The Influence of the Fuel Type on the Specific Heat Consumption of Clinkering Plants

D. Radu, A. David and Z. Ghizdavet

"Politehnica" University of Bucharest, Faculty of Applied Chemistry and Material Science, P.O.BOX 12-134, Bucharest, Romania

Abstract: Actual issues regarding the reserves of fossil fuels often determine the change of the fuel type used in various clinkering plants. This change may affect the quality of clinker and also the degree of environmental pollution. On the other hand, the influences on the main thermo-technological parameters have been less studied. In this paper there is presented a mathematical model which can emphasize the effect of changing the fuel type in a clinkering installation on the specific heat consumption or on the kiln’s productivity. In the same time, there are given some case studies in which this mathematical model is applied to various clinkering plants.

Keywords: alternative fuels, heat balance, mass balance, clinkering plant

1. Introduction

A relatively long period of time, the fossil fuels were the most used fuels in the cement industry, especially black oil and natural gas.

In the last two-three decades a series of objective reasons determined the widening of the group of useable (and used) fuels in the clinkering plants [2]. The most important issues which sustained this policy are:

-the depletion aspect of the fossil fuel reserves, relatively easy to exploit at a low price;

-the impossibility to replace fuels with other energy sources to produce heat in the clinkering plants (because of the technological particularities of the industrial clinkering process; this is the reason why a series of unconventional kilns where the energy source is represented by plasma, microwaves or electron fascicule are practically only for scientific interest, possibly at a laboratory level) [3];

-the outpointing of a certain negative impact of the technological process on the environment, referring to the pollution with some gaseous components and with dust;

-the more and more frequent political aspects regarding the restrictions to the main traditional sources of fossil fuels.

These issues lead to finding new types of fuels, including combustible wastes from other industries (used tires, animal meal, used oils).

When changing the fuels which are burnt in a clinkering plant, some technical and economical aspects must be taken into account:

-maintaining the preset values of the clinker and cement’s proprieties, respectively their quality;

-not to increase the negative impact on the environment;

-not to modify significantly the main thermo-technological performance parameters of the clinkering plant.

If these main requirements are fulfilled, the final decision will be made only after a technical and economical study will be performed (regarding the supplementary production costs, the sources of alternative fuels, the flows and the period of time on which the alternative fuels can be used).

Changing the fuels modifies the burning conditions in the clinkering plant [2]. There will appear differences in the flow and composition of the combustion gases, in the gas-material and gas-wall-material radiative heat transfer. It is expected that the main thermo-technological parameters of the kiln, productivity and specific heat consumption, will show new values.

In this paper there is presented a new way to emphasize the effects of changing the fuels on the two main parameters, productivity and specific heat consumption.

2. Theoretical basis

It is very well known that both the productivity, as well as the specific heat consumption practically depends on all constructive and functional parameters of a given clinkering plant. Though there are a lot o parameters, most of them can be quantitatively correlated using some mass and heat balances [1,4,5]. These balances may be partial or/and general, when it concerns a certain subassembly (thermal aggregate), respectively the whole clinkering plant.

This paper refers to clinkering plants based on the dry process and made of:

- preheater with cyclones, rotary kiln, grate cooler (type I);

- preheater with cyclones, calciner, rotary kiln, grate cooler (type II).

If necessary, for each of these two types of plants a by-pass installation may be included in assembly balance.

In every case it is considered that the installation works in a stationary thermal regime. In this paper there are presented the general mass and heat balances of a type II plant, which also contains a by-pass. Various particular cases may be obtained by annulling a series of parameters from the balance relations.

