heat that escapes from the system. Reference such as [7] also says Waste heat is the energy associated with waste streams of air, exhaust gases, and/or liquids that leave the boundaries of an industrial facility and enter the environment.

The amount of waste heat (Q) can be calculated by using equation (1) [6]
\[ Q = C \cdot m \cdot \Delta T \] \[1\]  
Where  
- \( m \) = the mass of the heat carrying medium,  
- \( C \) = the heat capacity of the medium and  
- \( \Delta T \) = the temperature difference between the waste heat and ambient temperature

### 1.2 Heat recovery

As defined in [3] Heat recovery is a method of reducing the overall energy consumption of your site and therefore reducing the running costs. [8] Waste heat to power (WHP) is the process of capturing heat discarded by an existing industrial process and using that heat to generate power (see Figure 1) [8]

![Waste Heat to Power Diagram](image)

**Figure 1: Waste Heat to Power Diagram [8]**

Waste heat recovery has the following advantages [3 and 9]

- Reduces purchased power consumption (or reduces reliance on captive power plants), which in turn reduces operating costs.
- Mitigates the impact of future electric price increases
- Enhances plant power reliability
- Improves plant competitive position in the market
- Lowers plant specific energy consumption, reducing greenhouse gas emissions (based on credit for reduced

### 2. METHODOLOGY

#### 2.1. Description of the study area

Messebo Cement Factory Private Limited Company (MCF PLC) is one of EFFORT (Endowment Fund for the Rehabilitation of Tigray) group companies established in accordance with the commercial code of Ethiopia. The company is located in Mekelle town in the Regional State of Tigray, 780 km from Addis Ababa, capital city of Ethiopia. The plant is located 7 km to the north-west of Mekelle town near Messebo hills. The machineries of the plant are designed and supplied by world renowned cement technology supplier FLSmidth of Denmark. The construction of the Messebo Cement Factory started in February 1997 G.C and was completed at the end of 1999.
2.2 Data collection
In order to conduct this study, methods and procedures have great contribution for reaching the final result and of the paper. The methods used are discussed below in detail.

2.2.1 Primary Data

1. Direct measurement and observation
For this particular work the data were collected through measurements, formal and informal interview of company experts, machine manuals and direct observation. The temperatures of hot gases and air that loss to the atmosphere, heat loss by radiation were measured using the infrared thermometer, and direct observation from control class room (CCR).
II. Interview

For those conditions where the required information is not available written form or not directly measured (difficult to measure) making an interview is one part of data collection method.

2.2.2 Secondary data

Other sources are also used as complementary data source agents. Among these sources’ internet and reference books, different literature survey and documents of the company were used.

3. Result and discussion

3.1 Existing system

3.1.1 Use of hot gases in existing system

In Messebo Building Materials Production Plc the exhausted gases from Rotary kilns, pre-heater and Calciners are used to heat the incoming feed material and gases then exhausted to the atmosphere. The exhaust gas temperature is averagely around 325°C. Part of this gas is used in raw mills & coal mills for drying purpose. The solid material (i.e. Clinker) coming out of the Rotary kiln is at around 1300-1650 °C and is cooled to 100-120 °C using ambient air. This generates hot air of about 280-300 °C which simply is exhausted to the atmosphere.
3.1.2 Numerical calculation and thermodynamic analysis

In this portion we are calculating the amount of energy (heat) lost from 1kg of clinker the system and heat inputs to system required to 1kg of clinker. Besides the above figure 5 information we are also consider different data’s on each stage of calculation which recorded from CCR and we have used different thermo dynamics laws and principles to analyze the collected data such as Ideal gas laws, first law of thermodynamics thus we take the following thermodynamic assumptions:

- Our reference is 1kg
- Steady state working conditions.
- The change in the ambient temperature is neglected.
- Cold air leakage (false air) into the system is negligible i.e. no false air enters to the system and exit from the system.
- Consider the mass flow rate of air through tertiary air duct is negligible
- the system is control volume or open system
- The coal used is South Africa coal which has calorific value (heating value) of 4000-6500kcal/kg

