CO₂ Resulted from Fuel Combustion, Radiative Power of the Hot Gases and the Greenhouse Effect. Applications in the Clinkering Plants

D. Radu, Z. Ghizdavet and A. David

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

Abstract: Aspects especially regarding the access to new resources of fossil fuels, but not only, have determined the "activation" of other types of fuels besides the classical ones, in the cement industry also. In order to measure the thermo-chemical and energetic potential of some fuels in this paper there are given a number of parameters characteristic to the fuels: heat power, energy, volume, chemical composition of the hot gases and their radiative power. In this paper it is emphasized that in all cases the chemical composition of the fuel and, especially, the content of CO_2 is a parameter of great influence. Therefore, the role of CO_2 in the heat transfer in a clinkering plant is underlined. In the same time, the fuels are being compared through the implications of their CO_2 emissions on "the greenhouse effect".

Keywords: combustion, greenhouse effect, clinkering plant, hot gases

1. Introduction

Cement industry shows a continuous development for a foreseeable period of time. Inevitably, this will lead to an increase in fuel consumption.

The expansion of clinkering plants' number based on the dry process and calcination led to the lowest values of specific hest consumption.

Moreover, there is also the predicted depletion of the reserve of fossil fuels that can be economically exploited.

One of the most important possibilities of releasing these tensions is that of increasing the number of fuels which can be burnt in the clinkering plant.

The enlargement of the range of fuels which can be used in clinker production raises the problem of deciding one fuel over another.

In context, this paper aims to analyze three 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 within the rotary kiln.

-the influence of the burning conditions upon the greenhouse effect.

2. Thermo-chemical characterization of fuels

The development of the clinkering process based on calcination determined gradually the use of other types of flues, with low calorific value (inferior coal, bituminous shale), along with black oil, natural gases and coals with high calorific value.

In the last few years, especially in the calciner, many materials considered alternative fuels were burnt (tires, animal meal, waste oil etc). [1]

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

$$\sum_i x_i * X_i + \lambda * V_{at} \Leftrightarrow y_1 * CO_2 + y_2 * H_2O + y_3 * N_2 + y_4 * O_2 + \sum_j \xi_j * Z_j$$
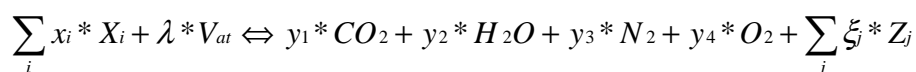
where: X_i are the atomic compounds of the fuel (C, H, S, etc.) or the molecular compounds of the fuel (CH_4, N_2, H_2, etc.); Vat - theoretical volume of air necessary for the complete combustion; λ – the coefficient of air in excess; Z_j – compounds of the hot gasses, except for those presented in an explicit way (CO_2, H_2O, N_2, O_2), including their dissociation products (CO, OH, , NO_x and so on), xi, y_1-y_4, ζ_j – stoichiometric coefficients.

In order to select the type of fuel which can be used a series of technological, economical, environmental demands are taken into account, which may sometimes be circumstantially imposed. Beside these, an important role is

that of the thermo-chemical characteristics of the fuel, like: calorific value, exergetic content, volume and composition of combustion gases, combustion temperature, etc.

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.

Regardless of the types of fuels used industrially, their energetic potential is determined by their chemical composition. In paper [1] there is presented a series of data about various gas (CG), liquid (CL) or solid (CS) fuels available in the cement industry. Some of them represent (possible) alternative fuels for the cement industry [2].

