CONTROLLED RANDOM SEARCH MODIFIED ALGORITHM IN THE PORTLAND CEMENT PRODUCTION WITH CO-PROCESSING

Ricardo Carrasco Carpio, ricardocarpio@cefetbambuí.edu.br
IFET –MG – Federal Institute of Educationm Science and Tecnology of Minas Gerais
Ana Carla de Souza Masselli Bernardo, anacarlasz@unifei.edu.br
Federal University of Itajubá, MG, Brazil – PO Box: 37500-903
Nelson Manzanares Filho, nelson@unifei.edu.br
Federal University of Itajubá, MG, Brazil – PO Box: 37500-903
Rogério José da Silva, rogeriojs@unifei.edu.br
Federal University of Itajubá, MG, Brazil – PO Box: 37500-903

Abstract. *Nowadays the high degree of the industrial activity as well as the increasing society life standard have been accompanied by a growing waste generation which represents one of the most serious environmental problems. The Portland cement industry is an energy consumption intensive industry. The Portland cement is resulting of mixture of raw materials such as limestone, clay, sand and others. The final product is obtained in high temperature (1450°C). Traditionally, the fuels used in the cement industry are coal, fuel oil, natural gas, petroleum coke and wastes with secundary fuels. The fuels (primary and secondary) must present chemical composition in order not to influence the stage of clinker production or clinkerization.The process of Portland cement production allow the introduction of very fuels. The possibility use of some industrial wastes in the cement production, as an alternative source of secondary raw materials, as well as of alternative secondary fuels has been a viable path to reduce the cement production cost. The main concern about the use of these fuels is the effects in the cement quality and the possible environmental impacts that they can cause. The difficulty is to know the optimum mixture these fuels. Through an optimization model in the Controlled Random Search Modified Algorithm (the algorithm is effective in searching for global minimum of a multimodal function, with or without constraints) is possible to analyze the influence those wastes in the production cost function the restrictions equations in the cement production.*

Keywords: *Portland Cement, Co-Processing, CRSA-VBR, Production Cost.*

1. INTRODUCTION

Portland cement is a manufactured product made by blending different raw materials and firing them at a high temperature in order to achieve precise chemical proportions of lime, silica, alumina and iron in the finished product. Therefore, Portland cement is essentially a mixture of calcium silicates and smaller amounts of calcium aluminates. The Portland cement industry is an energy consumption intensive industry. Clinker production is the most energy-intensive stage in cement production, accounting for over 90% of total industry energy use. Clinker is produced by burn in Rotary kilns (Worrel *et. al.,* 2000, Sprung et. al., 1993).

The fuels used in the cement industry are mineral coal, fuel oil, natural gas and petroleum coke. Due to the high temperatures of the production process (1450°C), the used fuel should have high calorific power. The fuel burning in high temperature leads to the formation of the pollutant NOx. The emission of this pollutant is controlled by environmental law.

To reduce the cost of production, the cement industries are using secondary fuels. The technique is called Co-processing (Bathy, 1995). In the Co-processing, the fuels are residues of several industries whose calorific power is compatible with the traditional fuels.

The use of residues in the cement production should be controlled for not causing damages to the environment. In recent years, there has been an increasing tendency to use industrial wastes as supplemental raw materials.

The reactions raw materials and fuels can be changing by the introduction into process of substances know as mineralizers. The mineralizers increases the acceleration of the chemical reactions, promotes the decrease of the fuel consumption and contributes for low emission the pollutant thermic NOx.

In the Portland cement production many variables are involved in the process. The cement production with secondary fuel and raw materials should be accomplished in a controlled way.

To obtain a reduced cost of production without harming the quality and the environment, optimization techniques can be used.