Table 1: some calculated and given value

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kiln output rate clinker</td>
<td>101.9</td>
<td>Tone per hour</td>
</tr>
<tr>
<td>Clinker temperature</td>
<td>120</td>
<td>Degree Celsius</td>
</tr>
<tr>
<td>Kiln feed temperature</td>
<td>80</td>
<td>Degree Celsius</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>25</td>
<td>Degree Celsius</td>
</tr>
<tr>
<td>Reference temperature</td>
<td>20</td>
<td>Degree Celsius</td>
</tr>
<tr>
<td>Atmospheric pressure</td>
<td>101.325</td>
<td>Kilo pascal</td>
</tr>
<tr>
<td>Moisture in fine coal</td>
<td>0.5</td>
<td>Percent</td>
</tr>
<tr>
<td>Moisture in kiln feed</td>
<td>0.5</td>
<td>Percent</td>
</tr>
<tr>
<td>Kiln feed rate (mkf)</td>
<td>130.97</td>
<td>Tone per hour</td>
</tr>
<tr>
<td>Mass of coal to feed calciner (mcc)</td>
<td>34000</td>
<td>Kg</td>
</tr>
<tr>
<td>Mass of coal feed to kiln (mck)</td>
<td>8000</td>
<td>Kg</td>
</tr>
</tbody>
</table>

So based on above assumptions and given data’s (Table 1 and figure 5) lets calculate the following heat loss or the output heat.
The general formula for heat output is given in equation (1) above is .

1. *Sensible heat in kiln feed (Q1)*: \( Q_{1} = \Delta T \times m_{Kf} \times C_{Pkf} \) ..........................(2)

Where \( m_{Kf} = \) mass of kiln feed, \( C_{Pkf} = \) specific heat of kiln feed

With kiln feed of typical lime saturation and calcium carbonate content the kiln feed to clinker factor would be expected to be around 1.54 due to loss of CO2 from the CaCO3. That factor is increased by the dust losses from the preheater to the raw mill and dust filters. If the factor is 1.75 then you must have high dust losses from the preheater so improving collection efficiency will reduce the factor. The true raw meal to clinker factor is given by: 1/(1 – Loss on ignition of kiln feed) the given percentage loose of material chemical lab. There is 34%-36% lost.

2. *Sensible heat due to cooling air (Q2)*:
\[ Q_{2} = m_{co} \times C_{p_{air}} \times (T_{a} - T_{r}) \] ..........................(3)

Where \( m_{co} = \) mass of cooling air, kg/kg clinker

3.1.3 Cooling air fans

**Cooler fans:** Instead of cooling the air itself, fans circulate air inside an ambient space. Circulation of air speeds up the evaporation of sweat on our body, hence giving a cool feeling. So, where a fan is only circulating the air, an air cooler is actually providing cool air for relief from hot weather.

As stated in [10] Heat Capacities of different Gas mixtures\( C_{p} \) is the average of the heat capacities of the components; given by the equation below:

\[ C_{p_{mixture}} = Y_{A}C_{p_{A}} + Y_{B}C_{p_{B}} + Y_{C}C_{p_{C}} + Y_{D}C_{p_{D}} \] ..........................(4)

Where, \( y \) is mole fraction or molar fraction \( (y_{i}) \) is defined as the amount of a constituent (expressed in moles), \( n_{i} \), divided by the total amount of all constituents in a mixture (also expressed in moles)\( n_{total} \)[11]

\[ Y_{i} = \frac{\sum_{i=1}^{N} n_{i}}{n_{total}} \]

Therefore \( C_{p_{mixture}} = \sum_{i=1}^{N} y_{i}C_{p_{i}} \) ..........................(5)

So let us calculate and Lets assume the gases will be modeled as ideal gases with constant specific heats.

The molar masses of N2, O2, H2O, and CO2 are 28.0, 32.0, 18.0, and 44.0 kg/kmol respectively. The air properties at room temperature are \( c_{p} = 1.005 \) kJ/kg.K, \( c_{v} = 0.718 \) kJ/kg.K, and \( k = 1.4 \) which is the ratio of \( c_{p} \) and \( c_{v} \).

