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ANALYSIS OF CO_2 GENERATION IN THE PORTLAND CEMENT PRODUCTION

Gustavo Pereira Tavares
gptavares@unifei.edu.br

Rogério José da Silva
rogeriojs@unifei.edu.br

Márcio Dimas Ramos
mdr@unifei.edu.br

Universidade Federal de Itajubá, Instituto de Engenharia Mecânica, Av. BPS, 1303, Bairro Pinheirinho, Itajubá, Brazil

Abstract. *The cement industry is characterized by high consumption of thermal and electrical energy, and half of all its cost comes from expenses with fuels and electric energy. Given this scenario, the cement industry is responsible for large environmental impacts caused in the anthropic, biotic and physical environment. These impacts are mainly due to the emission of the polluting gases generated by the burning of fuels. One example is the emission of CO_2, one of the main gases that causes global warming, where the cement industry is responsible for about 7% of the anthropogenic CO_2 released annually into the atmosphere. The coprocessing technique is considered as a global strategy for the mitigation of CO_2 emissions in cement factories, since it consists of the burning of industrial waste and environmental liabilities in the rotary kiln which, due to their calorific value, are used as fuel, thus generating a decrease in use of fossil fuels, and the wastes that are coprocessed are referred to as secondary or alternative fuels. This work proposes an analysis of CO_2 generation in cement plants through two case studies, one study using the burning of fossil fuels and the other operating with a mixture of alternative fuels and fossil fuels, comparing the results obtained in each case study. According to this context, the main strategies and technologies currently being developed for the reduction of CO_2 emissions generated in the production of Portland cement will be discussed.*

Keywords: *Coprocessing, Emission, Cement, Fuel, Energy*

1. INTRODUCTION

With greater awareness about environmental pollution, it is widely accepted that global warming is considered a threat in the present times. Around 61% of the world's CO_2 emissions come from electricity generation and industrial activities (SOGUT, 2011).

The cement industry is considered as energy-intensive is usually about half of its direct costs with fuel and electric power. Since fuel consumption is related, directly with the type of process and technology used, besides the process the demand for fuel is also determined by the chemical composition, mineralogical and the moisture of the raw materials used. The consumption of electricity is directly linked to the technology used in the grinding and crushing processes (MADLOOL, A. N. et. al., 2011).

Approximately 7% of global CO_2 emissions are generated in cement production. Depending on the type of process, the process emits between 800 and 900 kg of CO_2 per ton of cement produced. Much of the CO_2 emission corresponds to the process of calcination of the raw material ($CaCO_3$ dissociation in CaO and CO_2). the remainder is the result of the burning of fuels (GRUBB, 2015).

The global and potential strategies for mitigating CO_2 emissions in the cement plant are as follows: to improve energy efficiency, use of active additions in cement and the use of coprocessing (BENHELAL E. et. al., 2012).

This work proposes an analysis of the CO_2 generated in cement factory through two case studies, one study using the burning of fossil fuels and the other operating with a mixture of alternative fuels and fossil fuels, comparing the presented results of each case study. According to this context, the main strategies and technologies currently developed for the reduction of CO_2 emissions generated through the production of Portland cement.

2. PORTLAND CEMENT PRODUCTION

There are four types of cement production processes which are as follows: wet, semi wet, dry is the semi dry. But all processes follow basically the same manufacturing steps. In all the processes, there is the extraction of the raw materials, the mixing, the grinding and the heating of the same ones in the oven for the formation of the clinker (FARAG, 2012).

In the wet process during the grinding of raw materials, water is added, forming a paste that is taken to the oven, it needs a high consumption of thermal energy to allow its evaporation. This method was used in manufacturing because it is simpler and does not require particulate material filtering equipment (SAVAS, 2015). Already in the process via dry, the mixture is ground and added to the dry oven, in the form of powder without any addition of water. In grinding processes there are equipment for capturing and filtering the particulate material that is released (FELLAOU, S., BOUNAHMIDI T., 2017).

