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Review on Thermal Energy Audit of Pyro-Processing Unit of a Cement Plant

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ABSTRACT: *Energy consumption in cement factories is an important issue for the government as well as private organizations. The cement manufacturing industrial sector has become the worldwide energy consumer accounting for over 40% of overall energy consumption by the industrial sub-sector. Most of the thermal energy consumption by a cement manufacturing plant occurs in the Pyro-processing unit. Thus, the energy audit of the cement plant is an essential exercise to promote energy retrofitting measures. The aim of the energy audit is to reduce energy consumption in the plant, reduce energy costs and identify possible Energy Conservation and Management Opportunities (ECMOs). The aim of this study was to review the techniques of energy auditing which include Mass (Material) balance and Energy balance by considering energy conservation in the form of thermal energy that helps to fill the gap in energy efficiency improvement, policy development, and environmental analysis. Using the operational data of Kiln system of Messobo Cement obtained from the literature, the heat losses were quantified for major energy consuming components of the system using both the mass and thermal energy balance approach. The production line's capacity for clinker was 145.4 tons per hour, and both burners received a combined 25 tons of coal per hour. Energy balance tests were conducted in all areas of the pyro processing systems, and the findings revealed significant energy losses from the surface of the kiln systems, kiln exhaust, and cooler exhaust.*

KEYWORDS: energy consumption, rotary kiln, coal mill, raw mill, grate cooler, energy audit

INTRODUCTION

Energy consumption in the cement industry is significant, especially during chemical and physical reaction processes. A rotary kiln's dry process uses and loses a significant quantity of thermal energy. The cost of energy theoretically accounts for more than 55% of industrial costs. Increased energy use per unit of product would also directly affect the company's profitability, competitive advantage, and environmental emissions [1]. The popular and quickly developing subject of conversation today is energy management, balance, and conservation. The primary goals of an energy audit are to accurately account for energy usage, analyse how different components consume energy, and provide the specific data required to identify any potential chances for energy savings [2]. This review has concentrated on the thermal energy auditing of a cement factory's pyro-processing unit [3]. By minimising heat leakage, implementing heat recovery in the kiln, preheater, and grate cooler, altering the equipment, and raising awareness of energy conservation throughout the manufacturing processes, significant quantities of energy could be saved or conserved in the cement industry [1]. The necessity for reducing energy and energy-related emissions from the environment is therefore urgent [1]. In order to balance the overall energy inputs and its output, energy auditing is the first step and a crucial step in identifying the energy stream in facilities. It quantifies energy reoccurring according to its discrete function [1].

Energy Audit Techniques

Every energy audit typically involves [4]:

- Data collection and review
- Plant surveys and system measurements
- Observation and review of operating practices
- Data analysis.

The purpose, scale, and nature of the industry all influence the type of industrial energy audit that is undertaken. An industrial energy audit can be divided into two categories [5] based on these criteria:

Detailed audit (diagnostic audit) and preliminary audit (walk-through audit)

A preliminary energy audit is known as a walk-through audit. The majority of the time, readily available data is used for a straightforward examination of energy use and plant performance. The amount of measurement and data collection needed for this kind of audit is minimal. The simple payback period, or the amount of time needed to recoup the initial capital investment through actualized energy savings measures, is often the only consideration in an economic study [6].

Detailed audit (Diagnostic audit**):** More specific data and information are needed for extensive (or diagnostic) energy audits. Different energy systems (pump, fan, compressed air, steam, process heating, etc.) are typically assessed in detail through measurements and data inventories [7]. As a result, this type of audit takes longer to complete than preliminary audits.
Since they provide a more accurate picture of the plant's energy performance and more specific recommendations for improvements, the results of these audits are more thorough and useful [8].

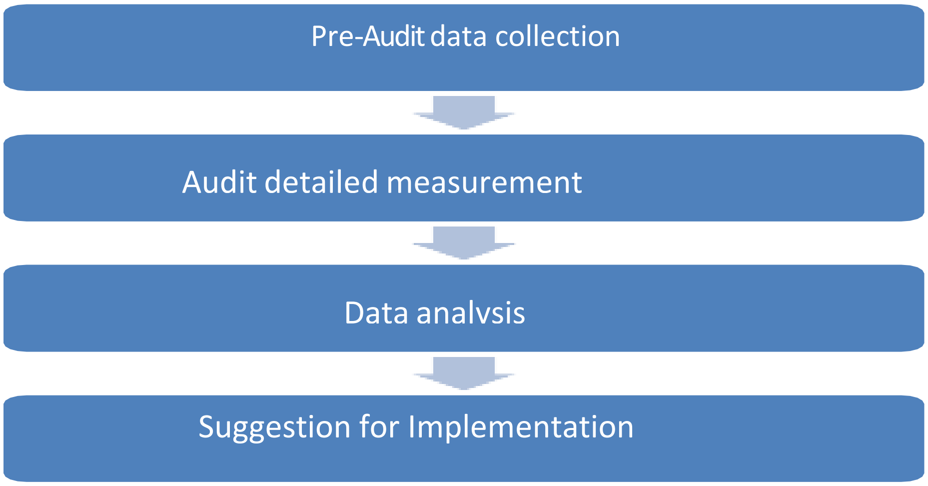


Figure 1: Processes of Industrial Energy Audit [8]

Advantages of Energy analyses: To identify the energy consumption and losses, Energy optimization, reduce operational cost, effective environmental performance, Alternative fuels, and raw materials, Increasing plant efficiency [9].

