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# Thermal Efficiency Evaluation of Souk Elkhamis Cement Rotary Kiln

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## ABSTRACT

نظراً لكون صناعة الإسمنت تعد من الصناعات المستنزفة للطاقة وخصوصا الحرارية منها, فدراسة أوجه ومجالات استخدام هذا الكم الكبير من الطاقة تعتبر من أهم الأولويات بهذا المجال. حيث تهدف هذه الورقة إلى تسليط الضوء على حيثيات وطرائق استخدام هذه الطاقة وحساب توزع الطاقة المنتجة من حرق الوقود بالفرن لتحديد مقادير المستفاد والمهدور منها وذلك بإجراء عملية الموازنة الحرارية للفرن. أوجدت هذه الدراسة أن حوالي 47 % فقط من الطاقة هو المستغل في إتمام العمليات والتفاعلات الكيميائية, والباقي حوالي 53 % يعتبر مفقودا. أن جزء من هذه الطاقة الحرارية المفقودة يستفاد منه في بعض الأغراض الأخرى اللازمة بهذه الصناعة كعمليات التجفيف والتحميص للمواد الأولية المغذية قبل دخولها للفرن ، وتنشيط عملية الحرق للوقود بالفرن ، وما إلى ذلك. والجزء الأخر والذي يقدر بحوالي 8.6 % يفقد ويهدر عبر سطح الفرن للمحيط. كما وجد أن الطاقة الحرارية الداخلة للفرن لإنتاج كيلوجرام واحد من الكلنكر تعادل 3658.53 كيلو جول\كجم وذلك عند عمل الفرن بحوالي 89% من طاقته الإنتاجية، في وقت أن مقدار الطاقة الحرارية المستخدمة والمسجلة عند الاختبارات الأولية التي أجريت في بداية التشغيل والتي كانت تساوي 3367.64 كيلو جول\كجم وذلك عند عمل الفرن بطاقة إنتاجية تفوق 100%، وهذا يشير إلى زيادة بقرابة 9 % من الطاقة. من ذلك توصي هذه الورقة بالبحث في أسباب هذه الزيادة، كما توصي بالتركيز على دراسة إمكانية الاستفادة من هذه الطاقة المهدورة والتي وجدت تساوي 313.27 كيلو جول\كجم وهو ليس بالمقدار الهين الذي يمكن إهماله أو تجاهله.

***الكلمات المفتاحية***: *الألياف الزجاجية، المواد المركبة، FRP، GFRP.*

Due to the fact that the cement industry is one of the discouraging energy-intensive industries, especially the thermal ones, study areas and aspects of the use of such a large amount of energy is one of the most important priorities in this area. This paper aims to highlight the merits and methods of use of this energy and calculate the output distribution of the energy produced from the burning of fuel to determine the amounts of wasted and used from them by conducting the thermal balance of the process in the kiln. It created that only about 47% of the energy is exploited in the completion of processes and chemical reactions, and the remaining approximately 53% is considered wasted. Part of this thermal energy lost is instrumental in some other purposes necessary in this industry as processes of drying and calcining of raw material nutrients before they entering the kiln, and stimulate the burning process of fuel in the kiln, etc., and the other, which is estimated at about 8.6% lose through the outer surface of the kiln to the surrounding. It was found that the total thermal energy entering the kiln to produce one kilogram of clinker equivalent 3658.53 kJ\kg when the kiln worked in about 89% of its production capacity, at the time that the amount of specific thermal energy used and registered when the initial tests carried out at the beginning of operating, which was equal to 3367.64 kJ\kg when the kiln worked with a capacity above 100%. This refers to the increase of approximately 9% of the energy.
This paper recommends research into the causes of this increase of amount of heat consumption. It also recommends focusing on the study of the possibility to recovering this wasted energy, which found equal to 313.27 kJ\kg which is not an insignificant amount that can be neglected or ignored.

***Key words**: Cement Industry, Rotary Kiln, Thermal Energy, Heat transfer modelling, Energy conservation.*

## 1. Introduction

Cement is one of the world's most important industries for several reasons. First, cement is an essential part of concrete which is the foundational material for any construction industry. Second, because of the importance of cement for assorted construction-related activities such as roads, residential and commercial buildings, tunnels and dams. There are over 150 countries that produce cement and/or clinker [1]. Cement production is an energy-intensive process it consuming about 4 GJ per ton of cement product. Theoretically, to produce one ton of clinker requires a minimum 1.6 GJ of heat [2]. Cement kilns are used for the pyroprocessing stage of manufacture of Portland cement. The kilns are the heart of cement production process, their capacity usually define the capacity of the cement plant. As the main energy consuming and greenhouse gas emitting stage of cement manufacture, improvement of kiln efficiency has been the central concern of cement manufacturing technology [3]. Over the past years, there have been an increasing number of studies performing energy analysis of cement manufacturing processes in order to identify potential opportunities for energy savings. Some of these studies have focused on cement processing kilns which constitute the largest components in any cement production facility.

