

Energy and Exergy Analyses of Egyptian Cement Kiln Plant With Complete Kiln Gas Diversion through by Pass

Laila M. Farag

Ceramics Dept. National Research Centre
Dokki, Cairo, Egypt

Article Info

Article history:

Received Jan 14, 2012

Revised Mar 2, 2012

Accepted Mar 8, 2012

Keyword:

Cement kiln plant
Cyclone preheater
Energy analysis
Fuel consumption
Precalciner
Rotary kiln

ABSTRACT

The present article deals with evaluation of energy and exergy efficiencies of an Egyptian dry process cement kiln plant with precalciner characterized by that the whole kiln gas is diverted through by pass. Such diversion is necessary to break the intense cycles of secondary constituents Cl, alkalis and sulfur that may arise between precalciner -preheater and kiln due to the high content of the raw materials of such secondary constituents. Based on average actual operation data of the process, energy and exergy balances have been established around the preheater-precalciner, the rotary kiln, the rotary cooler and the whole process.

Energetic- and exergetic efficiency of the process attains 40% and 25.7% respectively. Sum of the exergy outputs attains about 49% of total exergy input and irreversibility loss = 2354 kJ/kg clinker which represents about 51 % of total exergy input. Energy and exergy of the by pass gases are the largest output loss items (~770 and 416 kJ/kg cli respectively) followed by those of the preheater exit gases (~ 622 and 152 kJ/kg cli respectively).

For comparative purpose, the process was evaluated with considering no diversion of kiln gas through by pass. Energetic- and exergetic efficiency has been estimated in this case as 52% and 34 % respectively and the irreversibility attains 1840 kJ/kg clinker which represents about 52 % of total exergy input.

Copyright © 2012 Institute of Advanced Engineering and Science.
All rights reserved.

Corresponding Author:

Laila M. Farag
Ceramics Dept. National Research Centre
Dokki, Cairo, Egypt
E mail : Lailafarag_nrc@yahoo.com
Telp. : 00202/ 38351206

1. INTRODUCTION

Cement manufacture is one of the most energy intensive industries where energy is consumed mainly in the pyro-process in the kiln plant for producing clinker. The heat requirement in a cement kiln plant depends to a major extent on the technology applied. In modern dry process with precalciner, the specific heat consumption ranges from 2926 –4180 kJ /kg clinker depending on various operation and technical factors of the process (Rosemann, 1987).

In case of raw materials (mainly limestone and clay) containing relatively high content of secondary constituents, chlorides, alkalis and sulfates, intense cyclic phenomena develop between the kiln and the preheater-precalciner (Ritzmann, 1971; Goldmann et al., 1981; Kreft, 1985 ; Sprung, 1964 ; Farag, 1990). Those cycles are formed as a result of partial volatilization or dissociation of the secondary constituents at the high temperature of the kiln and their condensation to various degrees at the lower temperatures in the pre-heater- precalciner. Intense cycles would cause serious operation, clinker quality and emissions problems. In order to reduce the intensity of circulation phenomena by pass is mostly erected near the kiln inlet to permit a pre-estimated fraction of the kiln gas to leave the kiln at high temperature (1000–

1200 °C). By pass hot gases represent a point of considerable heat loss of the process caused by the escaped sensible and latent heat with by pass gases and dust (farag, 1990).

Cement manufacture is considered also an industry of intense CO₂ emission. CO₂ evolves from fuel combustion and from decomposition of carbonates which usually represent the major fraction of the clinker raw mix. Cement production accounts for about 8 % of total CO₂ emission from all human activities (IEA GHG R&D, 1999).

It is of vital and urgent importance, from both sides of environment and energy economy, to optimize the clinker production process in order to raise its performance as possible. Although energy analysis, based on the first law of thermodynamics, is used to reduce heat losses or enhance heat recovery, it does not give any information on the degradation of energy that occurs in the process. Exergy is a measure of quality and quantity of the energy sources unlike energy that is only about the quantity. Exergy can be described as the maximum available work which can be produced by a system when it comes to equilibrium with a reference environment (Morris and Szargut 1986). Exergy analysis based on the first and second laws of thermodynamics leads to better understanding of the influence of thermodynamic phenomena on the process effectiveness, comparison of the importance of different thermodynamic factors and determination of the most effective ways of improving the process under consideration. Recently many works have dealt with exergetic analyses of cement industry in order to attain the optimum sustainable situation of such vital strategic industry (Morris and Szargut 1986 ; Zafer et al., 2006; Kian, 2003 ; Koroneos et al. 2005 ; Shaleen et al. 2003 ; Kolip , 2010 ; Rasul et al. 2005) .