TABLE 1. General mass balance

Item	Parameter	Relation
	Inputs [kg/kg clinker]	
1	Specific raw meal consumption, after combustion	$F \cdot (1 - PC)$
2	The flow of ash which is added to the raw meal, resulted from the combustion of the solid fuel in the calciner	$a = \frac{y^k}{Hi^k} \cdot \varepsilon \cdot a \cdot Cs$
	Outputs [kg/kg clinker]	
1	The flow of clinker (it is considered as reference, equal to unit)	$m_{cl}^{re} = 1$
2	The flow of dust in the air exhausted from the grate cooler	$m_{pae}^{r} = x_{pae}^{r} \cdot V_{ae}^{r}$
3	The flow of dust in the combustion gases exhausted from the heat exchanger	$m_{pg}^{se} = x_{pg}^{se} \cdot V_{g}^{se}$

TABLE 2. General heat balance

Item	Parameter	Relation
	Inputs [kJ/kg. clincher]	
1	Specific heat consumption	Cs
2	Physical heat of the gaseous fuel	$Q_{fiz\_comb}^{c} = \frac{Cs \cdot y^c}{Hi^c} \cdot i_{comb}^{c}$
3	Physical heat of the solid fuel	$Q_{fiz\_comb}^{k} = \frac{Cs \cdot y^k}{Hi^k} \cdot i_{comb}^{k}$
4	Physical heat of the secondary air	$Q_{as} = \frac{V_{as} \cdot y_{comb}^{c}}{H_i^c} \cdot i_{comb}^{c}$
5	Physical heat of the tertiary air	$Q_{at} = \frac{V_{at} \cdot y_{comb}^{k}}{H_i^k} \cdot i_{comb}^{k}$
6	Physical heat of the cooling air	$Q_{ar}^{r} = V_{ar}^{r} \cdot i_{ar}^{r}$
7	Physical heat of the false air	$Q_{af}^{s+c} = V_{af}^{s+c} \cdot i_{ar}^{r}$
8	Physical heat of the raw meal	$Q_f = (F + m_{pg}^{se} + m_{pae}^{r}) \cdot i_f$
9	Physical heat of the humidity from the raw meal	$Q_{uf} = u \cdot (F + m_{pg}^{se} + m_{pae}^{r}) \cdot i_u$
	Outputs [kJ/kg.clincher]	
1	Physical heat of the air in excess	$Q_{ae}^{r} = V_{ae}^{r} \cdot i_{ae}^{r}$
2	Physical heat of the dust from the air in excess	$Q_{pae}^{r} = x_{pae}^{r} \cdot V_{ae}^{r} \cdot i_{pae}^{r}$
3	Physical heat of the combustion gases exhausted from the heat exchanger	$Q_{g}^{se} = V_{g}^{se} \cdot i_{g}^{se}$
4	Physical heat of the dust from the combustion gases	$Q_{pg}^{se} = x_{pg}^{se} \cdot V_{g}^{se} \cdot i_{pg}^{se}$
5	Physical heat of the clinker	$Q_{cl}^{re} = m_{cl}^{re} \cdot i_{cl}^{re}$
6	The necessary heat for the evaporation of the humidity from the raw meal	$Q_{evap} = F \cdot u \cdot L_v$
7	Heat lost in the environment	Q_l
8	Heat of reaction	Q_{form}
9	Physical heat of the by-pass gases	$Q_{g}^{bp} = \left(r^{bp} \cdot V_{ga}^{c} \cdot \frac{C_s \cdot y^c}{Hi^c} + \frac{F \cdot PC \cdot r^{op}}{\rho_{gt}} \right) \cdot i_{g}^{bp}$
10	Physical heat of the dust from the by-pass gases	$Q_{pg}^{bp} = x_{pg}^{bp} \cdot \left(r^{bp} \cdot V_{ga}^{c} \cdot \frac{C_s \cdot y^c}{Hi^c} + \frac{F \cdot PC \cdot r^{op}}{\rho_{gt}} \right) \cdot i_{pg}^{bp}$