1. **Sensible heat in kiln feed (Q1):**
\[ Q_{1} = m_{Kf} \times C_{Pkf} \times (T_{Kf} - T_{r}) \] °C

\( m_{Kf} = \) Kiln feed rate / Kiln output rate clinker

With kiln feed of typical lime saturation and calcium carbonate content the kiln feed to clinker factor would be expected to be around 1.54 due to loss of CO2 from the CaCO3. That factor is increased by the dust losses from the preheater to the raw mill and dust filters. If the factor is 1.75 then you must have high dust losses from the preheater so improving collection efficiency will reduce the factor. The true raw meal to clinker factor is given by:
\[
\frac{1}{1 - \text{Loss on ignition of kiln feed}} \text{ the given percentage loose of material chemical lab. There is 34%-36% lost.}
\]

\[
\text{Raw material feed to kiln} = \frac{100}{100-\text{lost}} \text{ but take the average lost is 35%}
\]

\[
\text{clinker production} = \frac{130.97 \text{ ton}}{1.5384} = 1.5384. \text{ But the raw material feed to kiln is 130.97} \text{ ton hour} \text{. Then the amount of clinker production from 130.97} \text{ ton raw materials is given by} \frac{130.97 \text{ ton}}{1.5384} = 1.5384, \text{ then}
\]

\[
\text{Clinker production} = \frac{1309.7 \text{ ton}}{1.5384} = 85.13 \text{ ton hour}. \text{ But the total clinker out let from the burner includes Ash from coal. But the percentage of Ash is 2.43%-3.01% of the total coal feed see the table 2 below .}
\]

Table 2: percentage of coal constituents in Messebo cement factory

<table>
<thead>
<tr>
<th>Elements found in coal</th>
<th>Percentage %</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>72-73</td>
</tr>
<tr>
<td>H</td>
<td>3-3.5</td>
</tr>
<tr>
<td>O</td>
<td>5.5-6</td>
</tr>
<tr>
<td>N</td>
<td>1.5-1.75</td>
</tr>
<tr>
<td>S</td>
<td>1.5-1.59</td>
</tr>
<tr>
<td>Ash</td>
<td>2.43-3</td>
</tr>
<tr>
<td>Moisture</td>
<td>0.25-0.3</td>
</tr>
<tr>
<td>Volatile</td>
<td>3.77-4.67</td>
</tr>
</tbody>
</table>

**Fixed carbon**

<table>
<thead>
<tr>
<th>Percentage %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.77-4.67</td>
</tr>
</tbody>
</table>

Material feed to kiln \((m_{ck}) = 130.97 \text{ kg hour} \), Mass of coal to feed calciner \((m_{cc}) = 34 \text{ kg hour} \)

\[
\text{Mass of coal feed to kiln} \ (m_{ck}) = 8 \text{ kg hour} \quad \text{M}_{\text{c}} = 130.97 \text{ kg hour}
\]

Total mass of the coals inter in to main burning system \(= M_{\text{c}} + M_{\text{ck}} = 42000 \text{ kg hour} \)

Then the amount of Ash produced from total coal feed is given by

\[
\text{Ash} \left( \frac{100}{100} \times 42000 \text{ kg hour} \right) \text{ let take us 3% from the interval of the above.}
\]

\[
\text{Ash} = \frac{2}{100} \times 42000 \text{ kg hour} = 1260 \text{ kg hour}.
\]

Then the total clinker production = clinker production from raw material + Ash = 85.13 \text{ ton hour} + 21 \text{ kg min}

Total clinker production = 1418.83 \text{ kg min} + 1260 \text{ kg hour} = 1439.83 \text{ kg kg clinker}

Then the above equation be comes

\[
Q1=1.5384 \times C_{\text{Pc}} \times \frac{\text{cal}}{\text{kgC}} \times (80-20) ^\circ \text{C} \quad \text{CPc}=1.09-1.55\text{J/gk (0.937073-1.24 cal/kg°C)}
\]

For this calculation take 1.24cal/kg k Therefor Q1 = 114.45 kcal/kg clinker

2. **Sensible heat due to cooling air (Q2)**

\[
Q2 = m_{\text{a}} \times C_{\text{Pair}} \times (T_{a} - T_{c})
\]

Where, \(m_{\text{a}}\) = mass of cooling air, kg/kg clinker

3.1.4 Cooling air fans Cooler fans

Cooling air fans are centrifugal fans used to cool the clinker by sucking atmospheric fresh air before crushed by the clinker crusher. As the atmospheric air is meet with the clinker heat exchange takes places. Then the atmospheric air becomes hot air. Part of this hot gas is suck to the kiln burner by the ID fan. But they remain is goes through the cooler Chimney by pulling of EP fan. See the below data that the system has nine fans and data was recorded from CCR computers of the cooler fans volume flow rate and pressure when the system runs.