The present article deals with energetic and exergetic analysis of an Egyptian cement kiln plant in which the raw meal is so rich in chlorides and sulfates that the whole kiln gas has to be expelled through kiln by pass (farag , 1990). For comparative purpose the process has been analyzed with considering no kiln gas diversion through by pass. Energy and exergy performance of the process has been evaluated.

2. EXERGY OF A SYSTEM (Rasul et al., 2005; Vedat, 2011):

The total exergy of a system can be divided into four components, namely: physical exergy, ex_{ph} , kinetic exergy, ex_{kn} , potential exergy, ex_{po} and chemical exergy, ex_{ch} . In a cement production process, however, the kinetic exergy and potential exergy are negligible compared to other two.

The specific physical exergy can be expressed as:

$$ex_{ph} = (h - h_o) - T_o (s - s_o) \quad (1)$$

Assuming ideal gas flow with constant specific heat, we have:

$$ex_{ph} = cp (T - T_o) - T_o (cp \ln T/T_o - R \ln P/P_o) \quad (2)$$

For the solid and liquid streams

$$ex_{ph} = cp ((T - T_o) - T_o \ln T/T_o) - v (p - p_o) \quad (3)$$

Assuming constant specific volume, v , at T_o with neglect of change in pressure, the last items in equations (2) and (3) can be neglected.

Chemical exergy is the maximum possible work that can be acquired during a process that brings the system from environmental condition (T_o, P_o) to the dead state (T_o, P_o, μ_{oi}). The chemical exergy of the ideal gas and liquid mixtures is computed from :

$$ex_{ch} = \text{sum of } x_i (ex_{ch,oi} + RT_o \ln(x_i))$$

Where x_i is the molar ratio of the species i , and $ex_{ch,oi}$ is the standard chemical exergy.

Three exergy efficiencies of a cement kiln plant are defined as follows:

1- Exergy efficiency, η_{ex} = clinker formation exergy/ exergy input.

It corresponds to the net thermal efficiency, η_g , defined as the fraction of fuel heat that is consumed as latent heats of various clinker forming reactions⁽¹⁾.

2- Anergy, ϕ , defined as the ratio of the exergy loss to the exergy input. It is expressed as follows:

$$\Phi = ex_{losses} / ex_{input}$$

3- The exergy destroyed or the irreversibility of a system, I_{sys} , is given as:

$$I_{sys} = ex_{input} - ex_{output} = T_o S_{gen}$$

Where S_{gen} is the entropy generated

3. OPERATIONAL DATA OF THE INVESTIGATED PROCESS:

The kiln plant consists of two strings, rotary kiln and rotary cooler; each string consists of 4 stages cyclone preheater and precalciner. Two air ducts conduct hot tertiary air from the cooler to the precalciners. Each precalciner and the kiln are separately fired with heavy fuel oil. Various required data for calculations have been obtained from recorded factory data or from actual measurements (farag, 1990). Average operation data of the process are shown in tables (1) and (2). Schematic diagram of the process is shown in fig (1).

Table (1) Average Operation data of the process:

- Productivity	4180 T/d
- Specific fuel consumption	0.106 kg heavy fuel oil*/kg cli.
- „ heat consumption	4323.5 kJ /kg cli.
- % fuel in calciners	69%
- % fuel in kiln	31%
- Rawmeal / clinker factor	1.92
- precalcination deg. in calciner	90 %
- Preheater exit gas temp.	270 -280 °C
- „ „ „ dust	0.19 kg/kg cli.
- O2 % in preheater exit gas	5 %
- by pass kiln gas temp.	1000 °C
- by pass kiln gas dust	0.109 kg/kg cli.
- O2 % in by pass kiln gas	2.7 %
- clinker outlet temp. from kiln	1400 °C
- injected water in the cooler (to assist cooling operation)	10 m ³ / hr 0.057 kg/kg cli
- Temp. of hot air from cooler	800 °C
- Temp. of clinker from cooler	150°C

- Data of heavy fuel oil used:
- C/H2 =7.7, d =0.95 kg/l ,Ch. Compⁿ (wt%) : 85.8% C , 11.15 % H2, 3% S , Hu = 40797 kJ/kg, Ho = 41800 kJ/kg, Vth.comb. air = 10.78 Nm3/kg fuel, V th.combⁿ. gases = 11.4 Nm3/kg fuel,
- Compⁿ. of combⁿ. Gases= CO2 + SO2 = 14.3 % , H2O = 10.9 % , N2 = 74.8%

Table 2 Chemical composition of raw materials, raw mix and clinker.