Energy Use in Cement Production

In cement mills, electrical and thermal energy are frequently used. The processing of the raw materials, the meal, and the final grinding of the material all require electrical energy in the production of cement. The most energy-intensive step in the production of cement is the creation of clinker, which uses thermal energy [11]. The fundamental steps in producing cement are: mining, preparing raw meal, forming clinker, and grinding the material into cement [12].

REVIEW OF RELATED WORKS

The German cement industry's energy-saving options and potentials were discussed, and the energy usage figures were provided in [13]. The research's main subjects are electrical and thermal energy-saving techniques, and the Energy Flow Diagram shows the conclusions reached. A thorough examination of the Material and energy balance for thermal energy-consuming equipment is not, however, included.

“Shaleen et al. [14]” did study on the energy balance in the cement industry. They based their analysis on information from an existing factory in India with an annual output capacity of 1 Megaton. The author calculated that the waste heat streams lost around 35% of the input energy. It was calculated that roughly 4.4MW of electricity could be produced utilising a steam cycle to recover heat from the steams using a waste heat recovery steam generator.

“Candali et al. [15]” used actual operational data to carry out an energy and energy analysis for a dry system rotary burner with pre-calcinations in a cement plant of a significant cement producer in Turkey. It found that the rotary burner's energy and energy efficiency values were 85% and 64%, respectively. However, the calculations weren't done in terms of per unit of Clinker, raising concerns about the accuracy of the overall result.

“Tahsin and Vedat [16]” conducted an energy audit examination of a dry-type rotary kiln system in a Turkish cement plant that can burn 600 tonnes of clinker per day. They discovered that convection plus radiation in the form of hot flue gas (19.15%), cooler stack (5.61%), and kiln shell (15.11%) losses approximately 40% of the entire input energy. The generation of waste heat recovery steam using a system that recovered 1MW of energy for heat lost through hot flue gas and colder exhaust was proposed.

“Rasul et al. [17]” did research using information from the Portland cement mill in Indonesia. They provided a straightforward approach to assess the thermal efficiency of the cement sector. The developed model was mainly constructed using mass and energy balances.

The findings were as follows:

i. Burning efficiency was 53.8%
ii. Heat recovery efficiency was 52.1%,
iii. while cooler efficiency was 48.%.

Despite the lack of specifics regarding the calculations for the convective and radiation heat losses in this study, the cooler experienced a high heat loss of 19% as a result of convection and radiation.

“Sogut et al. [18]” looked into heat recovery from a rotating kiln for a cement mill in Turkey. It was found that the heat recovery exchanger could use 5% of the waste heat. By installing this system, domestic coal and natural gas usage can be reduced by (51.55% and 62.62%, respectively).

METHODOLOGY

Heat and mass balance

A detailed heat balance conducted for the pyro-process of a typical cement plant comprises the pre-heaters, kiln, and grate cooler making quantitative analysis based on the collected data [19].

Expected results:

- Total heat input into the system
- Heat output from the system

- Identified energy used for clinker
- Estimated total heat losses from the system
- Specific heat consumption and System performance

Procedures for the analysis

To find the heat input to the system, the energy sources are first identified. For most cement plants, the energy sources are coal and husk, and their heating values are known. By carrying out mass balance, the total thermal energy consumption for the seated time can be quantified and the total heat input on 1kg base can be calculated as well using the formula below [20]:

$$Qin(heat\ input) = totalfuel(in\ kg) * low\ heating\ value = Mass * Cp(hv) \quad (1)$$

Calculating the heat output

Firstly, the useful or used heat is calculated 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, convective losses, and others will be summed up with the total heat input [21].

Estimation of specific energy consumption

Specific Heat Consumption (SHC) is obtained by dividing the total heat energy input by the total clinker or material production while the Specific Power Consumption (SPC) is calculated by dividing the total power consumption by the total material as shown below [22].

$$SHC = \frac{total\ heat\ input}{total\ clinker(kg)} \quad and \quad SPC = \frac{total\ power\ consumption}{total\ material(ton)} \quad (2)$$

Thermal Energy Auditing

An effective instrument for determining the real state of the kiln system is a heat balance. It enables a more accurate evaluation of the heat consumption and the potential for thermal energy improvement [23]. Limits must also exist for the measurement of input and output variables information regarding many characteristics, including temperature, size, and energy usage of the utility equipment. The Central Control Room (CCR) log sheet and actual measurements were used to record the data in the plant. The numerical specification for the mass and energy analysis will result from the quantification of the input and output streams [24].

Measuring Equipment

i. Thermocouples are used to measure the temperature of kiln exhaust gases and grate clinker cooler air.
ii. An infrared thermometer to measure the surface temperature of the kiln.
iii. Pitot static probe with exhaust manometer [25].