This modern dry-process Souk Elkhamis cement plant is located about 60 km, south of Tripoli. It is designed to produce 3000 Tons of clinker per day, and one million tons of cement annually, through two similar production lines. This plant has been commissioned in 1978 to “KHD Humboldt wedge industries anlagen AG Company”, to produce type 1 Portland cement (general purpose cement), [4]. There are many departments in the factory staring with raw materials crushers and ending with cement packing. The main components during pyroprocessing process are 4 stage cyclone pre-heater, rotary kiln, and grate type cooler. The kiln is keeping as focus in this study.

## 2. Mass and Energy Balance

The conservation of mass principle for control volume, C.V expressed as [5];

$$\begin{pmatrix} Total\ mass\ entering \\ the\ C.V \\ during\ \Delta t \end{pmatrix} - \begin{pmatrix} Total\ mass\ leaving \\ the\ C.V \\ during\ \Delta t \end{pmatrix} = \begin{pmatrix} Net\ change\ in \\ mass\ within \\ C.V\ during\ \Delta t \end{pmatrix}$$

$$m_{in} - m_{out} = \Delta m_{C.V.}$$

During a steady-flow process, the total amount of mass contained within a control volume does not change with time. Then the conservation of mass principle requires that, the rate of mass flow in to the control volume equal to the rate of mass flow out of it.

$$\sum m_{in} = \sum m_{out} \frac{kg}{sec} \ldots\ldots\ldots\ldots \quad (1)$$

The energy balance for control volume, C.V., generally expressed as;

(Rate of net energy transfer) = (Rate of change of energy).

$$E_{in} - E_{out} = \frac{dE}{dt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

During a steady-flow process, the total energy content of a control volume remains constant, thus the change in the total energy of the control volume is zero. Then the rate form of the general heat energy balance reduces for a steady-flow process to;

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$$\sum q_{in} = \sum q_{out} \frac{kJ}{sec} \cdots\cdots\cdots\cdots \quad (3)$$

The rate of net heat transfer into or out of the control volume, q when the change in kinetic and potential energies are negligible, and there is no work interaction is, [6];

$$q = m\,\Delta h = m\,C_p\,\Delta T \cdots\cdots [kJ] \cdots\cdots\cdots \quad (4)$$

While the net heat energy transferred, at specific mass is;

$$\dot{Q} = \dot{m}\,\Delta h = \dot{m} C_p\,\Delta T \quad \cdots\cdots \left[\frac{kJ}{sec}\right] \cdots\cdots\cdots\cdots \quad (5)$$

Where, Δh is the change of enthalpy, and, Cp is the specific heat at constant pressure.

The mass and energy balance analysis is used to evaluate the presence of heat energy from a rotary kiln process. Mass and heat balance around the control volume were performed a basis of 1kg clinker.

The data can be obtained from the plant records, while other relevant data for the analysis can be evaluated. The mass balance for the kiln has been described in Figure (1).

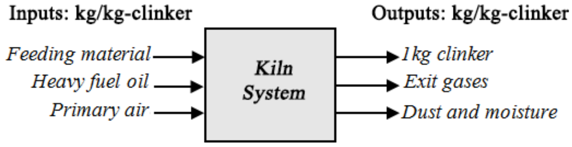


**Fig.(1)**: Mass balance of the kiln overall.

## 3. Chemical Compositions of Feeding Material and Clinker

The chemical compositions of feeding materials and clinker produced according to criteria required for the installation of the chemical substances included in the cement industry, which insures that the cement product in accordance with the Libyan standard specifications340/1997, are shown in Table (1).

**Table (1)**: Typical Raw Materials Mix and Clinker Chemical Compositions.

| Composition | Raw Material Mix | Clinker |
|---|---|---|
| CaO | 40 - 43% | 62 - 66% |
| $SiO_2$ | 12 - 14% | 19 - 24% |
| $Al_2O_3$ | 3 - 4% | 3 - 6.5% |
| $Fe_2O_3$ | 1.5 -3.0% | 2.5 - 4% |
| MgO | Up to 3% | Up to 4% |
| $SO_3$ | Up to 1% | Up to0.5% |
| $K_2O$ | Up to 2% | - |
| L.O.J | 34 - 37% | - |

## 4. Specifications of Heavy Fuel Oil Used

The heavy fuel oil is predominantly used in cement manufacturing. Souk Elkhamis cement plant is one of these factories, which used this type of fuel to produce the enough amount of heat required. The most important property of fuel oil is the ability to burn in the liquid state. Table (2) shows the typical specifications of heavy fuel oil used (Mazout).