Among the population set-based direct search methods for global optimization problems, Controlled Random Search Algorithms (CRSA) are probably the less known ones in the engineering community. In comparison with Genetic, Differential Evolution and Swarm Particle Algorithms, there are relatively few works about CRSA. However, their ease of implementation, fastness and good results obtained in some complex practical problems suggest that these algorithms could be used as a general purpose global optimization technique for continuous functions (Albuquerque *et. al*., 2007). Since the basic CRSA was proposed by Price (1977), some studies have been done in order to improve its robustness and convergence rate. Manzanares Filho *et al. (2005)* modified the CRS6 in a version named CRS-VBR. This version makes use of the function variability around the current best point aiming to balance diversification and intensification of searching.

In this work, the incorporation of mineralizers and wastes and its implication in Portland cement Production is analyzed by the optimization technique CRSA-VBR.

2. PORTLAND CEMENT PRODUCTION

The most common raw materials used for cement production are limestone, chalk and clay. Most commonly the main raw material, the limestone or chalk, is extracted from a quarry very close to the plant. The collected raw materials are selected, crushed, ground, so that the resulting mixture has the desired fineness and chemical composition for delivery to rotative kiln. The raw materials enter in the kiln and they react forming the compounds C_3A, C_4AF C_2S and C_2S that create the clinker, the main component of the Portland cement (Silva, 1994). The stages of Portland cement production are showed in the Fig.1.

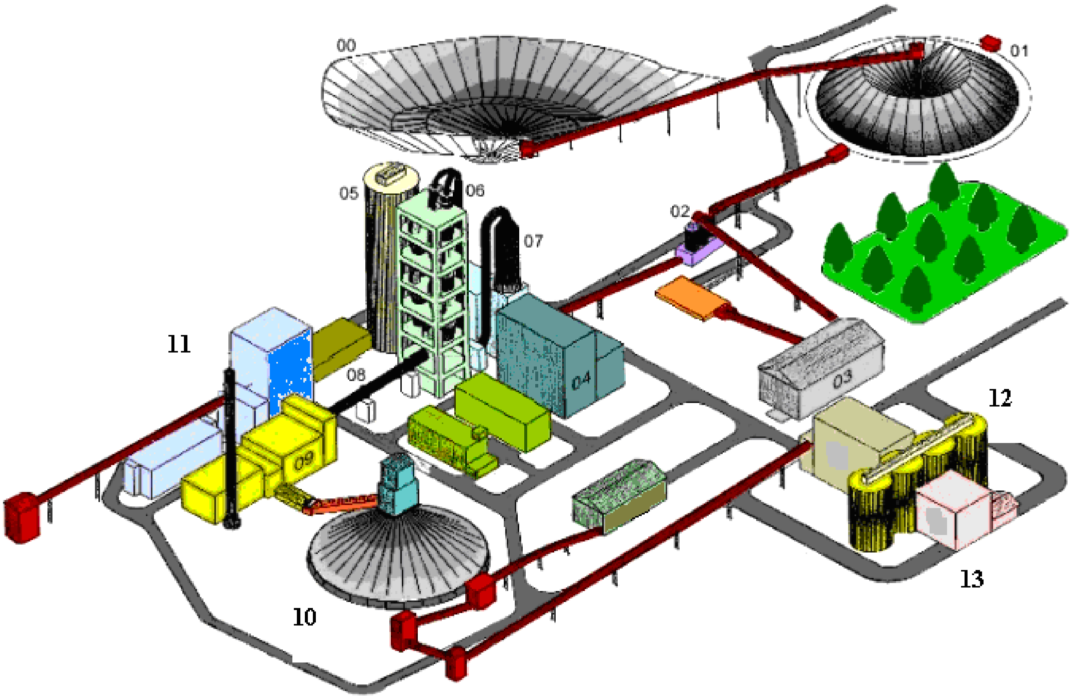

Figure 1. Stages of the Portland Cement Production: 00- Natural deposit of ores and crushering, 01- storage of limestone; 02 and 03- additives storage; 04- Raw mill; 5- Raw materials Storage; 06- Preheaters; 07- Cyclone; 08- Rotary kiln; 09- Clínker Cooler; 10- Storages of clinker and gypsium; 11- Fuels; 12-Cement Storage; 13- Package and expedition.