The following assumptions are established regarding the mass balance and heat balance of the preheated, rotary kiln and grate cooler in order to analyse the kiln system thermodynamically [1].

i. Consistent working circumstances
ii. The pre-heater is modelled as a vertical cylinder
iii. The cooler surface is modelled as a vertical plate
iv. The composition of the raw materials does not vary,
v. The average surface temperatures of the kiln do not change.
vi. The change in Ambient temperature is neglected

After taking the necessary measurement, the following heat items are calculated [1]:

- Heat of fuel combustion
- Exhaust gas from different equipment
- Heat of clinker
- Heat of evaporation
- Sensible heat of all material, coal, and air
- Heat radiation and convection of kiln, pre-heater, and grate cooler.

Mass and Energy Balance: Using the operational data of the Kiln system of Messobo Cement company located in Mekelle town in the Regional State of Tigray, approximately 780 km from Addis Ababa, the capital city of Ethiopia [1], the mass and energy balances were carried out as follows.

Table 1: Operation Data of Kiln System of Messobo Cement Factory [1]

Components	**Value**
Ambient temperature	27 ^{0}c
Production capacity	3000 t/h
Kiln feed	241 t/h
Produced clinker	145.4 t/h
Coal consumption	25 t/h
Husk Consumption	0.3 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/m^3

Surface temperature of kiln	275^0c (0-22 m),318 ^{0}c (22-46 m), 345 ^{0}c (46-70 m)
Surface temperature of the cooler	95^0c
Primary airflow rate	11700 m^3/h

Calculations, Results and Analysis

Mass Balance

Therefore, all input and output parameters were converted to per kilogram of clinker, and the material balance was completed as a result, in order to make the data fair for evaluation. To quickly determine the energy (thermal) consumption, the mass balance calculation is crucial [26].

$Mass\ input\ =\ Mass\ output$ (3)

The given feed mass per 1 kg of clinker is calculated below:

- $Mass\ of\ kiln\ , \dot{m}kiln = 241\frac{ton}{hr} = 241\frac{x10^3kg}{3600sec} = \mathbf{66.94kg/sec}$
- $Mass\ of\ clinker\ \dot{m}clinker = (145.4\ ton)/hr =\ (145.4\ x\ 10\text{^}3)/3600 =\ \mathbf{40.39kg/sec}$

Thus, mass of kiln feed required to produce unit kg of clinker is

- $Mkiln/Mclinker = (66.94kg/sec)/(40.39kg/sec) = \mathbf{1.66kgkiln/kgclinker}$
- $Mass\ of\ coal\ \dot{m}coal\ =\ (25\ ton)/hr =\ \ (25\ x10\text{^}3\ kg)/3600sec = \mathbf{6.94kg/sec}$

Mass of coal $\dot{m}_{coal}$ required to produce unit kg of clinker $= (6.94kg/sec)/(40.39kg/sec) = \mathbf{0.172kgcoal/kgclinker}$

- $Mass\ of\ husk\ \dot{m}husk\ =\ (0.3\ ton)/hr =\ \ 300kg/3600sec = \mathbf{0.083kg/sec}$

Mass of husk $\dot{m}_{husk}$ required to produce unit kg of clinker

- m_{husk}=$(0.083kghusk/sec)/(40.39kgclinker/sec) = \mathbf{0.00206kghusk/kg-cli}$
- $Mass\ of\ primary\ air\ \dot{m}p.air\ in\ \ kg/sec\ =\ (11700x\ 1.2)/3600 = \mathbf{3.9kg/sec}$

Mass of primary air ṁp.air required to unit kg of clinker =

- $M_{p\ air}$ $=3.9/40.4\ =\ \mathbf{0.0965kgp.air/kg\ clinker}$

Mass of primary air with 10% excess air is

- $\dot{m}p.air = \frac{3.9kg}{sec} +\ (3.9x0.1) = \mathbf{4.29kgp.air/sec}$

Mass of primary air with 10% excess $\dot{m}_{pair}$ required to unit kg of clinker

- $\dot{m}_{p.air} = 4.29/40.4 = \mathbf{0.1062} \boldsymbol{kg\ p.air/kg\ clinker}$

Table 2: Mass flow rate of cooling air in Messobo cement factory [1]

Cooling fan	**Air**	
	m^3/h	Kg/h
1	45,100	55,022
2	24,600	30,012
3	33,800	41,236
4	37,900	46,238
5	36,600	44,652
6	49,600	60,512
7	58,800	71,736
8	27,300	33,306
9	27,300	33,306
10	27,000	32,940
11	29,300	35,740
12	22,500	27,450
13	19,600	23,912
14	18,800	22,936

Source: Grate cooler log sheet, Messebo cement factory (MCF)

The cooling air driven in by the 14 fans is $\sum_{i=1}^{14} \dot{m}ifan = 558998\ kg/h\ =\ \mathbf{155.28} \boldsymbol{kg/sec}$

Mass of cooling air per unit clinker is

- $Mc.air/clinker\ =\ 155.28/40.39 = \mathbf{3.8445} \boldsymbol{kgc.air/kgclinker}$

Since from the total mass flow rate of cooling air 60% is vent, 25% tertiary and 15% secondary air.