The clinker process consists of the burning of the mixture of raw materials, known as raw, which causes the chemical reactions that take place in the kiln at an average temperature of 1450 ° C of the solids, forming the clinker. Soon after, the clinker undergoes a rapid cooling process (KOLIP, 2010). Figure 1 shows the steps for the production of Portland cement.

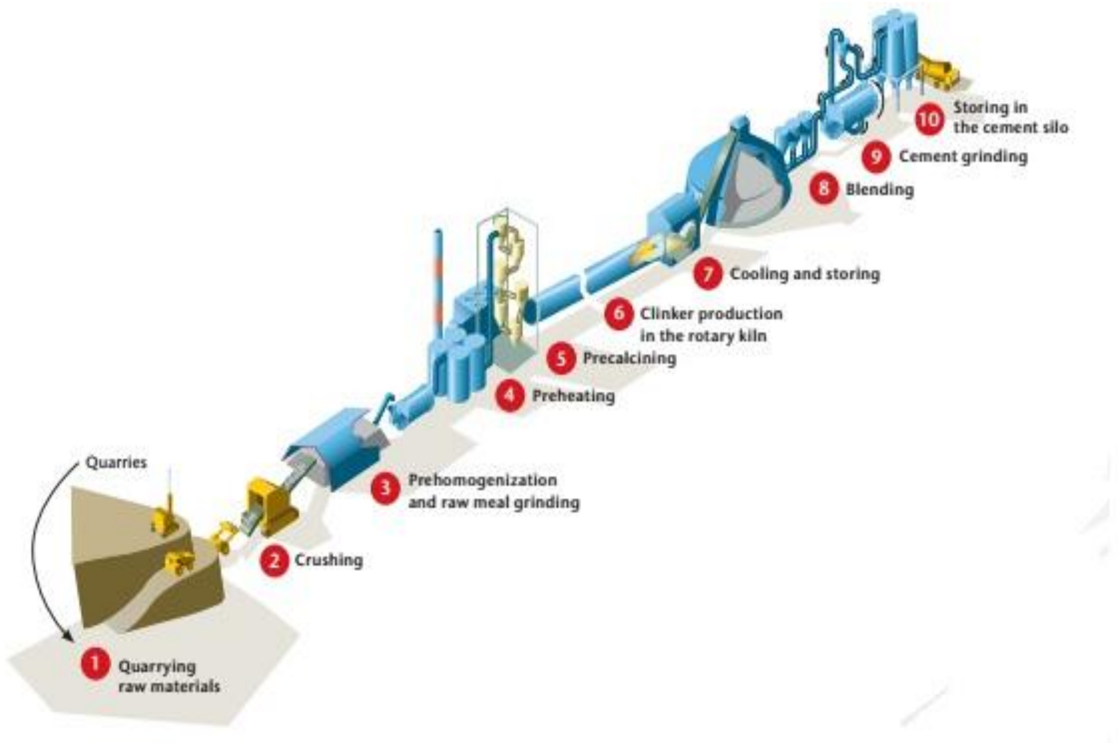

Figure 1. Shows the steps for the production of Portland cement.
Source: IEA (2009).

3. GLOBAL AND POTENTIAL STRATEGIES FOR THE MITIGATION OF CO_2 EMISSIONS

3.1 Energy Efficiency

The best energy efficiency is achieved through the modernization and construction of new cement plants that generally use more modern equipment available in the market. This equipment, despite having a high installation cost, promotes an economy in the consumption of electric and thermal energy.

The grinding process of raw materials and solid fuels presents a high consumption of electric energy. In Brazil, the vertical roller mill model has been used, since it has lower operating costs and has an energy consumption of about 40% less than the ball mill. Compared to the other models of traditional mills the one that presents displays greater electrical energy efficiency is the grinding mill of rollers of high pressure (BELATO, 2013).

With the use of six-stage preheaters, the residual heat of the exhaust gases from the rotary kiln is achieved, thus reducing the specific heat consumption and a higher thermal efficiency (KARELLAS S. et. al., 2013).