In the sintering (or clinkering) zone, the combustion gas reaches a temperature of 1800–2000°C. Once the clinker is formed it is cooled rapidly in order to ensure the maximum yield of alite (tricalcium silicate), an important component for the hardening properties of cement.

After cooling, the clinker is stored in the clinker dome or silo. The material handling equipment used to transport clinker from the clinker coolers to storage and then to the finish mill is similar to that used to transport raw materials.

The production of blended cements involves the intergrinding of clinker with one or more additives (fly ash, pozzolans, blast furnace slag, silica fume, volcanic ash) in various proportions.

In the Portland Cement production the Sílica, Alumina-Iron Modulus and the Lime Saturation Factor should be controlled. The modulus when controlled represent quality and reduction of consumption of energy in the production.

Silica Modulus. The Silica Modulus has influence on the burning of raw materials, clinker granulometry and liquid phase. This modulus is within the interval 2.3 and 2.7. The Silica Modulus (Eq. 1) is obtained as the ratio of the silicates oxide to the sum of the ferric oxide and alumina oxide.

$$MS = \frac{SiO_2}{Fe_2O_3 + Al_2O_3} \tag{1}$$

Alumina-Iron Modulus. This relationship influences mainly on the burning process, by acting on speed of the reaction of limestone and silica. The values for this modulus are within the interval 1.3 and 2.7.

$$MA = \frac{Al_2O_3}{Fe_2O_3} \tag{2}$$

Lime Saturation Factor. A high factor of lime saturation causes burning difficulties. Acceptable values for this factor are between 0.9 and 1.

$$LSF = \frac{CaO}{2,8SiO_2 + 1,1Al_2O_3 + 0,7Fe_2O_3} \tag{3}$$

The industry of Portland cement comes increasing its production every year. In 2005, they were produced 2.15 billion ton of cement in the world (CEMBUREAU, 2008). The introduction of residues as fuel or as secondary raw material it already substitutes about 25 percent of the total consumption.

2.1- Pollutants Emissions in the Cement Manufacture

The cement industry is a very pollutant source when the production process is not controlled. Thus, the environmental laws come increasing the control of pollutant as carbon dioxide, sulfur and nitrogen oxides.

The sulfur oxides are found in the raw material in SO2 form and also in the fuel. Depending on the sulfur quantity in the raw material, the use of combustible should to be analyzed for the emission of this pollutant does not overtake the limits allowed by law (Miller *et. al.* 2001).

The production of cement is an energy-intensive process that results in the emission of carbon dioxide from both the consumption of fuels (primarily for the kiln) and from the calcination of limestone.

Nitrogen oxides, NOx, is formed during fuel combustion by oxidation of the molecular nitrogen of the combustion air (thermal NO) as well as the nitrogen compounds in the fuels and raw materials (CEMBUREAU, 1999).

In Portland cement manufacturing, conditions favorable for formation of NOx are reached routinely because of high process temperatures.

The use of blended cements is a particulary attractive efficiency option since the intergrinding of clinker with other additives not only allows for a reduction in the energy used (and carbon emissions) in clinker production, but also corresponds to a reduction in carbon dioxide emissions in calcination as well.

The fuel cost and environmental standards encouraged cement manufacture world-wide to evaluate in Technologies for reduce this emissions.

2.2. Fuels Used in the Cement Industry

Traditional kiln fuels are mineral coal, petroleum coke, oil and natural gas. Due to the high cost of the derived products of petroleum, the fuels more used in the cement industry today they are petroleum coke and the coal. Materials like waste oils, plastics, auto shredded residues, waste tyres and sewage sludge are often proposed as alternative fuels for the cement industry. Also, all kinds of slaughterhouse are offered as fuel nowadays (Kaantee *et. al.*, 2004).