	Clay	limestone	raw mix	clinker
SiO2	46.1	3.56	13.99	27.3
Al2O3	21.23	0.53	3.48	5.09
Fe2O3	9.01	0.22	1.9	2.79
CaO	2.37	50.89	41.84	63.9
MgO	1.78	1.27	1.32	2.36
SO3	3.53	0.2	0.47	1.85
K2O	1.05	0.04	0.29	0.1
Na2O	1.29	0.21	0.43	
Cl.	0.72	0.2	0.33	

4. ENERGY AND EXERGY BALANCES AROUND THE PROCESS:

Energy and exergy balances have been established around each of the process parts (preheater-precalciner, rotary kiln and rotary cooler) and around the whole process.

Energetic efficiency and exergetic efficiencies of the system as defined above have been calculated and evaluated a for each process part and for the whole process as will be shown afterwards.

4.1. Chemical exergy of the heavy fuel oil :

It has been calculated on basis of fuel composition by applying the following equation (Koroneos, 2003):

$$Ex_{ch.f.} = H_u (1.0401 + 0.1728 \cdot X_H/X_C + 0.0452 \cdot X_O/X_C + 0.2196 \cdot X_S/X_C (1-2.0628 \cdot X_H/X_C).$$

Chemical exergy of the fuel = 43555.7 kJ / kg fu

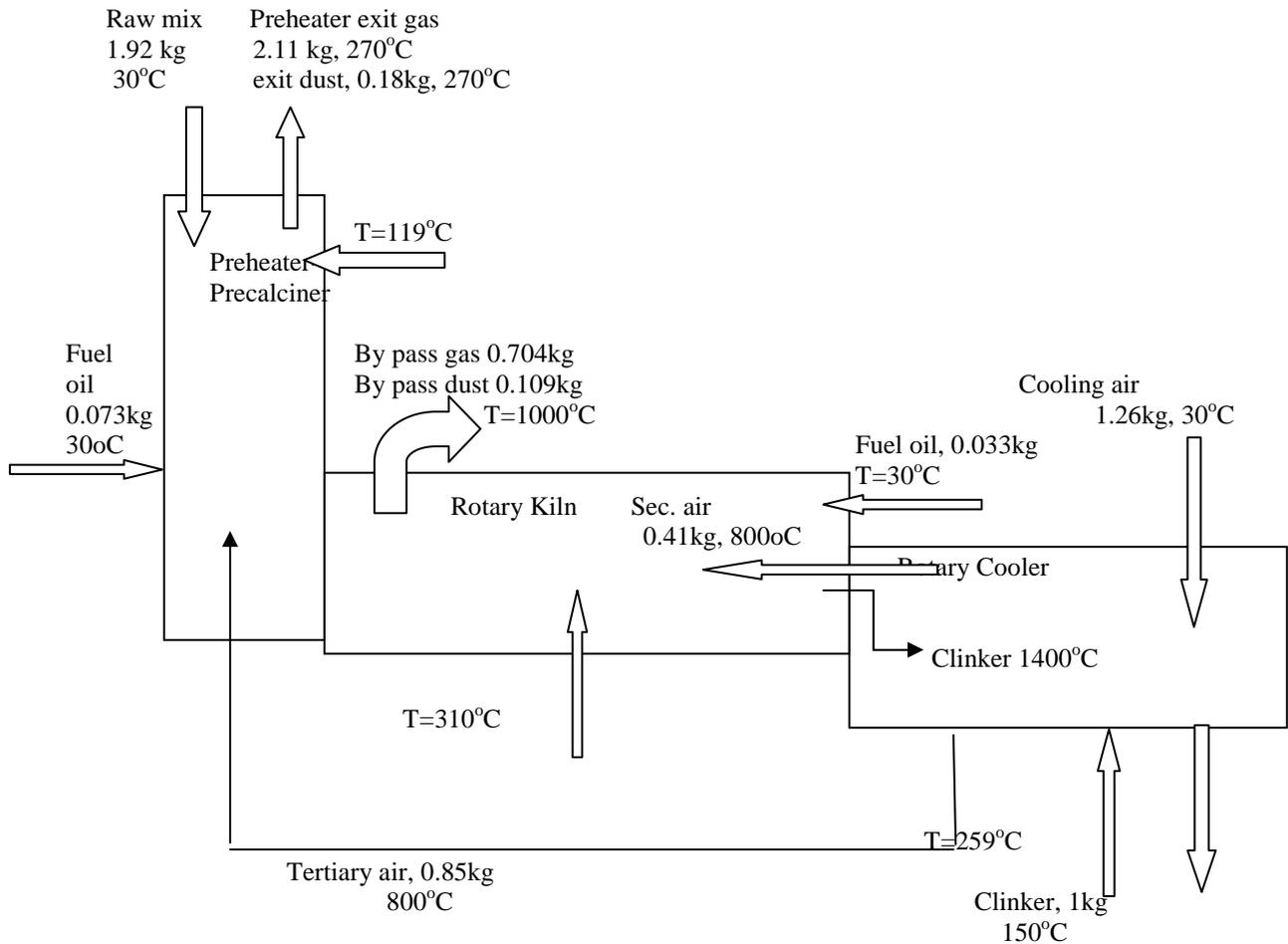


Figure 1. Schematic diagram of the kiln system.