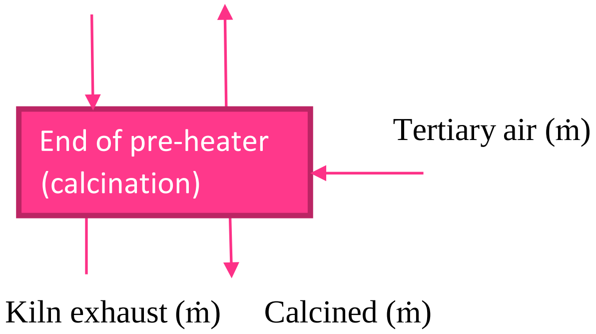
- $Tertiary\ air\ =\ 155.28\ kg/sec\ x\ 0.25\ =\ \mathbf{38.82} \boldsymbol{kg/sec}$
- $Tertiary\ air\ per\ unit\ clinker\ =\ 38.82/40.39 = \mathbf{0.961} \boldsymbol{kgt.air}$
- $Secondary\ air\ = 155.28kg/sec\ x\ 0.15\ =\ \mathbf{23.292} \boldsymbol{kg/sec}$

- $Secondary\ air\ per\ unit\ clinker\ = 23.292/40.39\ = \mathbf{0.577kgs.air/kgclinker}$

Mass of vent air per unit clinker

- $Mv.air/clinker\ = (0.6x\ 155.28)/(40.39) = \mathbf{2.3067kgv.air/kgclinker}$
- $Mass\ of\ clinker\ per\ unit\ clinker\ = \mathbf{40.39/40.39 = 1kgclinker}$

Mass balance of calciner *raw meal (ṁ) exhaust gas + dust (ṁ) [28]*



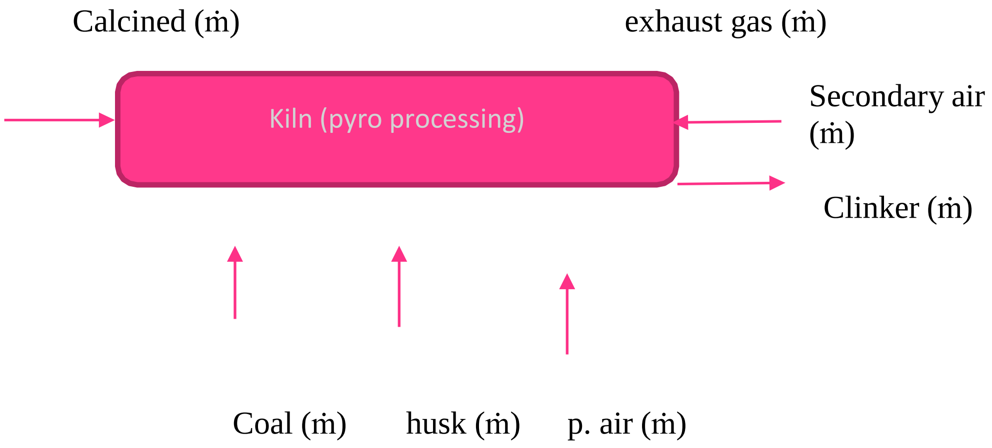
Calciner mass balance $\sum \min = \sum mout$

- $(\dot{M}_{raw\ meal}) + (\dot{m}_{T.air}) + (\dot{m}_{S.air}) = (\dot{m}_{calcined}) + (\dot{m}_{e.air\ \&\ dust})$

$$\frac{1.66kg}{kg}clinker + 0.961\frac{kg}{kg}clinker + 0.577\frac{kg}{kg}clinker = 1\frac{kg}{kg}clinker + (\dot{m}e.air\ \&\ dust)$$

- $(\dot{m}e.air\ \&\ dust) = \mathbf{2.198kg/kg\ clinke}$

Kiln mass balance [29]

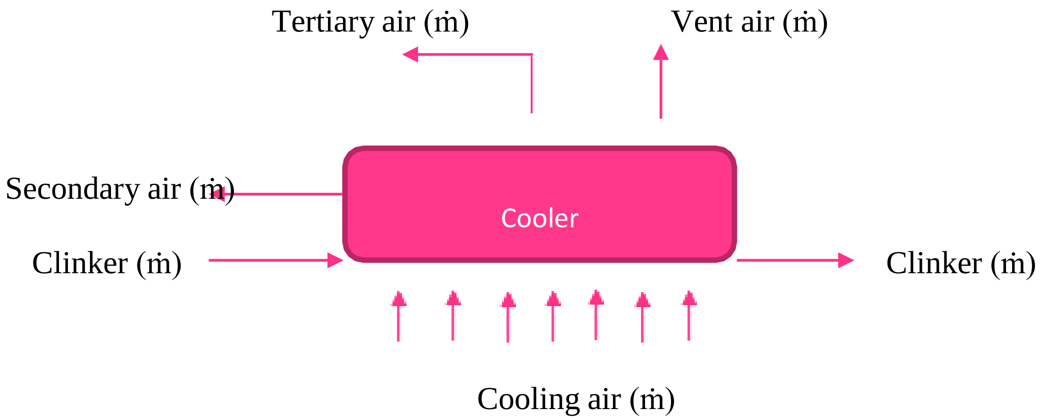


- ***Kiln mass balance*** (ṁ) $\sum min = \sum mout$
- $(\dot{m}coal) + (\dot{m}husk) + (\dot{m}p.air) + (\dot{m}s.air) + (\dot{m}calcined) = (\dot{m}clinker) + (\dot{m}e.air)$