To make possible the use of several of alternative fuels in the Portland cement production, it is necessary to know the composition of the fuel. The choice is normally based on price and availability. The energy and ash contents are also important, as are the moisture and volatiles contents (Kaantee *et. al.*, 2004). Somehow, they should all be fed into the burning chamber of the process.

One of the main methods for utilising waste is its use as an energy source. Waste is only suitable for use as a fuel if it has a chemical energy content. This energy content depends most of all on the size of the (organic) combustible fraction and on the moisture content. To better employ the chemical energy contained in wastes, alternative fuels have been developed which are mixtures of different wastes.

The clinker burning process is well suited for the use of various alternative fuels because of the long residence times in both rotary kiln and gas channels.

2.3. Mineralizers

Mineralizers are inorganic compounds which accelerate the process of reactions in solid phase, liquid phase and solid–liquid interface. They lead to major impacts on the determination of burning zone, the composition and formation of clinker minerals.

The effect of different mineralizers on the decrease of burning temperature of Portland clinker was the object of many researches. Fluorosilicates improve the chemical activity of clinker mixture minerals and accelerate the reactions of clinkerization at low temperatures (1300–1350 ◦C). Fluorides, according to different authors, have also a favorable action on the formation of clinker minerals by decreasing the thermal energy consumption (Kacimi *et. al.,* 2006).

The cost of substances mineralizadoras is elevated. Her use is viable when it is found in the residue. The temperatures that occurring the reactions with or without mineralizers are showed in Tab. 1.

Table 1: Chemical Reactions that occur with or without mineralizers.

Chemical Reactions	Temperature with Mineralizers (°C)	Temperature without Mineralizers (°C)
Raw materials	60	60
$MgCO_3 \rightarrow MgO + CO_2$	60 and 660	60 and 660
$CaCO_3 \rightarrow CaO + CO_2$	660 and 800	660 and 800
$3CaO + Al_2O_3 \rightarrow C_3A$	1100	1100
$4CaO + Al_2O_3 + Fe_2O_3 \rightarrow C_4AF$	1100	1100
$2CaO + SiO_2 \rightarrow C_2S$	1250	1250
$3CaO + SiO_2 \rightarrow C_3S$	1350	1450

3. MATERIALS AND METHODS

The high cost of energy and the high consumption of fuel requested in the process of clinkerization are relevant factors for the cement industry. The main objective of the model of optimization is to know the optimal point for the cost of Portland cement production with Controlled Random Search Algorithm in the version CRS-VBR.

3.1- Controlled Random Search Algorithm

The first version of the CRSA was proposed by Price (1977). Since the basic CRSA was proposed, some studies have been done in order to improve its robustness and convergence rate. Ali *et al.* (1997) presented a summary of the principal versions of CRSA developed until 1997 and also proposed a new version named CRS6/CRSI. All these CRSA versions were compared in various test problems and the proposed version appeared to be the most promising in that work. Lately, Ali and Törn (2004) compared the CRSI with Genetic and Differential Evolution Algorithms in several benchmark test problems. The results have shown that the CRSI would deserve improvements for increasing its robustness in finding global optimizers. But in terms of function evaluations, the versions CRS6/CRSI already proved to be competitive. A study of the convergence behaviour of CRSA was recently presented by Hendrix *et al.* (2001). Manzanares Filho *et al.* (2007) modified the CRS6 in a version named CRS-VBR. This version makes use of the function variability around the current best point aiming to balance diversification and intensification of searching.

This proposed algorithm, named CRS-VBR (Controlled Random Search using Variability Based Reflections), makes a selective use of the quadratic interpolations of CRSI (or CRS6) and takes into account the function variability around the current best point. Like in CRSI, three distinct points are taken from the current population P: the best point, $\mathbf{l}$, and two other ones at random. Then a mean function value and a local variability measure around the best point are calculated and used for evaluating the trial point.