4.2. Energy and exergy due to clinker formation:

The useful heat and useful chemical exergy due to clinker formation have been calculated using the data of the enthalpies of reactions of the raw mix to form clinker (Rosemann, 1987) and the standard chemical exergy values of the gas and solid flows in cement kiln plant (Morris and Szargut 1986) as shown in Table 3.

Table 3. Standard chemical exergy values of the gas and solid flows in cement plant
(Morris and Szargut 1986)

Species	Chemical Exergy (kJ/k mole)	Species	Chemical exergy (kJ/kmole)
Al ₂ O ₃ (s, α)	200400	CaSO ₄ (s, α)	8200
Al ₂ O ₃ .SiO ₂ (s)	15400	Fe ₂ O ₃ (s)	16500
CO(g)	275100	H ₂ (g)	236100
CO ₂ (g)	19870	H ₂ O(l)	900
CaCO ₃ (s)	1000	H ₂ O(g)	9490
CaCO ₃ .MgCO ₃ (s)	15100	K ₂ O (s)	413100
CaO(s)	101200	MgO(s)	66800
CaO.Al ₂ O ₃ (s)	275400	MgCO ₃ (s)	37900
2CaO.Al ₂ O ₃ (s)	460400	N ₂ (g)	690
3CaO.Al ₂ O ₃ (s)	500600	O ₂ (g)	3970
CaO.SiO ₂ (s)	23600	Na ₂ O(s)	296200
2CaO.SiO ₂ (s, β)	95700	SO ₂ (g)	313400
3CaO.SiO ₂ (s)	219800	SiO ₂	1900
CaS	844600	Fe ₂ O ₃ .SiO ₂	18400
4CaO.Al ₂ O ₃ .Fe ₂ O ₃	667000		

It has been considered that:

- Preheater exit dust is similar in chemical composition to the raw mix.
- By pass exit dust is similar in chemical composition to the clinker.
- Half the total C2S formation reaction takes place in the calciner and is completed in the kiln (Rosemann, 1987).

In the investigated process the actual amount of reacting raw mix = 1.728 kg to produce 1 kg clinker + 0.109 kg by pass dust. Its content of various components, in kg, are as follows ::

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O	Na ₂ O	Cl	LOI
0.24	0.06	0.033	0.72	0.02	0.008	0.005	0.007	0.0057	0.62

Its main compounds have been estimated as follows:

Clay content(estimated as Al₂O₃. 2SiO₂. 2H₂O) = 0.15 kg

CaCO₃ content = 1.285 kg.

MgCO₃ content = 0.04 kg

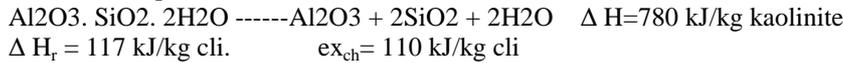
SiO₂ content = 0.17 kg

Table 4 shows the calculated enthalpies (ΔH_r), chemical exergies (ex_{ch}) and amounts of formed minerals of the different reactions of the raw mix:

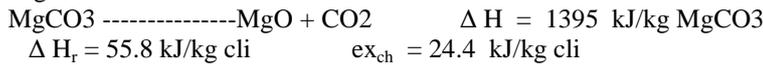
Table 4 Calculated enthalpies, chemical exergies and minerals amounts of the reactions of the raw mix (1.728 kg) to produce cement clinker

A-Formation of oxides and decomposition reactions:

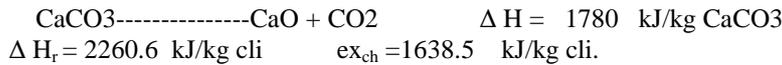
1- Kaolinit decomposition:



2- MgCO₃ dissociation :

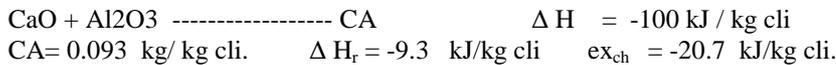


3-CaCO₃ dissociation :

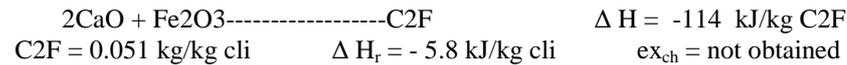


B- Formation of intermediates:

4- Formation of CA:



5- Formation of C2F



6- Formation of β -C₂S:

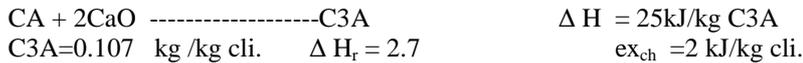


C- Clinkering reactions :

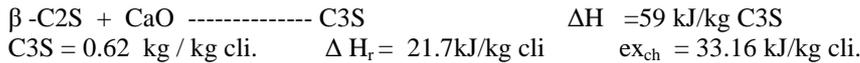
7- Formation of C₄AF:



8- Formation of C₃A:



9- Formation of C₃S:



From Table 4, it is concluded that:

Amounts of formed minerals in 1 kg produced clinker + 0.109 kg by pass dust are as follows : 0.62 kg C₃S, 0.22 kg C₂S, 0.11 kg C₃A, 0.09 kg C₄AF

Mineral composition of the produced clinker (in wt%) is as follows:

C₃S = 59.9 %, C₂S = 21.1%, C₃A = 10.3%, C₄AF = 8.7%

- Sum of consumed heat in all chemical reactions * = 1941.4 kJ/kg cli.
- Sum of consumed exergies in all chemical reactions = 1333.6 kJ/kg cli.
- consumed heat by by pass dust = 211.6 kJ/kg cli.

- consumed exergy by by pass dust = 145.9 kJ/kg cli.
- useful consumed heat and exergy by 1 kg produced clinker = 1729.8 kJ and 1187.7 kJ respectively.
- Heat and exergy consumed in reactions in preheater –precalciner corresponds to dissociation of clay and $MgCO_3$ +90% of $CaCO_3$ calcination + Formation of intermediate compounds (CA, C2F, ½ the amount of C2S : reactions 1+2+.9(3) + 4+5+.5(6) in the above table) = 1940.1 and 1334.2 kJ / kg cli. respectively
- Heat and exergy consumed in reactions in the kiln correspond to 10% of calcination of $CaCO_3$ + 50% of C2S formation + clinkering reactions (reactions 0.1(3) +0.5 (6) +7+8+ 9 in the above table) =1.3 and -0.6 kJ/kg cli. respectively. It is noteworthy to mention that the main duty of the kiln is to attain the required temperature for the clinkering reactants to form clinker (~1450°C).

4.3. Results and discussions:

- Mass , energy and exergy balances around the process

a-Preheater- precalciner:

Table 5 shows the calculated balances of mass, energy and exergy around the preheater – precalciner:-

Table 5 Mass, energy and exergy balances around the preheater-precalciner

Input items	mass Kg	Temp, °C	cp kJ/kg°C	Energy kJ/kg cli.	Exergy kJ/kg cl
1-raw meal	1.92	30	0.83	47.6	~ 0
2-fuel oil	0.073	30		2977.5	3179
3- tertiary air	0.85	800	1.08	733.8	361
4-false air	0.59	30	1.004	24.9	~0
5-water vapor From cooler	0.032	800	2.	52.5	25.2
-----	-----			-----	-----
Sum	3.455			3836.3	3565.2
Output items					
1- hot meal	1.17	800	1.002	937.6	460.1
2- flue gases	2.114	270	1.09	622.7	152.3
3- flue dust	0.18	270	1	48.6	11.9
4-reactions – heat exergy				1940.1	1334.5
5- evapn of residual Water		100		41.9	8.4
5-wall losses				245.4	59.1
-----	-----			-----	-----
Sum	3.464			3836.3	2026.3

Calculated energetic efficiency η_g and exergetic efficiencies η_{ex} , ϕ , I_{sys} :

$$\eta_g = (\text{reactions heat}) / (\text{fuel heat} + \text{tertiary air heat})(100)$$

$$= 1940.1 / 3711.3 \times 100 = 52.3 \%$$

$$\eta_{ex} = (\text{reactions exergy}) / \text{exergy of fuel and tertiary air}(100) = 1334.5 / 3540 \times 100 = 37.7 \%$$

$$\phi = 2026.3 / 3565.2 (100) = 56.8 \%$$

$$I_{sys} = \text{Irreversibility} = (3565.2 - 2026.3) = 1538.9 \text{ kJ/kg cli.}$$

$$= 43.16 \% \text{ of total exergy in}$$

From balances of energy and exergy around the preheater-precalciner, it is found that:

the largest exergy output item from preheater –precalciner is the chemical exergy of the reactions followed by exergy of the hot meal then the exergy of exit flue gases and dust.. Getting use of enthalpy and exergy of flue gas and flue dust e.g in preheating the raw mix represents a significant potential for raising the process performance.

b- Rotary kiln:

Table 6 shows the calculated balances of mass, energy and exergy around the rotary kiln.