**Table (2)**: Typical Specifications of Heavy Fuel Oil [7,20].

| | Parameters | values | Units |
|---|---|---|---|
| Composition | Carbon, C | 86.5 | % |
| | Hydrogen, $H_2$ | 12.4 | % |
| | Sulphur, S | 0.25 | % |
| | Nitrogen, $N_2$ | 0.18 | % |
| | Oxygen, $O_2$ | 0.05 | % |
| | Ash | 0.0061 | % |
| | Density at 120°C | 0.840 | kg/l |
| | Specific gravity at 15.6 °C | 0.9276 | - |
| | Flash point | 93 | °C |
| | Pour point | 72 | °C |
| | Gross heat of combustion, Hu | 10509.8 | % |
| | Temperature at burner | 120 | °C |

## 5. Models and Assumptions

The main following assumptions are considered for solving the problem:

1. The heat losses from the kiln surface are calculated by considering natural convection as well as thermal radiation.
2. The kiln operates in steady state condition.
3. The kiln is in smooth rotating around it is axis.
4. Compositions of feeding raw material mix and of fuel oil are not change all the time for all subsequent calculations.
5. Feed rate of raw material and fuel are considered as constant.
6. The kiln is simplifying plane surface horizontal cylinder without any existence of deformations and distortions.
7. The heat is transferred in steady state condition.
8. Assume the kiln surface subdivides to recognize the area of each zone.
9. The surface is assumed gray and diffuse in all calculations of this study, (independent of radiation wavelength and direction), so that:
   Surface emissivity,$\varepsilon_\lambda = \varepsilon_\theta = Constant$, [8].
   Where;$\varepsilon_\lambda$is spectral emissivity, and$\varepsilon_\theta$ is directional emissivity.
10. The view factor, F12 is for radiation that travels from surface 1 to surface 2. In this study, the surface 2 (air surface) are completely surrounds surface 1 (kiln surface), and the kiln is modeled simply as a cylinder, so that the view factor is always 1, [6].
11. The emissivity is assumed to be a constant value (0.95) throughout the calculations. While the actual kiln surface emissivity is to be measured, the value of (0.95) is believed to be an appropriate estimation based on different references for the surface is assumed dark brown rough oxidized steel plate [9,10].
12. The thermo physical properties of the fluid air are constant.
13. No heat transfer in axial direction.
14. Neglect the effect of the air Humidity.
15. Neglect the wind effect and the fluid around the kiln is moves under the buoyancy force acting.
16. All gas streams are assumed to be ideal gases at the given temperatures.
17. Cold air leakage into the system is negligible.
18. The change of granules size of feeding material and it is motion inside the kiln are neglected.

## 6. Total Heat Input

The overall heat energy entering the system consists of; heat generated by burning the fuel inside the kiln, and sensible heat in raw meal, fuel, and primary air entering the kiln [12].

The major part of the total amount of heat input is produced by burning the fuel; it is about 97% from the total heat entering the system [9, 19].The essential parameters required to determine the amount of heat energy produced by burning the fuel are presented in Table (3):

**Table (3)**: Basic Data and Measurements.

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| Parameters | Values | Unit | Reference |
|---|---|---|---|
| Exhaust gases temperature | 1253 | K | measured |
| Preheater temperature | 843 | K | measured |
| Kiln discharge temperature | 1473 | K | measured |
| Cooler temperature | 643 | K | measured |
| Precipitation dust temperature | 623 | K | measured |
| Fuel Density at 120°C, $\rho$ | 0.840 | ton/m$^3$ | Plant data |
| Fuel Heating value, Hu | 10509 | kcal / kg$_{fuel}$ | Fuel data |
| Fuel injected | 126.2 | m$^3$/24h | Plant data |
| Clinker produced | 1337 | Ton/day | Plant data |
| Specific heat of clinker, *Cp* | 0.86 | kJ/kg K | [53`55] |
| Clinker factor | 0.6296 | kg$_m$/kg$_{cli.}$ | Plant data |
| Air used | 1.5 times | - | [11] |
| Loss of ignition | 0.357 | % | Plant data |

All measurements were taken at one day, when the kiln working with 89% of it is capacity, and all calculations are referring to 1kg clinker.

### 6.1. Heat Generated by Burning the Fuel

The mass of fuel flow rate,$m_{fuel} = V_{fuel} \times \rho_{fuel} \frac{ton}{day}$

$$m_{fuel} = 126.2 \frac{m^3}{24h} \times 0.84 \frac{ton}{m^3} = 106.01 \frac{ton}{24h}$$

The quantity of fuel required to produce *1kg* of clinker is:

$$\dot{m}_{fuel} = \frac{m_{fuel}}{m_{clinker}} = \frac{106.01 \frac{ton}{24h}}{1337 \frac{ton}{24h}} = 0.07929 \frac{kg_{fuel}}{kg_{clinker}}$$

From Eq 5, the specific heat input by Combustion of fuel is:

$$\dot{Q}_{fuel} = \dot{m}_{fuel} \cdot Hu_{fuel}$$

$$\dot{Q}_{fuel} = 0.07929 \frac{kg_{fuel}}{kg_{clinker}} \times 10509 \frac{kcal}{kg_{fuel}}$$

$$\dot{Q}_{fuel} = 833.427 \frac{kcal}{kg_{clinker}} = 3488.73 \frac{kJ}{kg_{clinker}}$$

### 6.2. Sensible Heat

The calculations of sensible heat in raw meal of feeding materials, heavy fuel oil used, and primary air entering the kiln are;

The quantity of feeding material is equals to the ratio of rate of raw materials mix feeding to rate of clinker produced as;

$$\dot{m}_{materials} = \frac{24.3056}{15.4745} = 1.57 \frac{kg_{materials}}{kg_{clinker}}$$

The quantity of primary air entering the kiln is1.81 $\frac{kg\ air}{kg\ clinker}$.