TABLE 1. Chemical characteristics of fuels

| Fuel type	Fuel code	Fuel name	Chemical composition	Low calorific value, H_i, $[kJ/Nm^3]$ or $[kJ/kg]$	Place
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	17
	CG2	Gazogene gas	10.3%CO_2; 24.3%CO; 4.5%CH_4; 21.8%H; 39.1%N	7039	16
	CG3	Gazogene gas	7.6%CO_2; 0.6%O_2; 25.3%CO; 3%CH_4; 14.1%H; 49.4%N	5796	18
	CG4	Gas fuel	96%CH_4; 2%C_2H_6; 1%C_3H_8; 0.5%N; 0.5%CO_2	36621	7
	CG5	gas from Podeni	97.5%CH_4; 1.8%C_2H_6; 0.7%C_3H_8	36750	6
	CG6	Natural gas from Aricești	98.97%CH_4; 0.45% C_2H_6; 0.19%C_3H_8; 0.39% C_4H_{10}	36408	8
Liquid	CL1	Liquefied gas	82.5%C; 17.5%H	48414	1
	CL2	Black oil	85.2%C; 12%H; 1.6%S; 0.8%O; 0.4%N	42732	2
	CL3	Black oil	84.32%C; 11.2%H; 1.79%O; 0.56%N; 2.13%S	41379	5
	CL4	Black oil with low percentage of sulfur	87.5%C; 11.2%H; 0.6%S; 0.2%O; 0.5%N	42531	4
	CL5	Black oil with high percentage of sulfur	85%C; 11.8%H; 2.5%S; 0.3%O; 0.4%N	42584	3
Solid	CS1	Lignite	40.32%C; 3.87%H; 2.26%N; 18.06%O; 6.45%S; 29.04% ash	15923	14
	CS2	Lignite	35.44%C; 3.33%H; 3.33%N; 13.51%O; 1.4%S; 42.99% ash	13868	15
	CS3	Coal	73.53%C; 5.4%H; 16.8%O; 0.62%S; 3.65% ash	28434	11
	CS4	Coal	80%C; 3.5%H; 2.2%N; 14.3%O	28617	10
	CS5	Peat	58%C; 5%H; 2%N; 35%O	20007	12
	CS6	Used tires	83.87%C; 7.09%H; 2.17%O; 0.24%N; 1.23%S; 5.4% ash	36151	9
	CS7	Animal meal	-	18000	13
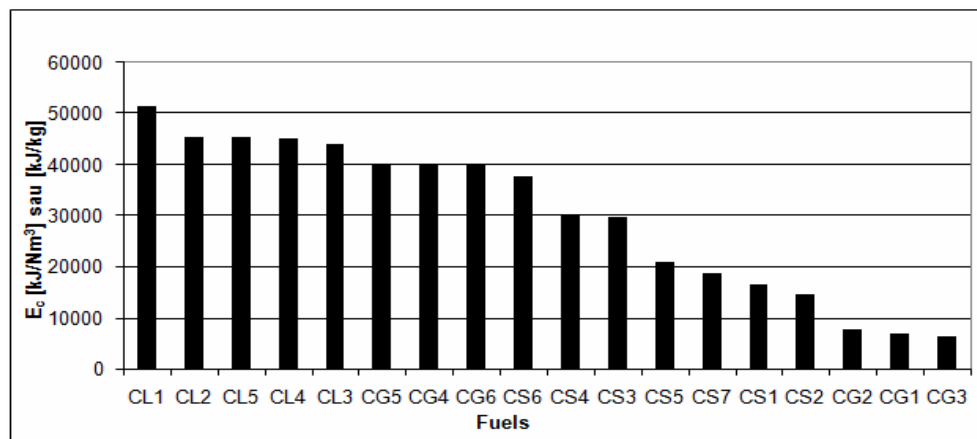
Figure 1. Exergy of fuels expressed in conventional fuel kilogram

By analyzing the data from table 1, it results that H_i is a sufficient criterion to estimate the energetic potential of each fuel. Because of the heterogeneous measure units, the comparison can not be expanded to fuels of different types. In order to do that, it is proposed 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 $H_i=29300kJ/kg$.

The last column of table 1 indicates the place of each fuel in an array of all 18 considered fuels. The array decreases from the maximum value with respect to the value of H_i, expressed in equivalent c.c.

Fuels characterized by higher values in kg.c.c. present a higher energetic content. A possible replacement of a fuel with another one, for a given clinkering plant, can be made only if their energetic equivalent, expressed in kg.c.c, is similar when the main burner, which is placed in the rotary kiln, is taken into consideration. The differences may be higher when fuels are burnt in the calciner, which is the place for the $CaCO_3$ from the raw meal dissociation.

The evaluation of complex fuels' exergy can not be made because of the difficulties regarding the numerical evaluation of the entropy. However, for technical calculus, due to the analysis of a large number of fuels, a series of relations were set for E_c [4]:

-for solid fuels: $E_c = H_i$; for liquid fuels $E_c = H_i \cdot 1.037$; for gas fuels $E_c = H_i \cdot 1.022$.

Figure 1 shows the exergy of the considered fuels. In this case also, in order to compare the exergetic content of different types of fuels E_c is expressed (like H_i) in c.c.kg. The series is decreasing with respect to Ec. The fuel with the highest value for exergy, expressed in equivalent c.c., presents the highest energetic potential.

3. Characterization of combustion products

Volume and chemical composition of the hot gases

Knowing the chemical composition of the fuel several volumes can be evaluated: the volume of air necessary for combustion, the volume of the combustion gases as well as the volume of their components.

It is emphasized that it is difficult to compare a certain type of fuel with another one, because V_{ga} and its gas components may be expressed in heterogeneous units.

In order to compare fuels from different categories with regard to the volume of hot gases and their CO_2 content the gas volume was expressed in homogeneous units:

$$V'ga = \frac{Vga}{Hi} \qquad [Nm^3/GJ] \qquad (2)$$

Knowing the chemical composition of the fuels, the volume of air necessary for the combustion, as well as the volume and composition of the hot gases can be calculated.