Table 3: volume flow rat of cooler fans

<table>
<thead>
<tr>
<th>Fan</th>
<th>Volume flow rate(m³/min)</th>
<th>Suction pressure(mbar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>74</td>
<td>52</td>
</tr>
<tr>
<td>2</td>
<td>74</td>
<td>48</td>
</tr>
<tr>
<td>3</td>
<td>91</td>
<td>45.5</td>
</tr>
<tr>
<td>4</td>
<td>639</td>
<td>60.8</td>
</tr>
<tr>
<td>5</td>
<td>146</td>
<td>52.2</td>
</tr>
<tr>
<td>6</td>
<td>221</td>
<td>45.4</td>
</tr>
<tr>
<td>7</td>
<td>208</td>
<td>59.1</td>
</tr>
<tr>
<td>8</td>
<td>237</td>
<td>57.6</td>
</tr>
<tr>
<td>9</td>
<td>259.8</td>
<td>55.3</td>
</tr>
<tr>
<td>Total</td>
<td>1949.8</td>
<td>495.9</td>
</tr>
</tbody>
</table>
But mass flow rate of a given system is given by the ration of volumetric flow rate to specific volume. As stated in equation (7) below.

\[
m_{\text{co}} = \sum \frac{\dot{V}}{V}
\]

but from ideal gas law \( PV = nRT \) where \( P \) is the pressure of the gas, \( V \) is the volume of the gas, \( n \) is the amount of substance of gas (also known as number of moles), \( T \) is the temperature of the gas and \( R \) is the ideal, or universal, gas constant. From this the specific volume of a substance is the ratio of the substance’s volume to its mass. It is the reciprocal of density

\[
\frac{v}{p} = \frac{RT}{p}
\]

\[
v = \frac{RT}{P}
\]

So

\[
m_{\text{co}} = \frac{\sum \dot{V}}{V} = 1949.8 \text{m}^3/\text{min} / 15.26 \text{m}^3/\text{kg} = 127.77 \text{kg/min}
\]

So \( Q_2 = m_{\text{co}} \times C_{\text{P, air}} \times (T_a - T_r) = 127.77 \text{kg/min} \times 1.005 \text{kcal/} \text{kg/} \text{C} \times (25 - 20) \text{C} = 642 \text{kcal/ min of clinker}
\]

3. Sensible heat in primary air (Q3): this includes both mass of primary air to kiln and mass of primary air to calciner. To calculate the mass of this air the primary fun flow rate and suction pressure is important.

Primary air fans: Primary air fans are a fan that are used to suck fresh air for starting calcinations by calciner side and for starting burning by the main kiln side as the coal is feed from coal mill by the help of blower to both sides. See the table below.

<table>
<thead>
<tr>
<th>Fan</th>
<th>Direction that fan in side</th>
<th>Suction pressure(mbar)</th>
<th>Suction capacity(m³/min)</th>
<th>Atmospheric temperature (T_p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Calciner</td>
<td>19</td>
<td>67.36</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>Kiln</td>
<td>20.8</td>
<td>73.75</td>
<td>25</td>
</tr>
</tbody>
</table>

- So mass of primary air to Calciner = volume of flow rate of primary air fans to calciner divided by specific volume of air and
- mass of primary air to kiln = volume flow rate of the fun that sucks the kiln air divide by specific volume of the air
- mass of primary air to calciner = \( \frac{\dot{V}}{v} = \frac{\dot{V}}{67.36} \text{m}^3/\text{min} \) \( v = \frac{RT}{P} = \frac{287 \text{N.m/kg.k} \cdot 298 \text{k}}{5510 \text{N/m}^2} = 45.01 \text{ m}^3/\text{kg} \) so mass of primary air to calciner = 1.49 kg/min
- mass of primary air to kiln = \( \frac{\dot{V}}{v} = \frac{\dot{V}}{73.75} \text{m}^3/\text{min} \) \( v = \frac{RT}{P} = \frac{287 \text{N.m/kg.k} \cdot 298 \text{k}}{2080 \text{N/m}^2} = 41.12 \text{ m}^3/\text{kg} \) mass of primary air to kiln = 1.79 kg/min