Table 6 mass, energy and exergy balances around the rotary kiln

Input items	mass Kg	Temp, °C	cp kJ/kg°C	Energy kJ/kg cli.	Exergy kJ/kg cl
1- hot meal	1.17	800	1.002	937.6	460.5
2- secondary air	0.41	800	1.08	355.6	168.6
3- fuel	0.033	30		1346	1437.3
4- water vap	0.016	800	2	25.6	12.6
From cooler					
4- primary+False air	0.166	30	1.004	5.5	~0
-----	-----			-----	-----
Sum	1.795			2670	2079
Output items					
1- clinker	1	1400	1.09	1521.5	939
2- flue gases	0.704	1000	1.09	770.1	416.2
3-by pass dust	0.109	1000	1.07	113.9	59.1
4- wall losses				263	128.4
5- clinker formation					
Energy				1.3	
Exergy					-0.6
6- dust formation Exergy					-0.06
-----	-----			-----	-----
Sum	1.795			2669.8	1542.04

$$\eta_g = \text{sensible heat gained by the clinker} / (\text{fuel heat} + \text{secondary air heat}) = (1521.5 - 937.6) / (355.6 + 1346) \times 100 = 34.3\%$$

$$\eta_{ex} = (939 - 460.5) / (168.6 + 1437.3) \times 100 = 29.8\%$$

$$\phi = 1542.04 / 2079 = 74.2\%$$

$$I_{sys} = 2079 - 1542.04 = 537 \text{ kJ}$$

$$= 25.8\% \text{ of total exergy input}$$

As seen from balance data, % exergy lost as irreversibility in the kiln is less than in the preheater - precalciner. This can be attributed to the smaller role of chemical reactions in the kiln than in the preheater precalciner from the energetic and exergetic point of view. Energy and exergy of by pass gas represent a considerable % of energy and exergy output (~ 28 % and ~ 27 % respectively).

c- Rotary cooler:

Table 7 shows the calculated balances of mass, energy and exergy around the cooler.

Table 7 Mass, energy and exergy balances around the rotary cooler

Input items	mass Kg	Temp, °C	cp kJ/kg°C	Energy kJ/kg cli.	Exergy kJ/kg cl
1- hot clinker	1	1400	1.09	1521.5	1043.6
2- cooling air	1.26	30	1	37.9	~0
3- injected water	0.057	30	4.18	7.14	
-----	-----			-----	-----
Sum	1.317			1566.5	1043
Output items					
1- clinker	1	150	0.82	123	18.16
2- hot air	1.26	800	1.08	1089.7	543.3
3- steam	0.057	800	2.05	93.5	40.2
4- water evaporation				133.4	26.8
5- wall heat loss				129.8	57.02
-----	-----			-----	-----
Sum	1.317			1569.4	685.5

η_g (thermal efficiency) = gained heat by cooling air / maximum possible heat loss by clinker = $(1089.7 - 37.9)/(1521.5 - 24.6)(100) = 70.2\%$

η_{ex} = exergy of hot air / total exergy in (100) = $543.3/1043 (100) = 52 \%$

ϕ = exergy output / exergy input
= $685.5/1043 (100) = 65.7 \%$

I_{sys} = Irreversibility = $1043 - 685.5 = 357.5$ kJ/kg cli.
= 34.3% of total exergy input.

As clear from balance data around the cooler, exergy lost as latent heat and sensible heat of steam = 67 kJ/kg cli. (~ 10% of exergy output). This steam (from injected water) plays the same role in assisting the cooling operation as the exhaust hot air from grate cooler. The difference is that it is technically more feasible to get use of the enthalpy of hot exhaust air than that of the hot steam. Besides, the rate of clinker cooling in grate cooler is more controllable than in rotary cooler..

d- The whole process:

Table(8) shows the overall balances of mass, energy and exergy around the whole process (preheater-precalsiner, kiln and cooler)

Table 8 Mass, energy and exergy balances around the whole process

Input items	mass Kg	Temp, °C	cp kJ/kg°C	Energy kJ/kg cli.	Exergy kJ/kg cl
1- raw meal	1.92	30	0.83	47.6	~0
2- total fuel	0.106			4323.5	4616.7
3- cooling air	1.26	30	1.004	37.9	~0
4- injected water	0.057	30	4.18	7.14	~0
5- false- +primary air	0.813	30	1.004	24.4	~0
-----	-----			-----	-----
Sum	4.16			4440.54	4616.7
Output items					
1- clinker	1	150	0.82	123	18.16
2- preheater gas	2.114	270	1.09	622.7	152.3
3- ,, ,, dust	0.18	270	1	48.6	11.9
4- by pass gases	0.704	1000	1.09	770.1	416.2
5- by pass dust	0.109	1000	1.07	113.9	59.1
6- H2O evap. In cooler	0.057	100		133.4	26.8
7- clinker forming energy, exergy				1729.8	1188
8- by pass dust Forming energy, exergy				211.6	145.4
9- preheater wall loss				245.4	59.1
10- kiln ,, ,,				263	128.4
11- cooler ,, ,,				129.8	57.02
-----	-----			-----	-----
Sum	4.16			4391.3	2262.1