3.2 Active Additions

The active additions are the raw materials with binder characteristics that are mixed to the clinker in the grinding phase, thus generating the various types of Portland cement without losing the final quality of the cement. Currently the most used additives are waste from industrial activities, thus giving a correct destination to these industrial wastes and also reducing the consumption of thermal energy and CO_2 emissions. The most commonly used additions are as follows: gypsum, limestone, slag, fly ash, pozzolana and others (RAMOS, 2015).

The choice of the raw material to be chosen as an additive will depend on several factors, which are the following: availability, price, chemical composition, current legislation, among others. In Brazil, all the contents of active additions in the clinker are governed by ABNT standards (RAMOS, 2015). Table 1 shows the global average of the various types of active additions in cement production from 1990 to 2013.

Table 1. World mean of use of the various types of active additions in cement production from 1990 to 2013.

Region	Year (% mass of cements)	Gypsum (% mass of cements)	Limestone (% mass of cements)	Slag (% mass of cements)	Fly ash (% mass of cements)	Pozzolana (% mass of cements)	Others (% mass of cements)
World	1990	3,76	1,94	4,1	1,15	1,2	3,81
	2000	4,26	3,88	3,77	1,64	1,62	1,64
	2005	4,4	5,29	4,15	2,67	1,65	1,24
	2006	4,57	5,33	4,45	3,14	1,69	1,06
	2007	4,6	5,66	4,7	3,41	1,9	1,01
	2008	4,58	5,82	4,92	3,7	1,96	1,04
	2009	4,45	6,1	4,5	4,3	2,08	1,06
	2010	4,52	6,21	4,6	4,38	2,05	0,97
	2011	4,49	6,44	4,85	4,31	1,95	0,95
	2012	4,29	6,7	5,09	4,24	2,14	0,86
	2013	4,24	7	4,91	3,95	2,01	0,98

Source: WBCSD (2017).

As shown in Table 1, the use of the various types of additions has increased the production of Portland cement. Since gypsum is the only addition, it is always present in Portland cement whose function is to regulate the time of hardening.

3.3 Coprocessing

The coprocessing technique consists in the burning of industrial waste and environmental liabilities to replace the raw materials to be used as active additions. Waste which is used as secondary or alternative fuels because of its calorific value, by reducing the use of conventional fossil fuels, such as coal and petroleum coke. In the world industrial wastes such as blast furnace slag and ash from coal burning are used as active additions for the purpose of reducing the use of conventional raw materials (RAHMAN, A. et al., 2015).

Emissions of CO_2 generated through the burning of fuels can be reduced by using alternative fuels that have a low carbon content in comparison to fossil fuels. It is important to highlight that, in addition to using industrial waste and environmental liabilities for raw material substitution, coprocessing is an alternative in comparison to disposal of waste in landfills and incineration, characterizing, unlike these, the consumption of large volumes of waste without generating new environmental liabilities (KADDATZ, K. T. et. al. 2013). Table 2 shows the worldwide rate of fossil fuels and alternative fuels from 1990 to 2013.

Table 2. World rate of use of fossil and alternative fuels from 1990 to 2013.

Region	YEAR (% total energy)	Fossil and mixed wastes (% total energy)	Biomass (% total energy)	Fossil fuel (% total energy)
World	1990	1,66	0,3	98
	2000	4,37	0,84	94,8
	2005	5,65	2,33	92
	2006	6,79	2,76	90,4
	2007	7,3	2,74	90
	2008	7,72	3,09	89,2
	2009	8,42	3,37	88,2
	2010	8,93	3,3	87,8
	2011	9,17	4,04	86,8
	2012	9,47	4,85	85,7
	2013	9,64	5,63	84,7

Fonte: WBCSD (2017).

According to Table 2, it is possible to observe that the use of alternative fuel has been increasing, resulting from the creation of energy policies that encourage the use of the mixture of fossil fuels with alternatives, thus forming a blend that is burned in rotary kilns.