So \( Q_3 = m_p \times C_{\text{P, air}} \times (T_p - T_i) \) but \( m_p = \) mass of primary air to kiln+ mass of primary air to calciner; \( m_p = 1.79 \text{kg/min} + 1.49 \text{ kg/min} = 3.28 \text{ kg/min} \)

Then \( Q_3 = m_p \times C_{\text{P, air}} \times (T_p - T_i) = 3.28 \text{ kg/min} \times 1.005 \text{kcal/} \text{Kg/} \text{K} \times (25 - 20) \text{C} \)

\[ Q_3 = 16.4 \text{ kcal/ min of clinker} \]

4. Sensible heat of fuel (Q4): before directly goes to calculation see the following necessary date’s or points
- The coal temperature is increasing from atmospheric temperature to 75°C during drying by absorbing heat from hot gas
- The temperature of the hot gas used for coal mill is maximum-minimum(220-210°C) and the outlet after drying is from(90-80)°C

The temperature of the hot gas used for raw mill is the same as the temperature outlet from pre heater (mostly 325°C) and the out let after drying the raw material is mostly 110°C. Having these points in mind let us calculate

\[
Q_4 = m_{\text{fuel}} \times C_{\text{fuel}} \times (T_{\text{fuel}} - T_i) = m_{\text{fuel}} \times \frac{124 \text{ kcal}}{\text{kg/°C}} \times (75 - 25)\text{°C}
\]

Here the mass of fuel is not known. We can get as follow

1kg clinker = 780 k cal
1kg of South Africa coal = 6500kcal
\[ y \text{ kg SA} = 780 \text{ kcal} \]
\[ 1\text{kgSA} \times 780\text{kcal} = y \text{ kg SA} \times 6500\text{kcal/kg of clinker} \]
\[ y = 0.12\text{kg which is m_{fuel}} \]
\[ Q_4 = 0.12\text{kg} \times 6500\text{kcal/kg of clinker} \]
\[ Q_4 = 7.44\text{ kcal/kg of clinker} \]

**5. Heat from combustion of coal(Q5):**

\[ Q_5 = m_{fuel} \times \text{caloric value of the South Africa coal} \]
\[ Q_5 = 0.12\text{kg} \times 6500\text{kcal/kg of clinker} = 780\text{ kcal/kg of clinker} \]

**3.1.5 Heat out put**

6. **Heat formation clinker (\(\Delta H_R\)):** Heat of formation of clinker: This is the heat to convert the raw material to clinker. This is termed the theoretical heat of formation of the raw meal, from first principles by using heat of reaction data. A more rapid estimation of this heat can be done by using a formula developed by ZurStrassen (1957) which gives good agreement with basic calculations. This formula is:

\[ Q_{th} = 2.22A + 6.4MgO + 7.64CaO - 5.11SiO_2 - 0.59Fe_2O_3 \]

Where \(Q_{th}\) = theoretical heat of the formation

\[ A, M, C, S, F \] are the percentage of \(A\), \(MgO\), \(CaO\), \(SiO_2\) and \(Fe_2O_3\) in the clinker

\[ \Delta H_R \] = 2.22(13.5) + 6.4(0.0004) + 7.646(79.9) – 5.116(5.4) – 0.59(1.5) = 612.408 kcal/kg clinker

7. **Heat in preheater exit dust(Q6):**

\[ Q_6 = m_d \times CP \times (T_e - T_r) \]

Where \(m_d\) = mass of dust

From table the company uses averagely 130.976t/h from this 90% of this fed is going to the system the rest is returned as a dust through preheater to the atmosphere. That means from the total 130.976 TPH i.e. \(130.976 \times \frac{90}{100} = 117.84\) TPH is go to the system and 13.097 TPH is return as a dust. 13.097 TPH=218kg/min is its mass flow rate.