## 7. Total Heat Output

Generally the heat living the kiln by five following ways:

1. Waste heat discharge with clinker to cooler.
2. Waste heat with exhaust gases.
3. Heat losses with dust.
4. Heat lost with steam due to humidity.
5. Kiln shell heat losses.

### 7.1 Waste Heat Discharge with Clinker

The average of specific heat losses with clinker discharge to cooler can be calculated by applying Eq 5,[2]:

$$\dot{Q}_{clinker} = \dot{m}_{clinker}\ \Delta h = \dot{m}_{clinker}\, C_{p\ clinker}\ \Delta T \quad \left[\frac{kJ}{sec}\right]$$

$$\dot{Q}_{clinker} = 1 \frac{kg_{clinker}}{kg_{clinker}} \times 0.86 \frac{kJ}{kg_{clinker}\ K} \times (1473 - 643)\ K$$

$$\dot{Q}_{clinker} = 713.8 \frac{kJ}{kg_{clinker}\ K}$$

### 7.2 Waste Heat with Exhaust Gases

There are many gases exhausted from combustion the fuel, primary air, and chemical reactions product which wasted part of heat out of kiln. These gases are; $CO_2$, $H_2O$, $SO_2$, $O_2$, and $N_2$.

The combustion of 1 kg of fuel is [2,7]:

$$C: 0.86 \times \frac{32}{12} = 2.29\ kg_{O_2}$$

$$H_2: 0.12 \times \frac{16}{2} = 0.992\ kg_{O_2}$$

$$S: 0.25 \times \frac{32}{32} = 0.25\ kg_{O_2}$$

Every *1 kg* of fuel combustion required:$2.29 + 0.992 + 0.25 = 3.5\ kg_{O_2}$

The amount of oxygen required:

$$\dot{m}_{O_2} = 0.0793 \times 3.5 \frac{kg_{O_2}}{kg_{fuel}} = 0.278 \frac{kg_{O_2}}{kg_{clinker}}$$

Total air quantity:

$$\dot{m}_{air} = 0.278 \times \frac{100}{23} \times 1.5 = 1.81 \frac{kg_{air}}{kg_{clinker}}$$

The quantities of waste gases are:

$$\dot{m}_{CO_2} = 0.0793 \frac{kg_{fuel}}{kg_{clinker}} \times 0.86 \frac{kg_{O_2}}{kg_{fuel}} \times \frac{44}{12} = 0.253 \frac{kg_{O_2}}{kg_{clinker}}$$

$$\dot{m}_{H_2O} = 0.0793 \frac{kg_{fuel}}{kg_{clinker}} \times 0.124 \frac{kg_{H_2O}}{kg_{fuel}} \times \frac{18}{2} = 0.09 \frac{kg_{H_2O}}{kg_{clinker}}$$

$$\dot{m}_{SO_2} = 0.0793 \frac{kg_{fuel}}{kg_{clinker}} \times 0.25 \frac{kg_{SO_2}}{kg_{fuel}} \times \frac{64}{32} = 0.04 \frac{kg_{SO_2}}{kg_{clinker}}$$

$$\dot{m}_{O_2} = 0.0793 \frac{kg_{fuel}}{kg_{clinker}} \times 0.05 \frac{kg_{O_2}}{kg_{fuel}} + \frac{0.278 \frac{kg_{O_2}}{kg_{clinker}}}{1.5} = 0.189 \frac{kg_{O_2}}{kg_{clinker}}$$

$$\dot{m}_{N_2} = 0.0793 \frac{kg_{fuel}}{kg_{clinker}} \times 0.18 \frac{kg_{N_2}}{kg_{fuel}} + \frac{0.931 \frac{kg_{N_2}}{kg_{clinker}}}{1.5} = 0.635 \frac{kg_{N_2}}{kg_{clinker}}$$

The Specific Heat, *Cp*, for the gases is [3]:

*Cp* for $CO_2$ = 1.322 kJ/ kg.K,

*Cp* for $H_2O$ = 2.596 kJ/ kg.K,

*Cp* for $O_2$ = 1.141 kJ/ kg.K,

*Cp* for $N_2$ = 1.241 kJ/ kg.K, and

*Cp* for$SO_2$ = 3.4689 kJ/ kg.K.