η_g (net thermal efficiency) = $1729.8/4323.5(100) = 40 \%$

η_{ex} (net exergetic efficiency) = $1187.7/4616.7(100) = 25.7 \%$

ϕ (anergy) = $2262.1 / 4616.7 = 49 \%$

I_{sys} = Irreversibility = 2354.6 kJ/kg cli.
= 51% of exergy input

As clear from the established balances of energy and exergy the process as a whole is of low performance. Efficiencies of first law and second law of thermodynamics are 40% and 25.7 % respectively. Irreversibility loss is large; it represents more than half of the exergy input. Magnitudes of energy and exergy output items arranged in a descending order are as follows:

By pass exit gases – pre-heater exit gases – by pass dust – kiln wall losses – preheater wall losses - cooler wall losses. Potentials for raising the process performance are summarized in decreasing such output loss items through applying technical means for getting use of their energy and exergy.

4.4. Energetic and exergetic analyses of the process with considering no gas diversion through by pass:

For comparative purpose energy and exergy balances have been established around the process with considering that no gas is diverted through by pass i.e the whole kiln gas flows upwards to the precalciner – preheater.

Specific fuel consumption has been estimated through establishing heat balance around the whole process for basis 1 kg clinker with considering :

- excess air factor for fuel combustion , $\lambda = 1.3$
- preheater exit dust= 10% of raw mix.
- Raw mix / clinker = 1.72 kg/kg
- preheater exit temperature = 300 °C

a- Heat input items:

- 1- raw mix = 1.72 (0.83) (30) = 42.8 kJ
- 2- fuel heat = x (40797) kJ
- x total specific fuel consumption (in calciner and kiln) kg/kg clinker
- 3- cooling air = 1.26 (1.004)(30) = 37.9 kJ
- 4- excess air = (1.29 (10.78) (x) (1.3) -1.26) (1.004)(30)= 544.5 (x) – 38

b-Heat output items:

- 1- clinker: 1 (0.82) 150 = 123 kJ
- 2- preheater gases = (1.43 (11.4 (x) (1.3) + 0.52+.057) 1.09 (300) = 6930 (x)+ 188.6
- 3- preheater flue dust = 0.17 (1) (300) = 51 kJ
- 4- reactions heat = 1729.8 kJ
- 5- H₂O evaporation in cooler = 0.057 (560) (4.18) = 133.4 kJ
- 6- preheater wall losses = 245.4 kJ
- 7- kiln wall losses = 263 kJ
- 8- cooler wall losses = 129.8 kJ

Equating the sum of heat inputs and heat outputs , the specific heat consumption x has been estimated as 0.082 kg oil /kg clinker. It means saving of about 0.025 kg oil / kg clinker representing ~ 23 % of the fuel consumption of the process with 100 % kiln gas by pass ratio. Table 9 shows balances of mass, energy and exergy around the process with no gas diversion through by pass:

Table 9 Mass , energy and exergy balances around the process with no gas diversion through by pass

Input items	mass Kg	Temp, °C	cp kJ/kg°C	Energy kJ/kg cli.	Exergy kJ/kg cl
1- raw meal	1.72	30	0.83	42.8	~0
2- total fuel	0.081			3304.6	3528.7
3- cooling air	1.26	30	1.004	37.9	~0
4- injected water	0.057	30	4.18	7.14	~0
5- false- + primary air	0.2	30	1.004	6.15	~0
-----	-----			-----	-----
Sum	3.32			3398.6	3528.7
Output items					
1- clinker	1	150	0.82	123	18.16
2- preheater gas	2.24	300	1.09	732.5	196.8
3- ,, ,, dust	0.17	300	1	51	13.8
6- H ₂ O evap. In cooler		100		133.4	26.8
7- clinker forming				1729.8	1187.7
Energy, exergy					
9- preheater wall loss				245.4	59.1
10- kiln ,, ,,				263	128.4
11- cooler ,, ,,				129.8	57.02
-----	-----			-----	-----
Sum	3.41			3407.9	1687.8

$$\eta_g \text{ (net thermal efficiency)} = 1729.8/3304.6(100) = 52.3 \%$$

$$\eta_{ex} \text{ (net exergetic efficiency)} = 1187.7/ 3528.7(100) = 33.6 \%$$

$$\phi \text{ (anergy)} = 1687.8 / 3528.7 = 47.8 \%$$

$$I_{sys} = \text{Irreversibility} = 1840.9 \text{ kJ/k} = 52.2\% \text{ of exergy input}$$

Comparing Table 9 with Table 8, the great effect of diversion of kiln gas through by pass on decreasing the performance and exergy efficiencies of the process is clear. The irreversibility in case of no gas diversion is smaller by about 22% of its value in the other case. However its percentage of total exergy input is nearly the same in both cases (51-52%). Specific fuel consumption decreases by about 23% on change from 100 % to 0 % kiln gas diversion through by pass.