4. CASE ANALYSIS

The analysis consists of using real operational data from a cement plant, analyzing CO_2 emissions in two cases. In case study 1, the clinker furnace operates only on fossil fuels, which are: coal and petroleum coke. In case study 2, a mixture of fossil and alternative fuels will be used which are: coal, petroleum coke and tire.

Table 3 shows the percentage of fuel used in the case studies. Table 4 shows the chemical composition of fuels by mass percentage. Now Table 5 shows the composition of the raw material per mass percentage.

Table 3. Percentage of fuel used in the case studies.

Fuels	Case Study 1	Case Study 2
Petroleum Coke	70	50
Mineral Coal	30	35
Scrap Tires	-	15

Source: AUTHOR.

Table 4. Chemical composition of fuels by mass percentage.

Components	Petroleum Coke (%)	Mineral Coal (%)	Scrap Tires (%)
C	91,95	67,87	72,30
H	3,63	4,63	7,10
S	0,79	0,35	1,54
N	2,63	1,44	0,36
O	0,89	8,50	5,00
PCI (kJ/kg)	34930	28000	32850

Source: BELATO (2013); USGS (2017).

Table 5. Composition of the raw material by percentage of mass.

Components	%
$CaCO_3$	77,14
SiO_2	14,58
Al_2O_3	2,78
Fe_2O_3	2,61
$MgCO_3$	2,43
SO_3	0,10
Na_2O	0,16
K_2O	0,20

Source: PAREEK (2017).

The main parameters for the kiln-operated cement plant equipped with six stage preheaters are shown in Table 6 (SINGH, R et al., 2017).

Table 6. Parameters used in the case studies.

Standard Parameter	Value
Mass flow of clinker (ton/day)	5000
Specific fuel consumption (kJ/kg clinker)	2872
Initial fuel temperature (°C)	25
Clinker outlet temperature from rotary kiln (°C)	1450
Clinker outlet temperature from cooler (°C)	120
Pre-heater six stages exhaust gases temperature (°C)	278
Hot air exhaust temperature (°C)	278
Cooling air temperature (°C)	25
Stack dust temperature (°C)	278
Oxygen free in calciner (dry basis) (%)	4.36
Oxygen free in rotary kiln (dry basis) (%)	3.6

Source: SINGH, R et al. (2017).

This system was subdivided into four control volumes, one control volume for the preheater, one for the precalciner, one for the clinker rotary kiln, and one control volume for the clinker cooler, as can be observed in Figure 2.

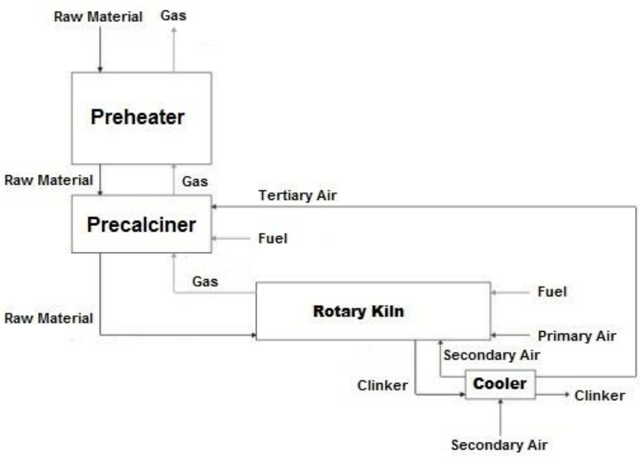

Figure 2. Block diagram of the Portland cement manufacturing process.
Source: AUTHOR.

5. RESULTS

The main objective of the paper is to analyze the carbon dioxide emissions generated by the chemical reactions of the raw material and by the combustion of fuels in the production of Portland cement. Figure 3 shows the graph with the results obtained from the two case studies.