Applying Eq. 5 to find the amount of specific heat wasted with exhaust gases:

$$\dot{Q}_{CO_2} = m_{CO_2} \cdot C_{p\ CO_2} \cdot \Delta T$$

$$\dot{Q}_{CO_2} = 0.25 \frac{kg_{CO_2}}{kg_{clinker}} \times 1.332 \frac{kJ}{kg_{CO_2} K} \times (1253 - 843) K$$

$$\dot{Q}_{CO_2} = 135.5 \frac{kJ}{kg_{clinker}}$$

$$\dot{Q}_{H_2O} = 95.79 \frac{kJ}{kg_{clinker}}$$

$$\dot{Q}_{O_2} = 88.42 \frac{kJ}{kg_{clinker}}$$

$$\dot{Q}_{N_2} = 323.09 \frac{kJ}{kg_{clinker}}$$

$$\dot{Q}_{SO_2} = 56.89 \frac{kJ}{kg_{clinker}}$$

The heat loss with $CO_2$ from calcium carbonates ($CaCO_3$) of using materials, when dissolved to calcium oxide (CaO) and carbon dioxide ($CO_2$), that blows up with gasesinside the kiln is determined as fellow:

$$\dot{m}_{CO_2} = 0.6296 \frac{kg_{clinker}}{kg_{material}} \times 0.76 \frac{kg_{CaO_3}}{kg_{clinker}} \times 0.44 \frac{kg_{CO_2}}{kg_{CaCO_3}} \times 1.6 \frac{kg_{material}}{kg_{clinker}}$$

$$\dot{m}_{CO_2} = 0.3 \frac{kg_{CO_2}}{kg_{clinker}}$$

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Applying Eq. (5):

$$\dot{Q}_{CO_2} = 0.3\,\frac{kg_{CO_2}}{kg_{clinker}} \times 1.322\,\frac{kJ}{kg_{CO_2}K} \times 410\,K = 162.61\,\frac{kJ}{kg_{clinker}}$$

The total heat energy wasted with exhaust gases, $\dot{Q}_{eg}$ is;

$$\dot{Q}_{eg} = 135.5 + 95.79 + 56.89 + 88.42 + 323.09 + 162.61$$

$$\dot{Q}_{eg} = 862.3\,\frac{kJ}{kg_{clinker}}$$

### 7.3 Heat Losses with Dust

The quantity of dust exhausted is determined by Exhaust Dusting Fan (E.D. fan). The quantity of air produced by fan is: $2.7 \times 10^5 m^3/h$.

The dust density outlet of kiln is $35\,\frac{g}{m^3}$ of air produced by fan [13].

The dust flow rate, $m = \frac{270000\,\frac{m^3}{h} \times 35\,\frac{g}{m^3}}{1000 \times 3600} = 2.263\,\frac{kg\ dust}{Sec}$.

$$\dot{m} = \frac{2.263\,\frac{kg\ dust}{sec}}{15.4745\,\frac{kg\ clinker}{sec}} = 0.17\,\frac{kg_{dust}}{kg_{clinker}}$$

Then applying, Eq 5;

$$\dot{Q}_{dust} = 0.17\,\frac{kg_{dust}}{kg_{clinker}} \times 1.09\,\frac{kJ}{kg_{dust}K} \times 330\,K = 61.15\,\frac{kJ}{kg_{clinker}}$$

### 7.4 Heat Lost with Water Vapor, $H_2O$

#### 7.4.1 Water Vapor from Raw Material

The contamination of humidity in raw material [4]:

$$\dot{m}_{H_2O} = \left(0.04\,\frac{kg_{H_2O}}{kg_{Ls}} \times 0.124\,\frac{kg_{Ls}}{kg_{material}}\right) + \left(0.575\,\frac{kg_{H_2O}}{kg_{clay}} \times 0.24\,\frac{kg_{clay}}{kg_{material}}\right) + \left(0.85\,\frac{kg_{H_2O}}{kg_{iron\ \ ore}} \times 0.1\,\frac{kg_{iron\ \ ore}}{kg_{material}}\right) =$$

$$\dot{m}_{H_2O} = 0.253\,\frac{kg_{H_2O}}{kg_{material}}$$

About 2/3 of this value is evaporated in pre-heater cyclones, then [13];

$$\dot{m}_{H_2O} = 0.253\,\frac{kg_{H_2O}}{kg_{material}} \times 0.34 \times 1.57\,\frac{kg_{material}}{kg_{clinker}} = 0.14\,\frac{kg_{H_2O}}{kg_{clinker}}$$

By applying, Eq 5;

$$\dot{Q}_{H_2O} = 0.14\,\frac{kg_{H_2O}}{kg_{clinker}} \times 2.474\,\frac{kJ}{kg_{H_2O}K} \times 325\,K = 112.57\,\frac{kJ}{kg_{clinker}}$$

#### 7.4.2 Water Vapor from Waste Gas

$$\dot{m}_{H_2O} = 1.81\,\frac{kg_{air}}{kg_{clinker}} \times 0.34 \times 0.1\,\frac{kg_{H_2O}}{kg_{air}} = 0.181\,\frac{kg_{H_2O}}{kg_{clinker}}$$

By applying, Eq 5;

$$\dot{Q}_{H_2O} = 0.181\,\frac{kg_{H_2O}}{kg_{clinker}} \times 2.474\,\frac{kJ}{kg_{H_2O}K} \times 325\,K = 145.53\,\frac{kJ}{kg_{clinker}}$$

### 7.5 Kiln Shell Heat Losses

The part of heat which produced by burning the fuel will be transferred to the kiln outer surface by radiation, convection, and conduction despite to the thermal resistance insulators lining, (refractory bricks). This heat is transferred (wasted) to the surrounding due to temperature differential (driving force).