The data presented in table 1 and figure 2 suggested a possible correlation between V_{ga} and H_i.

Figure 3 shows a linear increase of the volume of hot gases with the increase of the lower calorific value of the fuel used in the combustion in the clinkering plant. The following relation was deducted and it has a high correlation coefficient:

$$V_{ga} = 0.0003 * H_i + 0.5567 \qquad (3)$$

Similarly, a statistic analysis made on the data regarding the volume of CO_2, V_{CO2}, coming from combustion, (Nm^3/Nm^3 or kg. of fuel) and H_i (kJ/ Nm^3 or kg. Of fuel) showed a possible correlation between the two parameters. This correlation is described by the following relation:

$$V_{CO2} = 0.662 \cdot \ln(H_i) - 5.474 \qquad (4)$$

The resulted correlation coefficient is $R^2 = 0.961$.

Relations (3) and (4) emphasize that if fuels characterized by a high calorific value are burnt in the clinkering plant, the volumes of CO_2 and of hot gases will be higher. Increasing the hourly flows of gas exhausted from the installation, the greenhouse effect will increase as well.

In the same time, at a fixed concentration of dust exhausted with the hot gases, its flow will increase, when V_{ga} is higher.
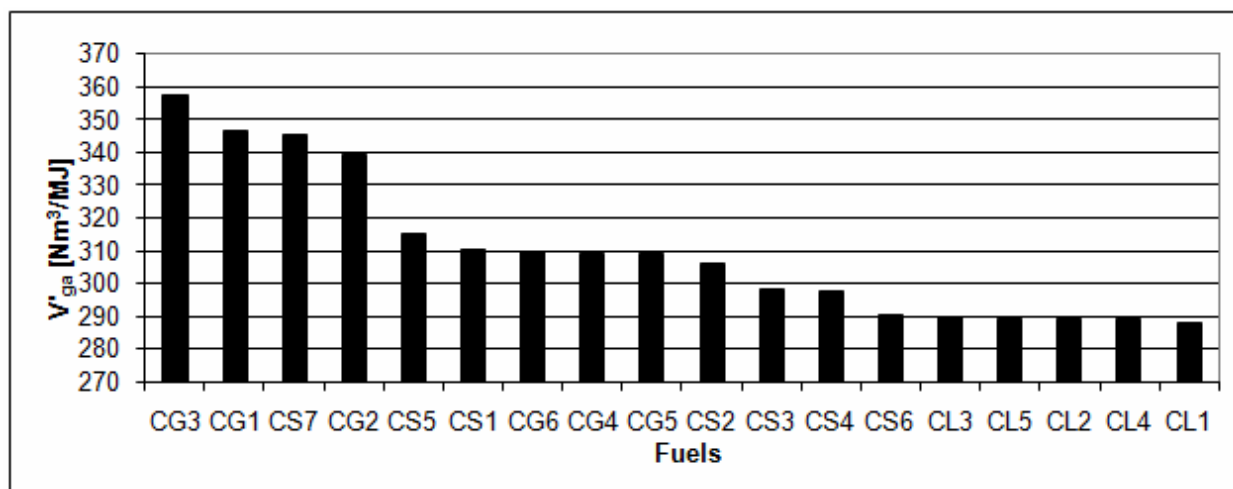

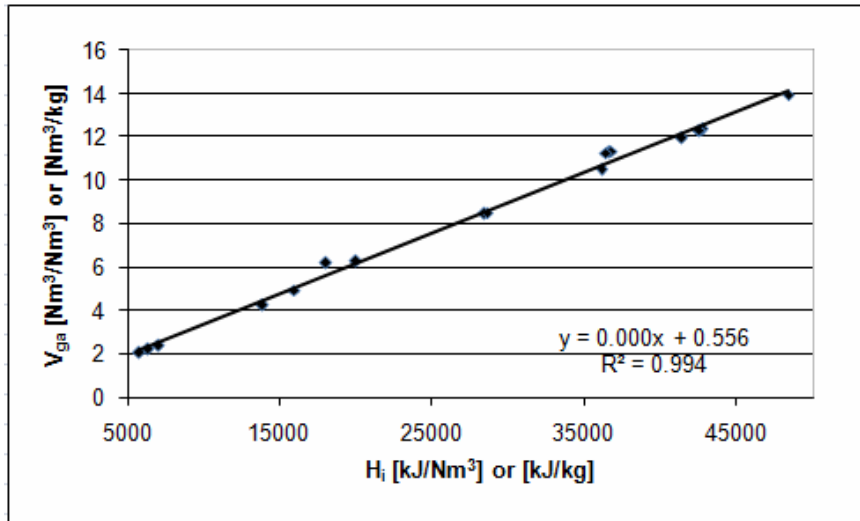Figure 2. Values of normalized volumes of combustion gases

Figure 3. The change in combustion gases volume with respect to the low calorific value of the fuel.