Since there is no mass change of CaO in kiln (pyro processing),

- $(\dot{m}calcined) = (\dot{m}clinker)\ (0.172 kg/kg\ clinker) + (0.00206\ kg/kg\ clinker) + (0.1062\ kg/kg\ clinker) + (0.577\ kg/kg\ clinker) = \dot{m}e.air$
- $\dot{m}e.air = \mathbf{0.85726 \frac{kg}{kg} clinker}$

Cooler mass balance



Overall Kiln mass balance [30]

$$\sum Min = \sum Mout$$

- $(\dot{m}clinker) + (\dot{m}c.air) = (\dot{m}clinker) + (\dot{m}t.air) + (\dot{m}s.air) + (\dot{m}v.air)$

$1 + 3.8445\ kgc.air/kg\ clinker = 1 + 0.961 kgt.air/kgclinker + 0.577\ kgs.air/kgclinker + 2.3067$ kgv.air/kg$_{\text{clinker}}$

$$\mathbf{4.845 kg/kgclinker = 4.845 kg/kgclinker}$$

- $Total\ mass\ in\ per\ unit\ kg\ of\ clinker = \mathbf{4.845 kg}$
- $Total\ mass\ out\ per\ unit\ kg\ of\ clinker = \mathbf{4.845 kg}$

$$\mathbf{Therefore\ in\ cooling\ tower\ mass = \sum Min - \sum Mout = 4.845 - 4.845 = 0}$$

Energy balance

Energy balances is a system that helps to examine how the thermal energy is consumed. The procedures to analyses the heat are as follows:

For Heat Input

Heat input from coal combustion

$$Q_1 = m \times CV \qquad (4)$$

Where CV= calorific value of coal ($kJ/kg - coal$).
Coal is introduced at two parts:[31]

1. ***Kiln firing*** *(primary/main burner 40% from the total feed)*
    - $Q_{kiln} = (m \times CV) * 0.4 = \left[\left(0.172\, kg/kg - cli \times \frac{24960kJ}{kg}\right) \times 0.4\right] =$ $\mathbf{1717.248\, kJ/kg - cli = 412.6\, kCal/kg - cli}$
2. ***Calciner firing*** *(secondary burner 60% from the total feed)*
    - $Q_{cal} = (m \times CV) \times 0.6 = [(0.172\, kg/kg - cli \times 24960\, kJ/kg) \times 0.6] =$ $\mathbf{2575.872\, kJ/kg - cli = 619.2\, kCal/kg - cli}$

Therefore,

- $\mathrm{Q_1 = Q_{kiln} + Q_{cal} = 412.6\, Kcal/Kg - cli + 619.2\, kcal/kg - cli =}$ $\mathbf{1031.8c\, kcal/kg - cli}$

Heat input from Sensible heat by coal

- $\mathrm{Q_2 = m_{coal} \times C_p \times \Delta To = m_{coal} \times C_p \times (T - T_\infty)}$

Where: $m_{coal} = 0.172\ kg/kg - cli$
$C_P = 1.13\ kJ/kg - cli$
$T = 80\ °C\ and\ T_\infty = 27°C$

- $\mathbf{Q_2} = \mathrm{0.172\ Kg/Kg - cli * 1.13\ Kj/Kg - cli * (80\ °C - 27°C) =}$ $\mathrm{10.30108\, Kj/Kg - cli} = \mathbf{2.4762\ Kcal/Kg - cli}$

Heat input from raw material feed

- $\mathrm{Q_3 = m_{raw\ m.} \times C_P \times (T_f - T_\infty)}$

Where: $\mathrm{m_{raw\ m.} = 1.6\,6kg/kg - cli, C_P = 0.85\ kJ/kg\ °C\ and\ T_f = 80\ °C}$

- $\mathbf{Q_3} = \mathrm{1.6\,6kg/kg - clI\ \times 0.85}\ kJ\mathrm{/kg\ °C * (80\ °C - 27\ °C) =}$ $\mathbf{74.783\ kJ/Kg - cli = 17.977\ kCal/kg - cli}$

Heat input from Cooling Air

Based on the amount of clinker entering the cooler, the temperature, and the measured air flow rates, the heat balance of the grate cooler is performed [32]. Therefore:

- $\mathbf{Q_4} = \mathrm{m_{cooling\ air} \times h_{cooling\ air}}$

Where, $\boldsymbol{Q_4} = 3.8445\, Kg/Kg\ of\ cli \times 27.3\ kJ/kg = \mathbf{104.95485\ kJ/kg}$
$= \mathbf{25.23\, kCal/kg\ of\ cli}$

- $\boldsymbol{Total\ heat\ input} = Q1 + Q2 + Q3 + Q4 = 1031.8 + 2.4762 + 17.977 + 25.23 = \mathbf{1077.4832 kcal/kgclinker}$

For Heat Output

Heat loss due to dust from pre heater [33].