The heat losses from the kiln surface are calculated by considering natural convection as well as thermal radiation.

#### 7.5.1 Natural Convection

The kiln is assumed horizontal cylinder, so an empirical equations of a heated horizontal cylinder are used to calculate the natural convection heat transfer.

The heat transfer due to thermally induced natural convection at solid surface immersed in a fluid, in general can be correlated with the non-dimensional Grashof number, ***Gr***. It represents the ratio of the buoyancy force to the viscous force acting on the fluid and expressed as [6]:

$$Gr_d = \frac{g\,\beta\,\Delta T\,d^3}{\gamma^2} \cdots\cdots\cdots\cdots\cdots \qquad (6)$$

Where:

*g* is the gravitational acceleration, $m/s^2$.

$\gamma$ is the kinematic viscosity of the fluid, $m^2/s$.

$\Delta T$ is the temperature difference between the surface ($T_S$) and ambient temperature ($T_0$), K.

*d* is thediameter of the kiln outer surface(the characteristic length of geometry, Lc), m.

The volumetric expansion coefficient, $\beta$ used as ideal gases in this study, so [29];

$$\beta = \frac{1}{T_f}\left[\frac{1}{K}\right] \cdots\cdots\cdots\cdots\cdots \qquad (7)$$

Where; $T_f$ is the film temperature, and defined by:

$$T_f = \frac{T_S - T_O}{2} \text{by absolute temperature } K \cdots\cdots \qquad (8)$$

The heat transfer coefficient, *h* plays a major role in convection heat transfer. It is scaled to a non-dimensional number, Nusselt number, *Nu*:

$$Nu_d = \frac{h_d}{K} \cdots\cdots\cdots\cdots\cdots\cdots \qquad (9)$$

Where, K is the fluid heat conductivity.

The relationship between Nusselt number and Grashof number can be coined as:

$$Nu_d = c\,(Gr\,Pr)^n \cdots\cdots\cdots\cdots\cdots \qquad (10)$$

Where,

*Pr* is the non-dimensional Prandtl number,

*C* and *n* are the constants; the value of these constants essentially depends on the geometry of the surface and the flow regime which is characterized by the range of the Grashof number, [14].

When, Gr = $10^4$ - $10^7$ the flow is laminar, and Eq (10) becomes:

$$Nu_d = 0.48\,(Gr\,Pr)^{0.25} \cdots\cdots\cdots\cdots\cdots \qquad (11)$$

When, Gr = $10^7$ - $10^{12}$ the flow is turbulent, and, Eq (10) becomes:

$$Nu_d = 0.125\,(Gr\,Pr)^{0.333} \cdots\cdots\cdots\cdots\cdots \qquad (12)$$

When the Nusselt number is known, the heat transfer coefficient can be obtained by equation:

$$h = \frac{Nu_d\,K}{d}\left[\frac{W}{m^2K}\right] \cdots\cdots\cdots\cdots\cdots \qquad (13)$$

The natural convection heat transfer rate can be obtained by Newton`s low of cooling:

$$q_{conv} = A_S\,h\,(T_S - T_O)[W] \cdots\cdots\cdots\cdots \qquad (14)$$

Where; $A_S$ is the area of heat transfer surface, (kiln surface).

#### 7.5.2 Thermal Radiation

The heat flow by thermal radiation from gray and diffuse surface with a temperature of $T_S$ for any zone at the four times on day, to the ambient with a temperature of $T_0$ at these times is given by [14]:

$$q_{rad\,.(S\to 0)} = \sigma\,\varepsilon_s A_S F_{S\to 0}\,(T_s^4 - T_O^4)\ \ [W] \cdots\cdots\cdots\cdots\cdots \qquad (15)$$

Where;

$\sigma$ is the Stefan-Boltzmann$\left(5.67 \times 10^{-8}\,\frac{W}{m^2K^4}\right)$.

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$\varepsilon_s$ is the kiln surface emissivity = Constant.
$F_{S\to 0}$ is the view factor, for radiation that travels from kiln surface to the air surface = 1.
Note: all the temperatures in this equation are in Kelvin.

For more accurate results in the estimation of heat losses through the kiln outer surface, the kiln surface is divided into four zones, according to the types of refractory bricks used, and chemical reactions that occur inside the kiln, as well as reading of surface temperature measurements. Where taking the average temperatures of each zone as follows in Table (4).