Then mass of dust = kiln feed to clinker factor \(\times\) preheater return dust %

\[ m_d = 1.5384 \times 0.01 = 0.015384 \]

\[ Q_6 = 0.015384 \times 0.23 \text{ kcal/kg}^oC \times (325 - 20)^oC \]

\[ Q_6 = 1.079.7\text{ kcal/min of clinker} \]

8. **Heat in preheater exit gases (Q7):**

\[ Q_7 = m_e \times CP \times (T_e - T_r) \]

The exhaust gases through the preheater cyclone are \(O_2, CO\) and \(NO_x\) let as calculate their density on their dry bases because the moisture from kiln feed and coal in preheater is very small. Average of \(O_2\) is 26.36 and total average of \(CO\) is 0.62257 and the amount of \(NO_x\) is 2000-3000ppm which is averagely around 0.0025. so the totally is 26.98

<table>
<thead>
<tr>
<th>Exhaust gas</th>
<th>%</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>(O_2)</td>
<td>97.70</td>
<td>32</td>
</tr>
<tr>
<td>(CO)</td>
<td>2.3075</td>
<td>28</td>
</tr>
<tr>
<td>(NO_x)</td>
<td>0.0098</td>
<td>72</td>
</tr>
</tbody>
</table>

As written in different literatures at standard conditions, 0\(^o\)C and one atmosphere, one kilomole of gas occupies 22.414m\(^3\) and the universal gas constant is 8314.5 J/(kmol. K). So the density of the above gases at standard temperature and pressure (stp) is calculated as follow using equations (9 and 10).

\[ \rho_{stp} = \frac{\pi(d_e - 2d_i)^2}{4} \frac{\pi(2.61 - 2 \times .11)}{4} = 4.5m^2 \]

\[ \text{Volume flow rate of the hot gas} = \frac{\pi}{\rho} \]

- The temperature of exhaust gas averagely 325.16\(^o\)C
- The pressure is vary from 51.68 mbar but we take the most repeated 56mbar.(taken from CCR)
- The volume flow rate of the hot gas and we take from CCR(central control room) is 9500m\(^3\)/min
Volume flow rate of the hot gas = \( \frac{m}{\rho} \) = so the mass flow rate = \( \frac{m}{\rho} \times \rho \) = 9500m/min \times 1.42 kg/m = 13490 kg/min

Q7 = 13490 kg/min \times CP of the gases \times (325.16 - 20) ℃

But specific heat of mixture is given by

\[ \sum \frac{m_i}{\sum m_i} \times \left( \sum \frac{28kg/mol \times 1.02kJ/kg K + 32kg/mol \times 0.919kJ/kg K + 28kg/mol \times 0.995kJ/kg K + 46kg/mol \times 1.013kJ/kg K}{134kg/mol} \right) \]

So specific heat of the gases = 0.9817 kJ/kg K

Then heat in pre heater exit gases (Q7) is calculated as follow

Q7 = 13490 kg/min \times 0.9817 kJ/kg K \times (325.16 - 20) ℃

Q7 = 4041274 kJ/m = 1103267802 kJ/min

Q7 = 18387796.8 kJ/sec

9. Heat in clinker from cooler discharge (Q8):

Q8 = m_c \times CP_c \times (T_c - T_r)

Q8 = 1 \times 0.193 kcal/kg℃ \times (120℃ - 20℃)

Q8 = 19.3 kcal/kg clinker

10. Heat in cooler exhaust air (Q9):

the clinker grate cooler produces 1 - 2 kg/h of exhaust air per kilogram of clinker. Under normal operating conditions, this exhaust air has a temperature of approximately 280-300℃, which can temporarily increase to 350℃ or decrease to ≤230℃ under abnormal operation(condition).

Q9 = 1.5 kg/h \times 0.25 kcal/kg℃ \times (290 - 20) ℃

Air: CP_ce = 1.005

Q9 = 1.6875 kcal/min of clinker

11. Heat loss due to the radiation from the preheater cyclones and kiln surface:

Radiation loss = \( \sigma \times (T^4 - T_r^4) \times \text{surface area} \)

- Radiation loss from pre heater cyclones surface considered as cylindrical in geometry. So formula for finding the surface area of a cylinder is, with h as height, r as radius, and S as surface area is \( S = 2\pi r^2 + 2\pi rh \)

That is Surface area = \( 2\pi r^2 + 2\pi rh \)