- $Q_{dust} = m_{dust} * C_{p\ dust} * T_{dust} - T_{\infty}[$

But Cp_{dust} is function of exhaust temperature:

$$Cpdust\ (T) = a + bT + cT2 + dT3 \tag{5}$$

Where a, b, c and, d are raw meal heat capacity expansion coefficients and T is the temperatureof pre-heater exhaust gas temperature which is 320^0C = 593k.

Table 3: Raw meal coefficients [1]

A	0.206
B	$1.01x10^{-4}$
C	$-0.37x10^{-7}$
D	0

- $Cpdust = 0.206 + 1.01x10^{-4} * 593 + [-0.37x10^{-7} * (593)^2 + 0 * (593)^3] = \mathbf{0.279 kJ/kg.k}$
- $Qdust = \dot{m}dust\ x\ Cpdust\ x\ (Te, dust)$
- $Qdust = 1.543 kg/kgclinker\ x\ 0.279 kJ/kg.k\ x\ (320 + 273)$
- $Qdust = \mathbf{255.28 KJ/kgclinker} = \mathbf{61.37 kcal/kgclinker}$

Clinker discharge heat

- $Qclinker = \dot{m}clinker\ x\ Cpclinker\ x\ (Td.clinker - T\infty)$

But $Cp_{clinker}$ is function of clinker discharge temperature [34].

$$Cpclinker\ (T) = a + bT + cT2 + dT3$$

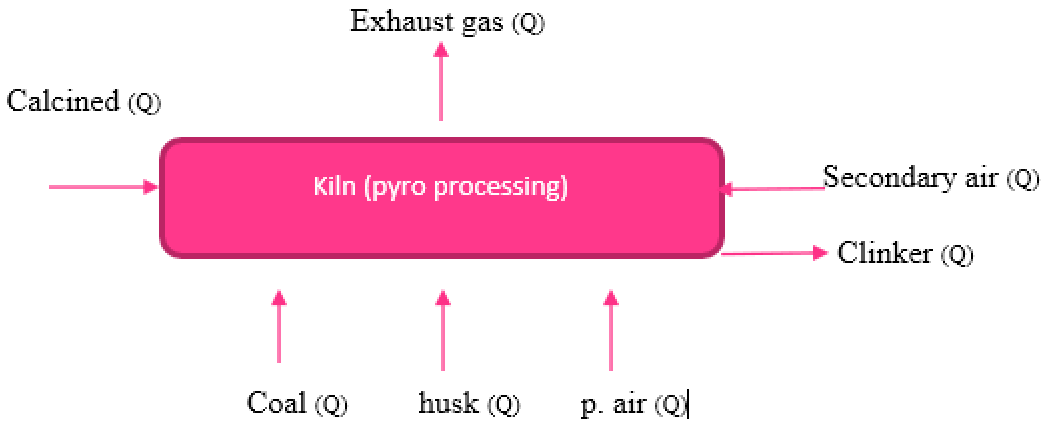
Where T is the temperature of clinker discharge, which is 920C = 365k, and a, b, c, and d are the raw meal heat capacity expansion coefficients

Table 4: Raw meal coefficients [1]

A	0.1742
B	$1.41x10^{-4}$
C	$1.28x10^{-7}$
D	$5.07x10^{-11}$

- $Cpdust = 0.1742 + 1.41x10^{-4} * 365k + 1.28x10^{-7} * (365k)^{2} + 5.07x10^{-11} * (365k)^{3}$
  $$= \mathbf{0.243KJ/kg.K}$$
- $Qclinker = \dot{m}clinker \; x \; Cpclinker \; x \; (Td.clinker)$
- $Qclinker = 1 \; x \frac{0.243KJ}{kg}.K \; x \; (92 + 273)Qclinker$

$$= \mathbf{88{\cdot}695KJ/kgclinker \; 21{\cdot}32kcal/kgclinker}$$



[35]

Calciner energy balance (Q)

- $\sum Qin = \sum Qout$
- $Qfeed + Qsec + Qteri = Qcalcined + Qexhaust + dust$

$$\begin{aligned} &1.66kg/kgclinker \; x \; 0.85KJ/kg.k \; x \; (80 + 273)K \\ &\quad + 0.577 \; kg/kgclinken \; x \; 1.38 \; KJ/kg.k(1450 + 273)K \\ &\quad + 0.966kg/kgclinken \; x \; 1.013KJ/kg.k \; (400 + 273)K \\ &\quad = Qcalcined + [0.577 \; x \; 1.1278(320 + 273)K + 135.2KJ/kgclinker] \end{aligned}$$