**Table (4)**: Averages of the surface temperature, $T_s$, measurements for every zone at four times on day with the ambient temperature, $T_o$, in related times.

| | | Temperature [°C] | | | | |
|---|---|---|---|---|---|---|
| | | $T_S$ . $Z_1$ | $T_S$ . $Z_2$ | $T_S$ . $Z_3$ | $T_S$ . $Z_4$ | $T_O$ |
| Time | 1 | 171 | 266 | 299 | 245 | 9 |
| | 2 | 167 | 271 | 310 | 246 | 5 |
| | 3 | 175 | 280 | 316 | 252 | 17 |
| | 4 | 193 | 291 | 302 | 263 | 11 |

Then calculate the heat losses through the kiln surface by applying the above previous equations, (6 – 15). The results of these calculations are shown in Table (5).

**Table (4)**: Results of shell heat loss calculations.

| | | Time | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | Average |
| q at zones [kW] | $Z_1$ | 832.42 | 816.94 | 832.38 | 1012.93 | 873.67 |
| | $Z_2$ | 704.64 | 736.87 | 761.90 | 832.43 | 758.96 |
| | $Z_3$ | 2203.34 | 2383.57 | 2419.23 | 2237.49 | 2310.91 |
| | $Z_4$ | 862.20 | 878.53 | 878.02 | 997.81 | 904.14 |
| Total | | 4602.60 | 4815.91 | 4891.53 | 5080.65 | 4847.67 |

## 7.6 Theoretical Heat Required Producing 1 kg of Clinker

The theoretical heat required in relevant process is assigned according to the following calculations [15,12], while theClinker Chemical Compositions is taken partially from Table (1), andpartially from plant data.

$$\dot{Q}_{Tr} = 4.11 \times H_{Al} + 6.48 \times H_{Mg} + 7.646 \times H_{Ca} - 5.116 \times H_{Si} - 0.59 \times H_{Fe}$$

$$\dot{Q}_{Tr} = 4.11 \times 5.7 + 6.48 \times 2.1 + 7.646 \times 64.9 - 5.116 \times 23.3 - 0.59 \times 3.6$$

$$\dot{Q}_{Tr} = \frac{411.9336 kcal}{kg_{clinker}} = 1724.35 \frac{kJ}{kg_{clinker}}$$

## 8. Kiln Thermal Efficiency

To determine the thermal efficiency of the Souk Elkhamis cement kiln thermodynamically, obtaining that the kiln is the system, [5];

Kiln efficiency, $\eta_{th} = \frac{Net\ Work\ Output}{Total\ Heat\ Input} = \frac{W_{net}}{\sum \dot{Q}_{in}}$

Since, $W_{net} = \sum \dot{Q}_{in} - \sum \dot{Q}_{out}$

Then, Kiln efficiency, $\eta_{th} = \frac{\sum \dot{Q}_{in} - \sum \dot{Q}_{out}}{\sum \dot{Q}_{in}} \ldots\ldots\ldots\ldots\ldots\ldots$ (16)

Where;
$\sum \dot{Q}_{in}$ is the overall of heat energy entering the system, and
$\sum \dot{Q}_{out}$ is the overall of heat energy living the system.

Accordingly, the thermal efficiency of the kiln is equal to:

$$\therefore\ \eta_{th} = \frac{3658.53 - 1932.97}{3658.53} = 0.471 \approx 47\%$$

## 9. Percentage of SHL to the Total Heat Input

The percentage of heat losses through kiln outer surface by convection and radiation at any day from the total heat input at this day is presented by;

$$Percentage\ of\ SHL = \frac{\dot{Q}_{SHL}}{\dot{Q}_{in}} \times 100$$

## 10. Evaluation of Mass and Energy Balance

The complete mass and energy balance for the system which calculated are presented in Table (6, A and B).

**Table (6A)**: The Input Mass and Energy Balance.

| Stream | Heat Flow Kg/kg cli | Specific Heat Cp KJ/kg °C | Temperature °C | Heat Energy kJ/kg cli. | % |
|---|---|---|---|---|---|
| Combustion of Fuel | - | - | - | 3488.73 | 95.4 |
| Sensible Heat ofFuel Oil | 0.079 | 1.172 [16] | 120 | 11.15 | 0.3 |
| Feeding Material | 1.57 | 0.9 [12,17] | 80 | 113.04 | 3.1 |
| Primary Air | 1.81 | 1.008 [17,18] | 25 | 45.61 | 1.2 |
| **Total** | **3.46** | - | - | **3658.53** | **100** |

**Table (6B)**: The Output Mass and Energy Balance.

| Stream | Heat Flow Kg/kg cli | Specific Heat Cp KJ/kg °C | Temperature °C | Heat Energy kJ/kg cli. | % |
|---|---|---|---|---|---|
| Clinker Discharge | 1.0 | 0.86 [15,18] | 545 | 468.70 | 12.81 |
| Exhaust Gas | 1.965 | * | 325 | 831.75 | 22.73 |
| Exit Dust | 0.17 | 1.09 [12] | 330 | 61.15 | 1.67 |
| Water Vapor | 0.321 | 2.474 [11] | 325 | 258.10 | 7.05 |
| Shell Heat Loss | - | - | - | 313.27 | 8.56 |
| Reaction Energy | - | - | - | 1724.35 | 47.13 |
| Uncounted | - | - | - | 1.21 | 0.03 |
| **Total** | **3.46** | - | - | **3658.53** | **100** |

* The average specific Heat, *Cp*, for the gases is$CO_2$ = 1.294 *kJ/kg K*, $H_2O$ = 2.474 *kJ/kg K*, $O_2$ = 1.122 *kJ/kg K*, $N_2$ = 1.215 *kJ/kg K*, and for $SO_2$ = 2.109 *kJ/kg K*, [11].