TABLE 3. Symbols used in the mathematical model

Parameter:			Index:		Exponent:	
Symbol	Explanation	M.U.	Symbol	Explanation	Symbol	Explanation
V	volumetric flow of gases (air)	Nm^3/kg clincher	ar	cooling air	r	cooler
Cs	specific heat consumption	kJ/kg clinker	a_comb	combustion air	c	kiln
R	by-pass fraction	—	as	secondary air	k	calciner
F	raw meal mass flow (theoretical)	kg/kg clinker	at	tertiary air	s	heat exchanger
PC	loss of ignition (as fraction)	—	ae	excess air	bp	by-pass
i	enthalpy	kJ/kg raw materials or kJ/Nm^3	af	false air	re	evacuated from cooler
c	specific heat	kJ/kg·grd raw materials or kJ/Nm^3·grd	asupl	air in excess to ensure full combustion		
xa	ash in clinker (as fraction)	—	gt	technological gases		
a	ash resulted at burning a kg of solid fuel	kg/kg fuel	ga	combustion gases		
m	mass flow	kg/kg clinker	g	total gases		
x	maximum allowed dust concentration in gas ⋯ evacuated from apparatus ⋯	kg/Nm^3	comb	fuel		
Q	heat flow	kJ/kg clinker	p	dust		
Lv	latent heat of evaporation	kJ/kg moisture	f	raw meal		
H_i	low calorific value of the fuel	kJ/kg fuel	cl	clinker		
y	fuel fraction in apparatus ⋯	—	u	moisture content in raw meal		
λ	excess air coefficient in apparatus ⋯	—	fiz_comb	sensible [heat] of the fuel		
C, H, S, O, W	carbon, hydrogen, sulphur, oxygen, water content in fuel	kg/kg solid fuel	l	lost		
			form	[heat of] reaction		

The mass balance equation is:

$$\alpha \cdot Cs + \beta \cdot F = \gamma \qquad (1)$$

where:

$$\alpha = \frac{y^k}{Hi^k} \cdot \varepsilon \cdot a$$

$$\beta = 1 - PC$$

$$\gamma = m_{cl}^{re}$$

The heat balance equation is:

$$\mu \cdot Cs + \nu \cdot F = \omega \qquad (2)$$

In equation (2) μ, ν and ω are functions quite complex which include the constructive and functional parameters and which are used to compute the heat quantities from the heat balance [1].

Some of the parameters are independent variables, others result from partial mass or heat balances. For example, the flow of air in excess results from a mass balance for air on an assembly which includes the grate cooler.

Also, between some parameters there is a direct correlation. For example, naturally the real raw meal consumption, F, and the specific heat consumption, C_s, are directly correlated. In this case, the model is solved, F and C_s are calculated, in an iterative way.

Additionally, with respect to the type of alternative fuel used, regarding the percent and composition of the ash, the value of the theoretical raw meal consumption (f) and the value of the ignition loss (PC) can be modified. Therefore, though the oxide composition of the clinker does not change, the composition of the raw meal, and as well F, are modified. More operational details regarding the final structure of the model are presented in paper [1].

3. Case studies

There was considered an installation functioning on the dry process with calcination. Initially, the installation used black oil for the combustion in both the kiln and the calciner. In table 4 there are presented the general data of the installation.

TABLE 4. The general data of the installation

Parameter	Value
The degree of decarbonation of the raw meal at the kiln's entrance	Maximum 80%
Air in excess in the kiln	20 %
Air in excess in the calciner	20 %
Air temperature	30 °C
Fuel temperature	100 °C
Raw meal temperature	60 °C
Clinker temperature	130 °C
The temperature of the air in excess	280 °C
The temperature of the combustion gases	240 °C
Dust concentration in the exhaust gases	60 g/Nm^3
Dust concentration in the air in excess	35 g/Nm^3
Cooling air flow	2.48 Nm^3/kg. clinker

The low calorific value of the black oil is 38770 kJ/kg.

The reference fuel is changed with oil coke, which is burned 55% in the kiln and 45% in the calciner (just like in the case of the reference fuel).

The chemical characteristics of the oil coke used are: the content of volatile substances 10-11%; ash 1%; low calorific value 30564 kJ/kg.

The effect of changing the fuel on the specific heat consumption should be emphasized, on condition that the productivity of the kiln will not change.

In table 5 there is presented a comparison between the flows of gas and of material for the reference case (C1) and for the alternative one (C2).

At the same time, in table 6 there are presented the global heat balances, for the two cases.