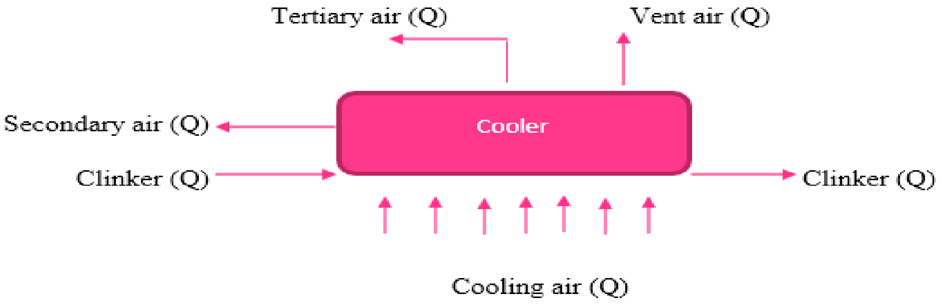
- $Qcalcined = 498.083 \; KJ/kgclinker + 1371.96KJ/kgclinker + 658.57 \; KJ/kgclinker - [385.89 + 135.2] \; KJ/kgclinker$
- $\mathbf{Qcalcined = 2007{\cdot}523KJ/kgclinker = 482.58kcal/kgclinker}$

From kiln energy balance

Kiln energy balance (Q),

$$\sum Qin = \sum Qout$$

- $Qcalcined + Qcoal + Q.husk + QS.air + Qp.air = Qclinker + Qs.air$
- $Qclinker = 2007.523KJ/kgclinker + [Qsensible + Qcombustion]coal + 0.00206\ x\ 16631.4KJ/kg + + 3.86\ KJ/kgclinker$
- $Qclinker = 2007.523KJ/kgclinker + 4293.12kJ/kgclinker + 34.26kJ/kgclinker + 1371.96\ KJ/kgclinker$
- $\boldsymbol{Qclinker = 7706\cdot 863\ KJ/kgclinker = 1852.61kcal/kgclinker}$



[36]

Cooling Energy balance

$$\sum Qin = \sum Qout$$

- $(Qclinker\ discharge) + (Qc.air) = (Qclinker) + (Qt.air) + (Qs.air) + (Qv.air)$

Therefor energy losses in the cooling tower due to vent and clinker discharge temperature is

- $Qloss = 82.425KJ/kgclinker + 1633.75KJ/kgclinker$
- $Qloss = 1716.175KJ/kgclinker = \boldsymbol{412.54kcak/kgclinker}$

Heat loss due to convection over the surface of kiln [37]

$$Q_{0\text{-}22m} = \frac{(Ts-27)}{R.0-22} = \frac{(275-27)}{R.0-22} \text{ where } R= \frac{1}{2\pi rL[h]@275^{\circ}c} = \frac{1}{2\pi * 2.3 * 22 * [6.393]@275^{\circ}c} = 0.00049$$

$$Q_{0\text{-}22m} = \frac{(275-27)}{0.00049} = 503.81 \text{ KJ}$$

$Q_{0\text{-}22m}$ = 12.47KJ/$kg_{clinker}$

$$Q_{22\text{-}46m} = \frac{(Ts-27)}{R.22-46} \quad \text{where} \quad R= \frac{1}{2\pi rL[h]@318^{\circ}c} = \frac{1}{2\pi * 2.3 * 24 * [6.524]@318^{\circ}c} = 0.000442$$

$$Q_{22\text{-}46m} = \frac{(318-27)}{0.000442} = 685.12 \text{ KJ}$$

$Q_{22\text{-}46m}$ = 16.96 KJ/$kg_{clinker}$

$$Q_{46\text{-}70m} = \frac{(T-27)}{R.22-46} = \frac{(345-27)}{R.22-46} \text{ where } R= \frac{1}{2\pi rL[h]@345^{\circ}c} = \frac{1}{2\pi * 2.3 * 24 * [6.575]@345^{\circ}c} = 0.000438$$

$$Q_{22\text{-}46m} = \frac{(345-27)}{0.000438} = 726.027 \text{ KJ}$$

$Q_{22\text{-}46m}$ = 17.97 KJ/$kg_{clinker}$

$$Total\ heat\ loss\ due\ to\ convection = \mathbf{47.4 kJ/kgclinker} = \mathbf{11.39 kcal/kgclinker}$$

Heat loss due to radiation [38]

Heat loss due to radiation over the surface of kiln can be calculated:

- $Q0 - 22 = \delta \varepsilon Akiln\ (Ts^4 - T^4\infty)/kgclinker$ (6)

Where 𝛿= Stephen botz man's constant (5.67*10-8 W/m2k4) and ε= emissivity factor (0.9 for rough oxidized steel kiln)

- $Q0 - 22 = 5.67 * 10 - 8\ W/m2k4\ x\ 0.9\ x\ (\pi x4.6mx22m) * (2754 - 274)/kgclinker$
- $\mathbf{Q0 - 22 = 92.73\ W/kgclinker}$
- $Q22 - 46 = \delta \varepsilon Akiln\ (Ts^4 - T^4\infty)/kgclinker$
- $Q22 - 46 = 5.67 * 10 - 8\ W/m2k4\ x\ 0.9\ x\ (\pi x4.6mx24m) * (3184 - 274)/kgclinker$
- $\mathbf{Q22 - 46 = 180.89\ W/kgclinker}$
- $Q46 - 70 = \delta \varepsilon Akiln\ (Ts^4 - T^4\infty)/kgclinker$
- $Q46 - 70 = 5.67 * 10 - 8\ W/m2k4\ x\ 0.9\ x\ (\pi x4.6mx24m) * (3454 - 274)/kgclinker$
- $\mathbf{Q46 - 70 = 250.6W/kgclinker}$