## 11. Conclusion

This study shows that about 47% of the energy is exploited in the completion of processes and chemical reactions, and the remaining approximately 53% is considered wasted. Part of this thermal energy lost is instrumental in some other purposes necessary in this industry as processes of drying and calcining of raw material nutrients before they entering the kiln, and stimulate the burning process of fuel in the kiln, etc., and the other, which is estimated at about 8.6% lose through the outer surface of the kiln to the surrounding. It was found that the total thermal energy entering the kiln to produce one kilogram of clinker equivalent 3658.53 kJ\kg when the kiln worked in about 89% of its production capacity, at the time that the amount of specific thermal energy used and registered when the initial tests carried out at the beginning of operating, which was equal to 3367.64 kJ\kg when the kiln worked with a capacity above 100%. This refers to the increase of approximately 9% of the energy.

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REFERENCE

[1] Anne Elizabeth, Oberlink, "*Non-portland Cement Activation of Blast Furnace Slag*", University of Kentucky Master`s Theses. Paper 25, (2010).

[2] Engin T., Ari V., "*Energy Auditing and Recovery for Dry Type Cement Rotary Kiln System- A Case Study*", Energy Conservation and Management, 46, pp. 551-562, (2004)

[3] Prajna Mohanty, Smruti Snigdha Patro, "*Processing and Characterization of PEEK with CKP Particles: Use of Industrial Waste in Composite Making*", International Advanced Research Journal in Science, Engineering and Technology, ISSN 2394-1588, Vol. 2, Issue May (2015).

[4] KHD Industrieanlagen AG; "*Specifications Documents of Souk Elkhamis Cement Plant*"; (1978).

[5] Y. A. Çengel, and M. A. Boles, "*Thermodynamics: An Engineering Approach*", Fifth Edition, McGraw-Hill, (2006).

[6] Cengel .Y.A, "Heat Transfer", Second Edition, McGRAW-Hill, USA, (2003).

[7] Khalifa M. G, Zohir A. E.and Wanis M. M. "*Study of the Main Energetic Parameters in the Rotary Kiln*", proceeding of first scientific environmental conference, Zagazig Univ., pp. 171-194, (2006).

[8] Yunus A. Cengel, Afshin J. Ghajar, "*Heat and Mass Transfer: Fundamentals and Applications*"; $4^{th}$ Edition; Chapter 12 "Fundamentals of Thermal Radiation", (2011).

[9] Hideyuki Tanaka, "*Cement Process and Energy Saving*", Technical Expert International Engineering Dept. The Energy Conservation Center, Japan, November, (2006).

[10] European Rotary Kiln Services Ltd; Barry Cooke, David Hey; "*Kiln Alignment Analysis for Souk Elkhamis Cement Plant*"; May (2009).

[11] Boateng, Akwasi, "*Rotary kilns: transport phenomena and transport processes*", Amsterdam; Boston: ElsevierButterworth-Heinemann, ISBN 978-0-7506-7877-3, (2008).

[12] R. K. Patil, M. P.Khond, L. G. Navale, "*Thermal Energy Assessment of Indian Cement Plant Specially Related to Rotary Kiln*", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) ISSN(e) : 2278-1684, ISSN(p): 2320–334X, pp 23-31

[13] KHD, Humboldt Wedag, "*Pre-heater Manual Sheets*", Plant Hand Book.

[14] William S. Janna, "*Engineering Heat Transfer*"; $2^{nd}$ Edition, ISBN 0-8493-2126-3, (2000).

[15] Kurt E. Peray, "*Cement Manufacturer`s Handbook*", Chemical Publishing Co., Inc. ISBN 0-8206-0368-6, New York, N.Y. (1979).

[16] Energy Efficiency Guide for Industry in Asia, "*Fuels and Combustion*", UNEP United Nations Environment Programmer, (2006).

[17] Shaleen Khurana, Rangan Banerjee, Uday Gaitonde, "*Energy Balance and Cogeneration for A Cement Plant*", Applied Thermal Engineering. No., 22, PP. 485–494. (2002).

[18] Holder Bank Cement Seminar, "*Heat Balances of Kilns and Coolers and Related Topics*", Energy Balance of Kiln; Switzerland, March, (1991).

[19] Ibrahim, A. Ibrahim, and I. Garba, "*Modeling of Sokoto Cement Production Process Using Afinite Automata Scheme*", An Analysis of the Detailed Model, ISSN 2250-3005, Vol. 04, Issue: May (2014).

[20] "*Certificate of Quality Fuel Oil*", issued by Azzawiya refinery in, (2012), No, F- 2/2012.