The radiative power of the hot gases

In rotary kilns, the heteropolar gases are responsible the heat transfer by radiation: CO_2, SO_2, water vapors, hydrocarbons, CO. Among these, the most important are CO_2 and water vapors.

The effect on the radiative heat transfer generated by various types of fuels through their CO_2 content is of interest (the effect of technological CO_2 is not taken into consideration, it is practically invariable, and it does not affect the conclusions) is obtained by the equations of the radiative power of the heteropolar gases.

The relation for E_{CO2} is:

$$E_{CO2} = 4*(p_{CO2}*h)^{0.33}*(T/100)^{3.5} \quad [W/m^2] \qquad (5)$$

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; 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:

$$E_{CO2} = 79960*p_{CO2} + 20786 \quad R^2=0.9961 \qquad (6)$$

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

$$E_{CO2} = 527428*p_{CO2} + 137106 \quad R^2=0.9961 \qquad (7)$$

For comparison, the emissive power of CO_2 for various fuels was referred to that of a reference fuel (black oil-CL3), and the results are presented in figure 4.
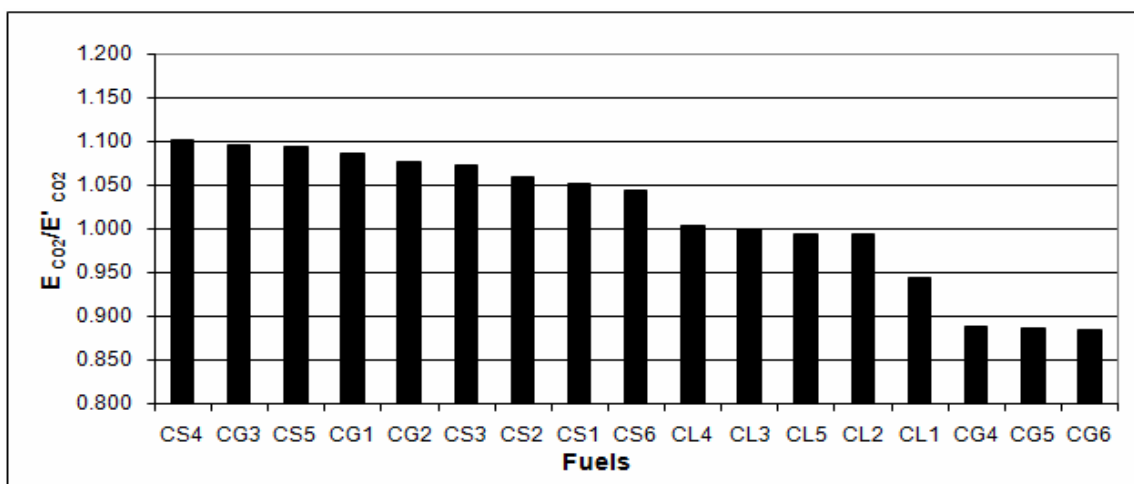

Figure 4. The emissive power of CO_2 referred to black oil

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4. Conclusions

In this paper it was emphasized that a comparison of the thermo-energetic potential of various fuels can be made with respect to many characteristics of the considered fuels end of the hot gases. The optimal choice represents a multicriteria decision which can be solved by different methods (for example value engineering [6]), for each specific case.

In a clinkering plant, the use of fuels with high calorific values that release significant amount of energy determines:

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

    -a more intense heat transfer;

    -for a fixed concentration of the dust evacuated with the hot gases from the cyclone tower, its flow increases, as well as the flows of CO_2, CO, NO_x.

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

    -a more intense gas-material heat transfer;

    - a negative impact on the environment.

A series of data, obtained from some CO_2 balances of the clinkering plant, show that the CO_2 from combustion represents approximately 50% of technological CO_2. This remark leads to the conclusion that even if the proper selection and burning of the fuel are made (or even if we consider a decrease in the amount of fuel), the maximum decrease in the amount of combustion-released CO_2 will be potentially lower than via reducing technological CO_2.

Therefore, only the optimization of the raw materials allow for the most of the reduction in CO_2 emissions. Moreover, a decrease in CO_2 content (one of the two main gaseous components responsible for the radiative heat transfer who is the preeminent heat transfer mechanism within the kiln) of the hot gases in the rotary kiln will induce a sharp negative effect on the amount of heat transferred to the material. Opposite to this, a reduction in the CO_2 coming from the raw meal's decarbonation will exert a considerably smaller negative effect on the heat transfer, as the temperature range within cyclones or calciner, where technological CO_2 is mainly produced, is significantly lower than in the kiln.

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