The Influence of Fuel Selection on Some Thermo-technological Parameters of the Rotary Kiln

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The continuous development of the cement industry, for a foreseeable time horizon as well, is accompanied by a series of problems related to the use of fuels. Some of these inherent difficulties, which accompany in an objective way the cement production, were partly solved by using alternative fuels coming from various sources. Usually, what is taken into account is the technological compatibility between these alternative fuels and the materials that are processed in the clinkering plant. Sometimes the environmental issues are being considered as well. However, the thermo technical particularities of the fuel combustion are seldom dealt with. In this article, is presented a first attempt to evaluate the radiative heat transfer of the combustion gases in a clinkering plant. Various types of fuels are being analyzed, fuels that are already used or that could be used in cement production.

Keywords: rotary kiln, heat transfer, emissive power

The thermo-technological clinker making process presents a series of characteristics which can determine a poor impact on the environment. These are:

-the necessity of high flows of superior fossil fuels (black oil, natural gas, coal). As an argument there is the fact that the actual clinkering plants have on average outputs in the range of 3000-5000 t/24h, reporting fuel intakes of 3000-3500 kJ/kg clinker.

At the same time, some of the clinker forming reactions occur at 1400-1450°C, which implies that the temperatures of the hot gases are slightly higher [1].

-the presence of some relatively important flows of CO_2, NO_x, SO_x etc., in the hot gases, which determine the increase of the environmental pollution degree and accentuate the greenhouse effect. In addition, there are also some important flows of CO_2 from the limestone dissociation, the most important raw material which is processed during the making of clinker.

Therefore, especially after the 1970s oil crises the research and industrial operations were accelerated in order to diminish or even eliminate the use of fossil fuels in the clinkering plants.

The materials used are mostly wastes, which has a positive impact on the environment [1-6].

The problems that are taken into account on the use of these alternative fuels refer to:

-reaction products should not affect in a negative way the oxide composition of the material from the kiln;

-the resulted hot gases should provide the temperature regime, calorific flows and the heat transfer conditions so that the various subprocesses can take place;

-as much as it is possible the flow of dangerous gases and greenhouse gases released into the atmosphere should not increase;

-the use of alternative fuels should provide economical advantages as well.

The main purpose of this paper is to approach from a different angle and less debated in the specialty literature the use of alternative fuels: thermo-technical effects and associated to the use of various fuels in clinker burning.

In context, this paper aims to analyze two main aspects:

-a brief listing of some thermo-chemical parameters that must be taken into account when comparing the energetic efficiency of fuels;

-revealing the role of carbon dioxide in the radiative heat transfer in the rotary kiln.

Thermo-chemical parameters associated with the combustion process

Regardless of the fuel diversity or the number of chemical reactions that occur when a fuel is burned, the combustion process can be described by a general expression:

$$\sum_i x_i \cdot X_i + \lambda \cdot V_{at} \Leftrightarrow y_1 \cdot CO_2 + y_2 \cdot H_2O + y_3 \cdot N_2 + y_4 \cdot O_2 + \sum_j \xi_j \cdot Z_j \quad (1)$$

where:

X_i are the atomic compounds of the fuel (C, H, S, etc.) or the molecular compounds of the fuel (CH_4, N_2, H_2, etc.);

V_{at} - theoretical volume of air necessary for the complete combustion;

λ – the coefficient of air in excess;

Z_j – compounds of the hot gasses, except for those presented in an explicit way (CO_2, H_2O, N_2, O_2), including their dissociation products (CO, OH, NO_x and so on);

x_i, y_1-y_4, ζ_j – stoichiometric coefficients.

From the thermo-technical point of view, analyzing the opportunity of using a new type of fuel has to account at least three main levels:

-estimating the thermo-energetic potential of the fuel;

-determining the emissive power by radiation of the hot gases resulted in the combustion process;

-establishing the concentration and flow of the polluting gases released in the atmosphere.

When comparing fuel efficiency the basis is represented by the low calorific value.

Low calorific value

The most important thermo-chemical parameter determined by the chemical composition of the fuel is the heat power – inferior, H_i, and respectively superior, H_s.

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Table 1
CHEMICAL CHARACTERISTICS OF FUELS