The basic CRSA for minimization can be described in six steps as follows (adapted from Al. et.a l., (1977) and Ali et. al., (2004):

1. Generate an initial population P of N random points in S: $P = \{\mathbf{x}1, ..., \mathbf{x}N\}$. Compute the function values of these points in an indexed way. Determine the worst point, $\mathbf{h}$, and the best point, $\mathbf{l}$, i.e., those points in P with the highest and the lowest function values, fh and fl, respectively. If a stopping criterion is already satisfied, then stop (for example, stop if $fh - fl < \varepsilon$, where ε is a given tolerance).
2. Generate a trial point $\mathbf{p}$ for replacing the worst point, $\mathbf{h}$.
3. If $\mathbf{p}$ is infeasible ($\mathbf{p} \in S$), go to step 2 (or alter $\mathbf{p}$ to be feasible).
4. Evaluate $fp = f(\mathbf{p})$. If $\mathbf{p}$ is unsatisfactory ($fp \geq fh$), go to step 2.
5. Update the set P by replacing the current worst point by the trial point: ($P \leftarrow P \cup \{\mathbf{p}\} / \{\mathbf{h}\}$). Find $\mathbf{h}$ and fh in new P. If $fp < fl$, then set $\mathbf{p}$, fp as new $\mathbf{l}$, fl.
6. If a stopping criterion is satisfied, stop; else go to step 2.

The two main differences among the available CRSA versions are related to (*i*) the generation mode of the Trial point (step 2) and (*ii*) the optional access to a local search phase whenever the best point is the newest in the population (when $fp < fl$ in step 5). It should be noted that all versions assume that $N >> n$ and it is typically suggested $N = 10(n + 1)$. These issues have motivated the study of possible improvements in the CRS-VBR algorithm. Basically, they intent to satisfy the following requests: (i) a better control of the quadratic interpolations usage of CRSI; (ii) a more selective application of the variability based reflections of CRS-VBR in order to provide a more exploratory searching in the initial phases of the optimization process and reduce the chance of premature population contractions; (iii) an improved feasibility forcing scheme based on the function variability.

The chemical composition of the raw material and the amount of inlet (in percentage) in the process of cement production is described in the Tab. 2. The wastes introduced in the process as secondary raw materials are presented in the Tab. 3. The conventional and secondary fuels are showed in Tab. 4.

Table 2: Chemical composition of the raw-materials for Portland cement production

Raw Material	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO
Limestone	48.94	5.83	1.39	0.62	0.83
Sand	3.13	53.67	22.0	6.48	1.22
Clay	0.94	92.22	3.61	3.36	0.23
Iron Oxide	0.75	3.53	1.89	90.18	0.20

Table 3: Chemical composition of the secundary raw-materials for Portland cement production.

Composition %	Residue 01	Residue 02	Residue Phosphogypsium
Ash	85.06	82.06	-
S	0.33	0.08	-
Cl	0.072	0.082	-
F	12.23	0.401	0.22
SiO_2	18.23	42.03	0.84
Al_2O_3	44.03	16.35	0.04
Fe_2O_3	2.69	12.25	0.39
CaO	5.01	10.41	23.87
MgO	3.02	2.64	0.03
K_2O	0.55	1.90	-
Na_2O	11.05	1.38	-
SO_4	-	-	54.47

Table 4: Chemical composition and calorific power of the Fuels

Composition %	Coal Residue	Petroleum Coke (Brazil)	Mineral Coal	Fuel Waste
S	0.08	0.73	-	-
H	2.03	3.16	1.59	3.11
C	69.01	90.76	57.67	69.56
N	0.03	1.46	0.34	1.16
Ash	15.32	0.40	10.16	57.21
SiO2	40.99	5.15	34.88	7.69
Al2O3	13.31	2.90	14.93	7.17
Fe2O3	20.95	83.62	37.11	12.10
CaO	12.94	3.72	8.2	8.56
MgO	2.02	0.44	0	1.53
Na2O	0.59	0.29	0.3	0.77
K2O	3.87	0.36	1.1	0.24
P2O5	1.44	0.28	-	-
SO3	0.91	2.72	-	-
TiO2	1.15	0.16	-	-
MnO	1.48	-	-	-
SrO	0.14	0.05	-	-
ZrO2	0.08	-	-	-
Cl	0.06	-	-	-
ZnO	0.06	-	-	-
MoO3	-	-	-	-
V2O5	-	0.32	-	-
PCI (Kcal/kg)	6035	8375	4910	3375