Table 6: area and surface temperature of cyclone4 and 5

<table>
<thead>
<tr>
<th>Cyclones</th>
<th>Length (m)</th>
<th>Diameter(m)</th>
<th>Surface area = ( 2\pi r^2 + 2\pi rh )</th>
<th>Max temp(℃)</th>
<th>Min temp(℃)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclone4</td>
<td>18</td>
<td>5.7</td>
<td>373.17</td>
<td>196</td>
<td>132</td>
</tr>
<tr>
<td>Cyclone5</td>
<td>18</td>
<td>5.7</td>
<td>373.17</td>
<td>291</td>
<td>155</td>
</tr>
</tbody>
</table>

Radiation loss from pre heater cyclone (Qc1) = \( \sigma \times (T_{max}^4 - T_{min}^4) \times \text{surface area} \)

Where \( \sigma = 4.88 \times 10^{-8} \text{kcal/m}^2 \cdot \text{K}^4 \)

Qc4 = 4.88 \times 10^{-8} \text{kcal/m}^2 \cdot \text{K}^4 \times (196^4 - 132^4) 373.17 m²

Qc4 = 20256.95 kcal

Qc5 = 4.88 \times 10^{-8} \text{kcal/m}^2 \cdot \text{K}^4 \times (291^4 - 155^4) 373.17 m²

Qc5 = 120020 kcal

So the total Radiation loss from pre heater cyclones surface = Qc4 + Qc5 = 140276.95 kcal = 587.199kJ

Radiation loss from kiln system: the kiln found in the company is 57m in length and 3.7 m in diameter and is divided in to 3 main zones. Kiln is cylindrical in geometry. So formula for finding the surface area of a cylinder is, with h as height, r as radius, and S as surface area is \( S = 2\pi rh + 2\pi r \)

That is Surface area = \( 2\pi r^2 + 2\pi rh \)
to calculate surface area of cylinder’s as shown in the table below

As shown in the above figure the kiln system have cylindrical shape so we calculating the formula which is used to calculate surface area of cylinder’s as shown in the table below

Table 7: kiln surface temperature and surface area

<table>
<thead>
<tr>
<th>Kiln zone</th>
<th>Length (m)</th>
<th>Diameter(m)</th>
<th>Surface area = 2πr² + 2πrh m²</th>
<th>Max temp(°C)</th>
<th>Min temp(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In let zone</td>
<td>16.5</td>
<td>3.7</td>
<td>213.187</td>
<td>291</td>
<td>149</td>
</tr>
<tr>
<td>Transition zone</td>
<td>33</td>
<td>3.7</td>
<td>404.88</td>
<td>298</td>
<td>151</td>
</tr>
<tr>
<td>Higher burning zone</td>
<td>1.5</td>
<td>3.7</td>
<td>38.97</td>
<td>300</td>
<td>161</td>
</tr>
</tbody>
</table>

So the heat loss due to radiation from the kiln surface calculated as follow using equation (10)

\[
Q_i = A_i \sum_{j=1}^{3} \sigma (T_{j}^4 - T_{min}^4) \times \text{surface area}
\]

\[
Q_{iz} = 4.88 \times 10^8 \text{ kcal/m}^2 \text{-k}^4 (298^4 - 151^4) \times 213.187 \text{ m}^2
\]

\[
Q_{iz} = 69474.61 \text{ kcal}
\]

Radiation Heat loss from transition zone (Qtz):

\[
Q_{tz} = 4.88 \times 10^8 \text{ kcal/m}^2 \text{-k}^4 (298^4 - 151^4) 404.88 \text{ m}^2 = 145543.72 \text{ kcal}
\]

Then total amount of heat output = ΔHr + Q6 + Q7 + Q8 + Q9 + Radiation loss from cyclone 4 and 5 + radiation loss from kiln surface

There for the total amount of heat output = 612.48kcal/clinker + 1.079kcal/min clinker + 1103267802kJ/min + 19.3kJ/kgclinker + 1.6875kcal/min clinker + 587.199kJ + 959.13kJ

= 2649.267kJ

Let us calculate the power gained from the heat loss for one month period of time. Power is the rate of using or supplying energy and is given by the following formula:

\[
P = \frac{\text{energy}}{\text{time}}
\]