Fuel type	*Fuel code*	*Fuel name*	*Chemical composition*	*Low calorific value, H_i, [kJ/Nm^3] or [kJ/kg]*
Gas	CG1	*Generator gas*	7.2%CO_2; 0.3%O; 26.4%CO; 3.6%CH_4; 16.3%H; 46.2%N	6388
	CG2	*Gazogene gas*	10.3%CO_2; 24.3%CO; 4.5%CH_4; 21.8%H; 39.1%N	7039
	CG3	*Gazogene gas*	7.6%CO_2; 0.6%O_2; 25.3%CO; 3%CH_4; 14.1%H; 49.4%N	5796
	CG4	*Gas fuel*	96%CH_4; 2%C_2H_6; 1%C_3H_8; 0.5%N; 0.5%CO_2	36621
	CG5	*Natural gas from Podeni*	97.5%CH_4; 1.8%C_2H_6; 0.7%C_3H_8	36750
	CG6	*Natural gas from Ariceşti*	98.97%CH_4; 0.45% C_2H_6; 0.19%C_3H_8; 0.39% C_4H_{10}	36408
Liquid	CL1	*Liquefied gas*	82.5%C; 17.5%H	48414
	CL2	*Black oil*	85.2%C; 12%H; 1.6%S; 0.8%O; 0.4%N	42732
	CL3	*Black oil*	84.32%C; 11.2%H; 1.79%O; 0.56%N; 2.13%S	41379
	CL4	*Black oil with low percentage of sulfur*	87.5%C; 11.2%H; 0.6%S; 0.2%O; 0.5%N	42531
	CL5	*Black oil with high percentage of sulfur*	85%C; 11.8%H; 2.5%S; 0.3%O; 0.4%N	42584
Solid	CS1	*Lignite*	40.32%C; 3.87%H; 2.26%N; 18.06%O; 6.45%S; 29.04% ash	15923
	CS2	*Lignite*	35.44%C; 3.33%H; 3.33%N; 13.51%O; 1.4%S; 42.99% ash	13868
	CS3	*Coal*	73.53%C; 5.4%H; 16.8%O; 0.62%S; 3.65% ash	28434
	CS4	*Coal*	80%C; 3.5%H; 2.2%N; 14.3%O	28617
	CS5	*Peat*	58%C; 5%H; 2%N; 35%O	20007
	CS6	*Used tires*	83.87%C; 7.09%H; 2.17%O; 0.24%N; 1.23%S; 5.4% ash	36151
	CS7	*Animal meal*	-	18000

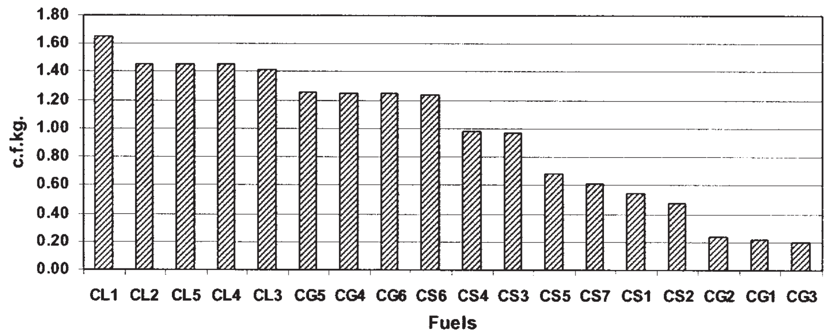

Fig. 1. Values of the inferior heat power equivalent expressed in conventional fuel kilogram (c.f.kg.)

Table 1 presents the chemical composition of the 18 fuels which are used or which could be used in the combustion process in a clinkering plant [1-3, 5-9].

Analyzing the data from table 1, results that for each type of fuels, H_i is a sufficient criteria to estimate the energetic potential of each fuel. Because of the heterogeneous measure units (kJ/Nm^3, kJ/kg), the comparison can not be applied to fuels of different types. In order to do that, it is proposed here that the energetic potential of fuels should be expressed in the equivalent kilogram of conventional fuel, kg.c.c., which has the low calorific value H_i=29300kJ/kg.

In figure 1 there is presented the energetic content of the 18 fuels, the ordering criteria being the equivalent conventional fuel, c.f.kg.

The fuel with the highest energetic potential is characterized by the highest value of H_i, expressed in c.f.kg. According to this criterion, the results may give the opportunity of using a new fuel in the burning process in the rotary kiln and/or calciner.

Hot gases

In order to compare fuels of different types by hot gases and by the CO_2 content of the hot gases, the gas volume was expressed in homogeneous measuring units. It was necessary to do so, because the volume of hot gases, V_{ga}, is calculated in Nm^3 and reported to Nm^3 or kg. of fuel, depending on the nature of the fuel.

The standardization of the measuring units can be made with the following relation:

$$V'_{ga} = \frac{V_{ga}}{H_i} \quad [\text{Nm}^3/\text{MJ}] \qquad (2)$$

Figure 2 shows that the highest values of V'_{ga} are presented by gas fuels CG3, CG1 and CG2, while the lowest values belong to the liquid fuels CL1 and CL4.