4- NUMERICAL MODEL

4.1 - The optimization problem

The purpose of the present work is to provide an analysis of an optimal point through optimization problem with multi-objective functions. The function cost of cement production considers the cost of raw materials, residues as secondary raw material, traditional and secondary fuels and energy consumption requested for grinding of clinker.
Objective function: The raw materials costs can be writen based on the costs of limestone x1 (R$34.0/ ton), clay x2 (R$0.93/ton), sand x3 (R$13.08/ton), iron oxide x4 (R$100.0/ton), mineral coal x5 (R$200.0/ton), Petroleum Coke x6 (R$160.0/ton). The residues x7 and x8 are considering secondary raw materials. To introduce the residues as secondary raw materials, the cement industries they receive on average R$20.0 per ton burned. The residue x9 (phosphogypsium) are considering the simbolic price R$1.00/ ton . The residues x10 and x11 are considering residues of the high calorific power. The cement industry receive R$31.0/ton. The price of the electric power supplied by the concessionary represents a cost of R$0.094/kWh. However the objective function is showed below:
The model is used to optimise process control and the use of alternative fuels while maintaining clinker product quality. It is also used to predict the possible changes in the combustion, precalcining and clinker formation processes. The waste tyre fuel for example also acts as a raw material in the clinker manufacturing process. Calculations with different descriptions of the clinker chemistry were made and evaluated against real process data where possible.

Function

$$f_1 = 34.0x_1 + 0.93x_2 + 13.08x_3 + 100.0x_4 + 200.0x_5 + 160.00x_6 - 20.0x_7 - 20.0x_8 + 1.00x_9 - 31.00x_{10} + 140.00x_{11} + (0.094.(5.76.(MS) - 5.82).\exp((-0.2.(MS)+0.98).4 \quad (4)$$

$$MS = \frac{13.19x_1 + 60.11x_2 + 95.10x_3 + 9.17x_4 + 4.21x_5 + 0.84x_6 + 42.03x_7 + 18.23x_8 + 0.84x_9 + 7.69x_{10} + 16.39x_{11}}{6.62x_1 + 27.7x_2 + 2.99x_3 + 76.32x_4 + 2.49x_5 + 0.89x_6 + 28.60x_7 + 46.72x_8 + 0.43x_9 + 19.27x_{10} + 5.2x_{11}} \quad (5)$$

$$62 \le 41.96x_1 + 0.05x_2 + 0.47x_3 + 1.74x_4 + 0.51x_5 + 0.67x_6 + 10.41x_7 + 5.01x_8 + 23.87x_9 + 8.56x_{10} + 5.82x_{11} \ge 68 \quad (6)$$

$$19 \le 13.19x_1 + 60.11x_2 + 95.10x_3 + 9.17x_4 + 4.21x_5 + 0.84x_6 + 42.03x_7 + 18.23x_8 + 0.84x_9 + 7.69x_{10} + 16.39x_{11} \ge 25 \quad (7)$$

$$3.5 \le 4.87x_1 + 21.42x_2 + 1.98x_3 + 6.64x_4 + 1.5x_5 + 0.47x_6 + 16.35x_7 + 44.03x_8 + 0.04x_9 + 7.17x_{10} + 2.39x_{11} \ge 6.5 \quad (8)$$

$$1.0 \le 1.75x_1 + 6.28x_2 + 1.01x_3 + 69.68x_4 + 0.99x_5 + 0.42x_6 + 12.25x_7 + 2.69x_8 + 0.39x_9 + 12.10x_{10} + 2.81x_{11} \ge 5.0 \quad (9)$$