TABLE 5. The flow of gas and the flow of material for the two cases

Technological parameter	Flows (C1)		Flows (C2)	
	Nm^3 or kg/kg. clinker	Nm^3 or kg/h	Nm^3 or kg/kg. clinker	Nm^3 or kg/h
Combustion air	0.979	69346	1.222	86558
Secondary air	0.392	27767	0.489	34638
Tertiary air	0.587	41579	0.733	51921
Air in excess	1.507	106746	1.264	89533
Total cooling air	2.486	176092	2.486	176092
Combustion gases	1.562	110642	1.820	128917
Fuel – total	0.089	6276	0.114	8068
- calciner	0.049	3452	0.063	4438
- kiln	0.040	2824	0.051	3631
Specific raw meal consumption	1.684	119283	1.691	119779
Dust in exhaust gases	0.092	6517	0.109	7721
Dust in air in excess	0.054	3825	0.044	3117

TABLE 6. Comparative heat balances of the installation

Heat quantities [kJ/kg. clinker]	Case (C1)	Case (C2)
Inputs		
Physical heat of the fuel	18.4	21.5
Physical heat of the air, including false air	101.9	101.9
Physical heat of the raw meal, including the humidity	87.3	87.7
Specific heat consumption	3434.9	3481.4
TOTAL	3642.4	3692.5
Outputs		
Physical heat of the air in excess	563.3	463.6
Physical heat of the dust in the air in excess	12.6	10.4
Physical heat of the combustion gases	776.4	922.5
Physical heat of the dust in the combustion gases	30.9	36.7
Physical heat of the clinker	100.7	100.7
The necessary heat for the evaporation of the humidity	27.9	27.9
Heat lost through radiation/convection from the heat exchanger, including the calciner	154.9	154.9
Heat lost through radiation/convection from the rotary kiln	146.5	146.5
Heat lost through radiation/convection from the grate cooler and tertiary air pipe	100.5	100.5
Heat of reaction (calculated)	1728.7	1728.7
TOTAL	3642.4	3692.5

The analysis of the data presented in tables 5 and 6 shows:

- maintaining the productivity at the same value when changing the reference fuel, black oil, with oil coke determines the increase of the total fuel flow (burned in both kiln and calciner), from 0.089 kg/kg.cl. to 0.114 kg/kg.cl.;

- the flows of combustion air, secondary air and tertiary air increase when burning oil coke in the installation, with approximately 25 % each, which is explained by the increase of necessary fuel per clinker unit;

- the total volume of combustion gases exhausted from the heat exchanger increases with 16.5%, which also implies the increase of the flow of the emissions exhausted into the atmosphere, with a negative impact on the environment because of the greenhouse effect.

- the specific raw meal consumption, F, increases from 1.684 kg/kg.cl. to 1.691 kg/kg.cl., so that the oxide composition of the clinker will not be affected by the changes applied to the installation when replacing the reference fuel with oil coke; in the alternative case the supplementary necessary of raw meal is 5000t/year;

- therefore, the specific heat consumption, C_s, of the clinkering plant increases as well with approximately 50 kJ/kg.clinker. This increase represents, for a productivity of the plant of 2000 t/24h, a supplementary necessary of fuel per year (330 days) of approximately 800t of black oil.

4. Conclusions

Changing one fuel with another one in a clinkering plant determines some modifications in the constructive and functional parameters of the plant. These influences may be emphasized using a mathematical model based on relations of partial and/or general mass, respectively heat balances.

In the particular case presented in this paper, that of a clinkering plant functioning on the dry process and with calcination, changing the reference fuel, black oil, with oil coke determines the increase of the flows of fuel, of air necessary for the combustion, and respectively of combustion gases, and also implies the increase of the specific raw meal consumption and of the specific heat consumption.

REFERENCES

1. Ghizdavet Z., Radu D., Methods of mathematical modeling applied to the cement industry,MatrixRom Publishing House, **2008**.
2. Radu D., Ghizdavet Z., David A., Romanian Journal of Materials, 4, **2009**, 326.
3. Teoreanu I., Thermo-technological installations, Technical Publishing House, Bucharest, **1979**.
4. xxx, National Institute of Cement CEPROCIM S.A., Manual of engineer from the cement industry vol. II, Technical Publishing House, Bucharest, **1999**.
5. Brunklaus J.H., Industrial kilns, Technical Publishing House, Bucharest, **1977**.

Received: 04 March 2010
Accepted: 10 June 2010