There for energy loss due to radiation in the kiln is:

- $\boldsymbol{Total\ heat\ loss\ =\ 524.22KJ/kgclinker\ =\ 126.0144kcal/kgclinker}$

Heat loss by radiation on cooler surface

Radiation loss on cooler surface (kcal/kg-cl)

- $QR = (hc + hr)(kcal/m2/h/K * surface\ area(m2) * (surface\ temp - amb\ temp)(℃)/clinker\ prod(kg - cl/h)$ [39] (7)

Where, hc=heat coeff of convection, (kcal/m2/h/K) = 2.236*(cooler surface temp-amb temp) ^0.25

- $Hr\ =\ heat\ coeff\ of\ radiation, (kcal/m2/h/K)\ =\ 4.876 * emissivity * ((cooler\ surface\ temp + 273)/100)\ \hat{}4 - ((amb\ temp + 273)/100)\ \hat{}4)/\ (surface\ temp - amb\ temp)\ Hc =\ 2.236(95 - 27)0.25,\&\ \ Hc = 6.42\ kcal/m2/h/K$
- $Hr =\ 4.876 * emissivity * ((cooler\ surface\ temp + 273)/100)\ \hat{}4 - ((amb\ temp + 273)/100)\ \hat{}4)/\ (surface\ temp - amb\ temp)$
- $Hr\ =\ 4.876 * 0.95 * ((368)/100)4 - ((300)/100)4)/(95 - 27)$
- $\boldsymbol{Hr\ =\ 6.97\ kcal/m2/h/K}$
- $QR = (hc + hr)(kcal/m2/h/K * surface\ area(m2) * (surface\ temp - amb\ temp)(℃)/clinker\ prod(kg - cl/h) =\ (6.42 + 6.975)(kcal/m2/h/K * surface\ area(m2) * (95 - 27)/145400\ kg - cl/h$
  $\boldsymbol{=\ 0.0064KJ/unit\ area * kgclinker\ =\ 0.00154kcal/kgclinker}$

Heat required for clinker formation

Formation energy of the clinker is calculated by using the Zur Strassen equation [40], [41].

- $Q\ (kcal/kg - cli)\ =\ 4.11[Al2O3] + 6.48[MgO] + 7.646[CaO]– 5.116[SiO2]– 0.59[Fe2O3]$

Where, Q = heat formation of clinker (kcal/kg-cli)

Table 5: clinker composition [1]

Component	Composition (%)
SiO2	23-24
Al2O3	4-5
Fe2O3	3.7-4.3
CaO	65.5-67
MgO	1.2-1.5

Al2O3, MgO, CaO, SiO2 and Fe2O3 =clinker composition

- Q = 4.11[4.5] +6.48[1.35] +7.646[66.25]–5.116[23.5]–0.59[4] = 419.4kcal/kg-cl
- $\boldsymbol{Total\ heat\ output\ =\ 1059.004 kcal/kgclinker}$

Uncounted heat loss

$$Uncounted\ heat\ loss\ = Total\ heat\ input - Total\ heat\ output\ [42] \qquad (8)$$

$$= 1077.4832 - 1059.004 = \mathbf{18.4792 kcal/kgclinker}$$

Overall Efficiency of Kiln system [43].

$$\boldsymbol{Efficency} = \frac{Heat\ requred\ for\ clinker}{Total\ heat\ input\ to\ the\ kiln} = \frac{419.4}{1077.4832} = \mathbf{38.92}\% \cong \mathbf{39}\%$$

FINDINGS AND CONCLUSION

The overall kiln system efficiency obtained using the secondary data from the literature was approximately (39%) which could be regarded as relatively low. This is because some kiln systems operating at full capacity would have an efficiency of 55% based on the same dry process methodology. The total mass in and mass out are equal each of which is approximately 4.845kg per unit mass of the clinker. This implies that there is no loss in mass.

From the heat balance calculation, it was observed that the input energy was found to be 1078 kcal/kg of clinker out of which 1032kcal/kg-clinker (95.7%) was from the combustion of coal and husk and the rest was from sensible heat of coal, row material and air. Whereas the output energy or calculated is 1059kcal/kg of clinker (98.2%) and the left or uncounted losses was 19kcal or 1.8%. The specific thermal energy consumption of the line is 1078 kcal/kg of clinker. Hence, the efficiency of the system (Pyro-processing unit of a cement plant) can be improved by recovering some of the heat losses. The recovered heat energy can be used for electricity generation. There is therefore a need for future research on the feasible waste heat recovery strategies needed to be incorporated so as to achieve considerable thermal energy savings.

RECOMMENDATIONS

To help the factory lower its thermal energy costs, a number of significant thermal Energy saving Opportunities (ECOs), such as housekeeping thermal energy saving measures and the use of alternative fuels, are advised for various system units. As a result of the research's findings, it is advised that the factory implement and track the following energy-saving options:

1. Opportunities for household (No or Low Cost) thermal energy conservation

2. Process Control and Improvement

3. Power Generation Using Waste Heat Recovery

4. Using other fuel sources (Biomass in cement technology)

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