$$2.0x_1 + 1.86x_2 + 0.43x_3 + 0.60x_4 + 0.09x_5 + 0.13x_6 + 2.64x_7 + 3.02x_8 + 0.03x_9 + 1.53x_{10} + 0.29x_{11} \le 6.5 \quad (10)$$

$$-7.33x_1 - 25.76x_2 + 85.83x_3 - 227.42x_4 - 3.51x_5 - 1.92x_6 - 46.63x_7 - 126.60x_8 - 0.49x_9 - 52.05x_{10} + 0.27x_{11} \ge 0 \quad (11)$$

$$4.68x_1 + 14.68x_2 - 87.03x_3 + 196.89x_4 + 2.51x_5 + 1.56x_6 + 35.19x_7 + 107.91x_8 + 0.32x_9 + 44.34x_{10} - 2.35x_{11} \ge 0 \quad (12)$$

$$-1.25x_1 - 0.56x_2 - 1.56x_3 - 237.24x_4 - 1.96x_5 - 1.0x_6 - 26.52x_7 + 34.62x_8 + 1.33x_9 - 35.18x_{10} - 7.45x_{11} \ge 0 \quad (13)$$

$$-1.63x_1 - 9.80x_2 - 0.11x_3 + 122.27x_4 + 0.33x_5 + 0.31x_6 + 6.31x_7 - 19.05x_8 + 0.68x_9 + 15.22x_{10} + 2.81x_{11} \ge 0 \quad (14)$$

$$-4.60x_1 - 209.95x_2 - 287.54x_3 - 85.74x_4 - 14.61x_5 - 2.70x_6 - 143.93x_7 - 103.45x_8 + 21.01x_9 - 31.98x_{10} - 48.20x_{11} \ge 0 \quad (15)$$

$$-0.62x_1 + 186.40x_2 + 255.24x_3 + 75.93x_4 + 12.91x_5 + 2.32x_6 + 126.62x_7 + 91.28x_8 - 21.33x_9 + 27.43x_{10} + 42.14x_{11} \ge 0 \quad (16)$$

$$20.557x_5 + 35064x_6 + 15525x_{10} + 25267x_{11} = 3200 \quad (17)$$

$$0.36x_1 + 0.85x_2 + 0.01x_3 + 0.55x_4 + 0.60x_5 + 0.20x_6 + 1.38x_7 + 11.05x_8 + 0.0x_9 + 0.77x_{10} + 0.15x_{11} \le 1.0 \quad (18)$$

$$0.78x_1 + 3.40x_2 + 0.02x_3 + 0.16x_4 + 2.06x_5 + 0.80x_6 + 1.90x_7 + 0.55x_8 + 0.0x_9 + 0.24x_{10} + 3.0x_{11} \le 1.0 \quad (19)$$

$$0.0x_1 + 0.0x_2 + 0.0x_3 + 0.0x_4 + 0.03x_5 + 0.02x_6 + 0.08x_7 + 0.07x_8 + 0.0x_9 + 0.0x_{10} + 0.12x_{11} \le 1.0 \quad (20)$$

$$3.0 \le 0.83x_1 + 1.0x_2 + 0.01x_3 + 0.04x_4 + 1.26x_5 + 1.05x_6 + 0.08x_7 + 0.33x_8 + 0.0x_9 + 0.0x_{10} + 0.27x_{11} \ge 5.0 \quad (21)$$

The content of raw-materials such as CaO, SiO_2, Al_2O_3, Fe_2O_3 and MgO are limited in the composition of the clinker. The content of CaO must be between 62 and 67% to equations (6). The content of SiO_2 must be between 19 and 25% to Equation (7). The amount of Al_2O_3 must be between 2 and 9% to Equation (8). The equations (9) refer the amount of Fe_2O_3 between 1 and 5%. The maximum content of magnesium is limited in 6.5% Eq. (10). Typical percentages of these elements in clinker, expressed as oxides, are: CaO = 65 ± 3%, SiO_2 = 21 ± 2%, Al_2O_3 = 5 ± 1.5%, and Fe_2O_3 = 3 ± 1% (Chaterjee, 2004).