5. CONCLUSION

It is of vital importance to try through technical means to decrease the kiln gas by pass ratio in modern cement dry process with precalciner as possible . With such decrease the process performance highly increases and irreversibility exergy losses markedly decrease . Utilizing energy of preheater exit gases and by pass kiln gases e g in raw meal preheating represents good potential for raising process performance. Besides, replacing the rotary cooler by grate cooler would lead to more feasible heat recovery from the exhaust hot air beside better control conditions for clinker cooling to give better product quality.

NOMENCLATURE:

h , specific enthalpy (kJ / kg); T , temperature (K); s , specific entropy (kJ/kg °K); R , gas constant, kJ/kg °K ; c_p , specific heat at constant pressure (kJ /kg. K); p , pressure (bar); v , specific volume at specified temperature, T_o (m^3/kg); H_u , lower heating value of the fuel (kJ/kg fuel); H_o , upper heating value of the fuel (kJ/kg fuel); X_C , X_H , X_O , X_S mass fractions of carbon, hydrogen, oxygen and sulfur in the fuel respectively.

Subscripts:

O, standard reference condition; r, raw mix; s, solid; α , β , solid solution phases

REFERENCES

- 1- Rosemann H, Locher F.W, Jeschar R (1987). Fuel energy consumption and operational behaviour of rotary cement kiln with precalcining. *Zement –Kalk – Gips.*, (10) : 489- 498.
- 2- Ritzmann H (1971). Cyclic phenomena in the rotary kiln systems. *Zement-Kalk-Gips.*, 24 (8): 383 – 343.
- 3- Goldmann W, Kreft W, Schutte R (1981). Cyclic phenomena of sulfur in cement kilns. *World Cement Technology*, (11) : 424 – 430.
- 4- Kreft W (1985). Alkali and sulfur vaporization in cement kilns in the presence of high chlorine intake levels. *Zement- Kalk- Gips.*, 38 (8): 418 – 424.
- 5- Sprung S (1964). The behavior of sulfur during the burning of cement clinker . *Schriftenreihe der Zementindustrie.*, H.31.
- 6- Farag L M (1990). Thermal evaluation of cement dry process with complete kiln exit gases removal through bypass. *Zement- Kalk- Gips.*, 43(11): 542-549.
- 7- IEA Greenhouse Gas R & D programme (IEA GHG R&D) 1999. The reduction of Greenhouse gas emissions from the cement industry, Report Number PH 3/7, Cheltenham, UK.
- 8- Morris DR, Szargut J (1986). Standard chemical exergy of some elements and compounds on the planet earth. *Exergy.*, 11(8) : 733-755.
- 9- Zafer U, Ziga S etal (2006). Energy and exergy analysis of a rawmill in a cement production. *Applied Thermal Engineering.*, 26 : 2479 – 2489.
- 10- Kian N (2003) . Exergy analysis , an effective approach for selection of sustainable technology and optimization of available systems- Three case studies in IRAN Cement Industry, IRAN Energy Efficiency Organization (SABA)
- 11- Koroneos C , Roubas G , Moussiopoulos N (2005). Exergy analysis of cement production. *Int. J. Exergy .*, 2 (1) : 55- 67.
- 12- Shaleen Khurana, Rangan Banerjee, Uday Gaitonde (2002) . Energy balance and cogeneration for a cement plant . *Applied Thermal Engineering* (22) : 485 – 494.(2005)
- 13- Kolip A (2010) . Energy and exergy analyses of a serial flow four cyclone stages precalciner type cement plant. *Scientific Research and Essays.*, 18(5): 2702 – 2712.
- 14- Rasul M G, Widiyanto W., Mohanty B (2005). Assessment of the thermal performance and energy conservation opportunities of a cement industry in Indonesia. *Applied Thermal Engineering.*, 25 : 2950 – 2965.
- 15- Vedat Ari (2011). Energetic and exergetic assessments of a cement rotary kiln system. *Scientific Research and Essays* 6 (6) : 1428-1438.
- 16- Koroneos C, Spachos T, Moussiopoulos N (2003) . Exergy analysis of renewable energy sources. *Journal of Renewable Energy* (28) : 295 -310.