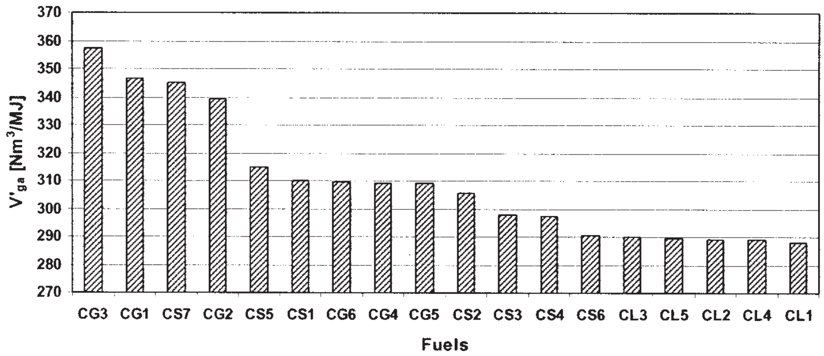

Fig. 2. Values of the normalized volumes of combustion gases

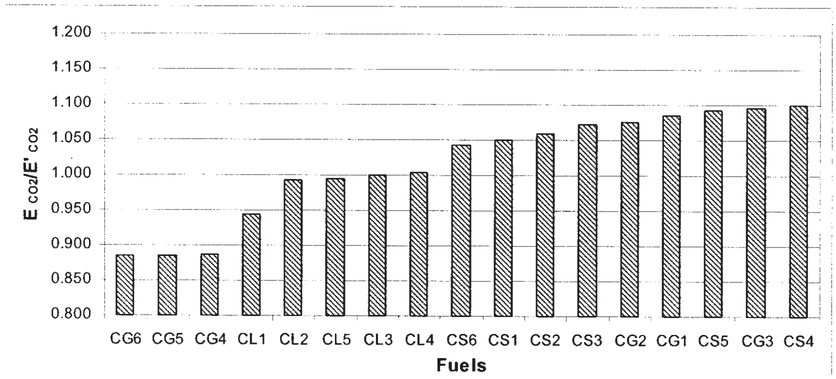

Fig 3. The emissive power of CO_2 referred to black oil.

The data presented in figure 2 emphasizes the fact that when an unit of heat (1 GJ) is produced, from the burning process results a normalized volume of hot gases, which increases with the decrease of the low calorific value. Therefore, according to the data presented in figure 1, from the gaseous fuels CG1 and CG2 have low calorific values. Also, among the liquid fuels, CL1, CL2 and CL4 have the highest values of H_i. In consequence the normalized volumes of the hot gases have minimal values.

In the clinkering plant these fuels are of real interest because they determine (in correlation with the specific heat consumption) lower hourly flows of hot gases which are exhausted into the atmosphere. Therefore, the flows of polluting emissions and dust will be diminished. Also, the necessary of power for the exhauster will be lower.

The emissive power by radiation of the hot gases

In rotary kilns, the heteropolar gases make the heat transfer by radiation: CO_2, SO_2, water vapours, hydrocarbons, CO. Among these, the most important are CO_2 and water vapors [9-11].

In this paper, due to its purpose, only the effect caused by the content of CO_2, resulted from the burning process of various types of fuels, on the emissive power by radiation of the hot gases is of interest. Therefore, the role of CO_2 in the heat transfer in the rotary kiln, as well as in influencing the "greenhouse effect" is emphasized.

Ultimately, these two effects (opposite) will be enhanced by the technological CO_2, resulted from the decarbonation of the raw materials.

All partial coefficients of heat transfer are calculated with respect to the emissive power of CO_2, E_{CO2}, and of the water vapors, E_{H2O}, and with respect to various temperatures (of the gases, of the material, of the interior surface of the kiln).

The relation for E_{CO2} is:

$$E_{CO2}=4\cdot(p_{CO2}\cdot h)^{0.33}\cdot(T/100)^{3.5}[W/m^2] \quad (3)$$

where:

p_{CO2} - partial pressure of CO_2 [bar];

h - medium path of the radiation [m]; h=0.9 . D, D- interior diameter of the kiln; for the calculations it was considered h=3.4m;

T – absolute temperature [K].

For the analyzed fuels resulted a linear variation of the emissive power with respect to pressure at 1400K, and the relation is:

$$E_{CO2}=79960\cdot p_{CO2}+20786 \quad (4)$$

$R^2=0.9961$

In addition, at 2400 K, the variation of the emissive power of CO_2 with respect to pressure is linear. The relation is:

$$E_{CO2}=527428\cdot p_{CO2}+137106 \quad (5)$$

$R^2=0.9863$

The emissive power of CO_2 was referred to a reference fuel - black oil CL3 - and the results are presented in figure 3.

The data presented emphasize that according to the given criterion – emissive power by radiation – the fuels CS4, CG3, CS5, CG1, CG2 are of interest (in general, all fuels with E_{CO2} higher than E'_{CO2} of the reference fuel).

Conclusions

In a clinkering plant, the use of fuels with high fuels that release significant amount of energy determines both positive and negative effects, listed in the following order:

-the increase of the volume of hot gases, which implies:

- a more intense heat transfer (the increase of the gas flow results in the increase of the speed of gas transport through the installation, which favors the convective component of the heat transfer);
- for a fixed concentration of the dust evacuated with the hot gases from the heat exchanger, its flow increases, as well as the flows of CO_2, CO, NO_x.

-the increase of CO_2 the percentage in the hot gases, which implies:

- the intensification of gas-material as well as gas-wall radiative heat transfer;

- the increase of the CO_2 percentage in the hot gases released from the installation, with a negative impact on the environment.

Modifying the heat transfer in the rotary kiln along with the change of the fuel type will also influence some thermo-technological parameters.

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