The equations (11) to (16) represent the restrictions of the modules of control of the mixture. this control guarantees the clinker quality. When it is used residues, the modules are altered. In this work the following data were considered:

• MS between 2,7 and 3,10;
• MA between 1,85 and 3,50;
• FSC between 95,7 and 107,8.

The total feeding of fuels must satisfy the specific heat consumption, presented in restrictions (17). The restrictions of Eq. (18) and Eq. (19) represent the acid oxide and the alkalis content in the raw material.

The amount of chlorine and súlfur in the Portland cement is showed in the restrictions (20) and (21).

5- RESULTS AND DISCUSSIONS

The technique CRSA – VBR is applicable to minimize the cost of Portland Cement Production. The results show that is possible the use of mineralizers and secondary raw materials in the Portland Cement Production.

With the introduction of the mineralizer (phosphogypsium), secundary raw material and secundary fuel are necessary reactions for the cement production happen in the temperature of 1.350°C (Bernardo *et. al.,* 2008). Besides, the decrease of temperature promotes the reduction of the clinkerization temperature and consequently the reduction of thermal NOx. Another advantage is the introduction of fuels with smaller calorific power.

In this work, the non-linear problem with objective function with linear constraints were presented. The compositions of the raw materials, fuels and mineralizers are taken as variables. The best value for the production cost and the amount of each variable is presented in the Tab. 5.

Table 5: Results of optimization

Function	**f_1(RS/ton of clinker)**
Production Cost	46.89
Variables	**%**
X_1	0.71
X_2	0.03
X_3	0.07
X_4	0.0001
X_5	0.02
X_6	0.05
X_7	0.01
X_8	0.005
X_9	1.30
X_{10}	0.02
X_{11}	0.032

Also, the amount of fuels used for clinker production with mineralizers was smaller than in the case without mineralizers, due to the decrease in the maximum clinkering temperature.

The results show that are possible to use the wastes such as secondary raw materials and fuels.

The use of this type of wastes has been well established, as can be seen in a recent work, in which the alternative use of massive amounts of phosphogypsum as a mineralizer was presented from Ozturk *et. al*., (2000).

The introduction of residues as raw material and fuel doesn't cross the limit of emissions of pollutant in the atmosphere. The amount of SOx and NOx is in agreement with the environmental laws.

In this work it was not considered the presents heavy metals in the residues. The introduction of these residues in larger amounts should be analyzed for not concentrating these metals in the cement.

Besides cost issues, mineralizers had lowered the kiln temperature and also had promoted the formation of C_3S, therefore improving the quality of the clinker. Finally, it must be pointed out that the use of certain type of secondary fuels, such as scrap tires, could also promote the decrease in the formation of pollutants, for example, the thermic NOx.

The combination of mineralizers and secondary raw materials and fuels could lead to a better solution for the Portland cement production.

For future works, the study of heavy metals in the residue should be investigated and on optimization problem will include another technique of global optimization and multicriteria optimization.

6. CONCLUSIONS

The CRS_VBR is applicable in the Portland cement Production.

The reduction of the temperature allows the consumption of fuel to be smaller. Also, with the reduction of the temperature, the use of fuels with small calorific powder is possible, and the reduction of Thermic NOx is verified in the process of Portland cement production.

The chemical compositions and burnability of these raw-materials and fuels (secondary) they were appropriate. The final cost and SOx and NOx emissions are smaller. These limits are acceptable for the environmental laws.

The study also indicates that a combination of mineralizers and residues show the most promising results. For future works, the study of heavy metals in the residue should be investigated.

In the numerical model, the final production cost is smaller when the introduce the secondary fuels and raw materials. The mineralizer (phosphogypsium) present other advantages, such as the lowering of the kiln temperature, the decrease the consumption fuels, and the improvement in the quality of the clinker.

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