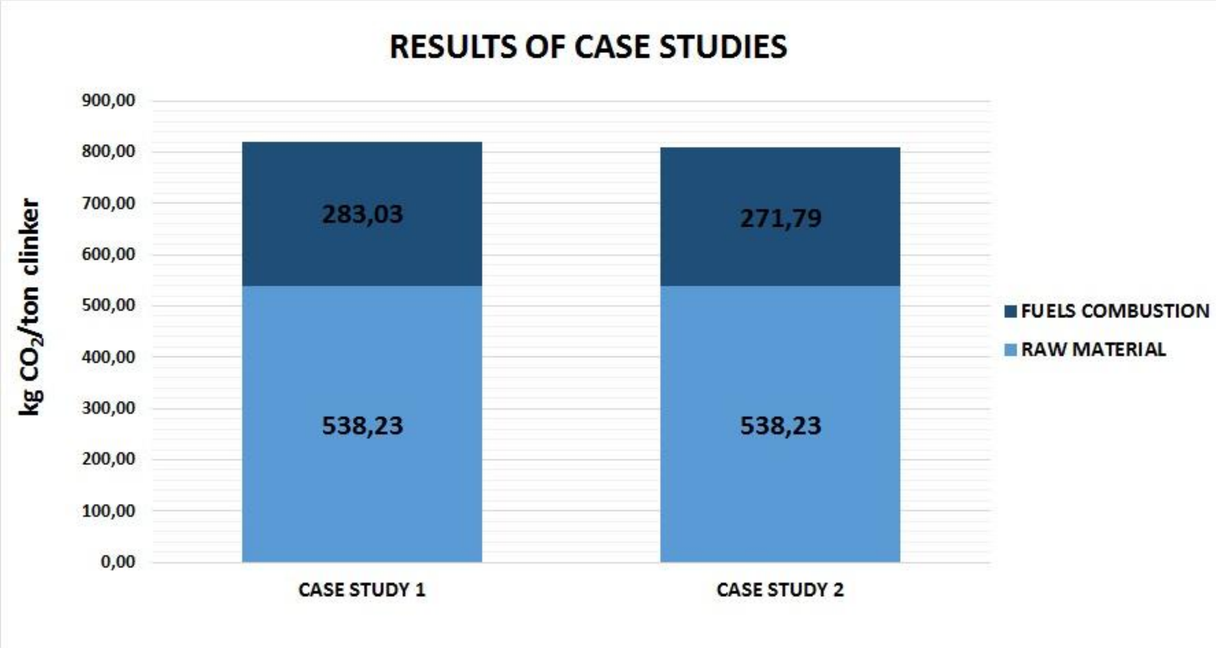

Figure 3. Graph with the results obtained by the two case studies.
Source: AUTHOR.

According to the results, the main source of CO_2 emissions is derived from the chemical dissociation reactions of $MgCO_3$ and $CaCO_3$, corresponding to about 60% of the total CO_2 emitted during the cement production process. Since the raw material emissions results, the raw material has presented little variation. With respect to the CO_2 emitted from the combustion of fuels, study 1 showed the highest CO_2 emission, approximately 4% higher than the case study 2. Considering 24 hours of daily work, with a clinker production of 5000 tons per day, represents a reduction in the CO_2 emission of 56,2 ton of CO_2 per day.

6. CONCLUSION

Considering the results of the model presented for the different mixtures of fuels, the emission results from 810 to 821 kg of CO_2 per ton of clinker were obtained for the two case studies. Since study 1 was the one that presented the highest CO_2 emission, approximately 4% higher in relation to fuel combustion than the case study 2.

Thus, a strategy to reduce it, would be the use of equipment with more energy efficiency, for example, the six-stage preheaters where one can get a better use of the residual heat of the exhaust gases of the rotary kiln that was used in this work. It can also be concluded that when burning used tires as an alternative fuel in coprocessing, there is a reduction in the amount of CO_2 emitted by the clinker manufacturing process, with consequent reduction of process cost. In addition, there will be a decrease in the consumption of fossil fuels during the clinker production process.

7. ACKNOWLEDGEMENTS

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