Where: Power is measured in watts (W)

\[
\text{Energy is measured in joules (J)}
\]

\[
\text{Time is measured in minute}
\]

3.1.5 summary of powers which is gained from heat loss and the amount birr saved

P1 (from exhaust dust) = Q6/1 month (hr) = 1.079kcal/kg min clinker/43200min = 0.1045w

P2 (from pre heater exit gases) = Q7/1 month (min) = 1103267802kJ/min/43200min = 25538w
P5 (from cyclone 4 and 5) = 587.199 kJ/43200 min = 13.59 kW
P4 (cooler exhaust air (Q9)) = 1.6875 kcal/min clinker/43200 = 0.163 W
P3 (from clinker from cooler discharge (Q8)) = 19.3 kcal/kg clinker/43200 = 1.87 W

P6 (from kiln surface) = 959.13 kJ/43200 min = 22.20 kW

But the average unit of the price of the electric city is 0.6 birr/kw. Having this point then let us calculate the Cost saving and Energy saved.

Cost saving = power gained (generated) × hours of usage in full capacity per month

Energy saved (from p1) = 0.1045 W × 720 hr = 75.274 kWh/month = 0.07527 kWh/month
Cost saving = 0.6 birr/kW × 0.07524 kW/ month = 0.045 birr/month

Energy saved (from p2) = 25538 W × 720 hr = 18387360 kWh/month = 18387.734 kWh/month
Cost saving = 0.6 birr/kW × 18387.734 kWh/month = 11032 birr/month

Energy saved (from p3) = 1.87 W × 720 hr = 1346 kWh/month = 1.34 kWh/month
Cost saving = 0.6 birr/kW × 1.34 kWh/month = 0.80 birr/month

Energy saved (from p4) = 0.163 W × 720 hr = 117.36 kWh/month = 0.11736 kWh/month
Cost saving = 0.6 birr/kW × 0.11736 kWh/month = 0.07 birr/month

Energy saved (from p5) = 13.59 kW × 720 hr = 9784 kWh/month
Cost saving = 0.6 birr/kW × 9784 kWh/month = 5870 birr/month

Energy saved (from p6) = 22.20 kW × 720 hr = 15984 kWh/month
Cost saving = 0.6 birr/kW × 15984 kWh/month = 9590 birr/month

4. CONCLUSION

The cement sector is one of the most energy highly uses industries. The clinker Calcination process is the most energy consuming in cement production, because of the exit gases from the clinker cooler and pre-heater and from the kiln surface.

The aim of this study was to determine the amount of heat loss energy and to identify the main source of the heat losses, and to set possible solutions.

The amount of heat loss and major heat losses for the system were identified as the preheater exhaust gases and heat carried away by cooler vent air (grate cooler). In addition to this the power generated and cost saved was discussed. See the table below main parts.

Table 8: summarized recoverable heat from selected devices

<table>
<thead>
<tr>
<th>Source of the heat loss</th>
<th>Amount of heat loss</th>
<th>1.60 Power generated (kw)</th>
<th>1.61 Energy saved (kWh/month)</th>
<th>1.62 Amount of 1.63 cost saved (birr/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preheater exhaust gases</td>
<td>1103267802 J/min</td>
<td>25.53</td>
<td>18387.73</td>
<td>11032</td>
</tr>
<tr>
<td>Kiln surface</td>
<td>959.13 kJ</td>
<td>22.20</td>
<td>15984</td>
<td>9590</td>
</tr>
<tr>
<td>Preheater cyclone 4 and 5</td>
<td>587.199 kJ</td>
<td>13.59</td>
<td>9784</td>
<td>5870</td>
</tr>
</tbody>
</table>

The power generated is used to powered 2480 light bulbs with 25-watt capacity. Generally important efforts are being made to continue for saving the energy for the cement industry, Successful reduction of fuel consumption contributes to lower fuel cost, higher clinker production, lower electricity consumption by recover the waste heat.

5. References

2. Jain, Mayank Soghoura and Dr. RK, Investigation of waste heat recovery in cement industry. P-ISSN 2349–8528, s.l.: International Journal of Chemical Studies, 03-10-2016.
6. Dr. Martin Pehnt, Jan bödeker et al., Industrial waste heat – tapping into a neglected efficiency potential. 2011