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THE DEVELOPMENT OF A SOFTWARE APPLICATION IN THE CO-PROCESSING OF RESIDUE IN THE CEMENT INDUSTRY

Ricardo Carrasco Carpio, ricardocarpio@cefetbambui.edu.br
Federal Institute of Minas Gerais - Campus Formiga, Av. São Luiz Gonzaga s/n, Bairro São Luiz - Formiga - MG - CEP 35570-000

Marcone dos Santos Guimarães, marcone-samonte@hotmail.com
Ezequiel Antônio Barbosa, ezequiel_iii@yahoo.com.br
Mateus Rodrigues Costa, mateuscomp@gmail.com
University Center of Formiga - UNIFOR MG, Av. Dr. Arnaldo de Senna, 328 - Bairro: Água Vermelha - Formiga / MG

Abstract. *Recently, the Cement Industry has been searching for solutions concerning with the fuels used for clinker production taking account, the electricity consumed in the production process, the polluting emissions control and the use of active additions, keeping the final product quality, i.e., the cement. These solutions must attend the product quality requirements, the environmental restrictions and also allow reaching a lesser final production cost. This study is intended to develop a software application to optimize the dosage and homogenizing of the raw material and fuels in the clinker production. This study also intends to patent the developed software. Employing this software, it will be even possible to evaluate the effects of the used residues in the clinker quality, in the environment, in the costs generated, in the electrical energy consumption, aiming to guarantee a better kiln operation stability, the reduction of energy consumption and the minimization of the environmental impact. On the other hand, this software will be handy to the cement industry in making efficient evaluations of the different types of alternative fuels which can be used as a substitute of the traditional ones (co-processing). Java language will be used to develop the optimization software. Java language was chosen because is one of the most used computational language in industries and college facilities. It is versatile and platform independent which makes it handling easy.*

Keywords: *Java, Co-processing of Residues, Cement Industry, Optimization.*

1. INTRODUCTION

The industrial growth along with its waste residues increasing (hazardous or not) has been representing a challenge to be overcome and constitute one of the great problems related to the environment in the last years, mainly for the industries that generate hazardous residues. According to the Brazilian Association of Treatment, Recovery and Disposition of Special Residues Companies (Abetre), 2.9 million tons of hazardous industrial residues is generated annually in Brazil. Only 600 thousand tons, about 22%, receive appropriate treatment. The remaining 78% are deposited improperly in landfills without any type of appropriate treatment. "ABETRE, (2003)".

Co-processing is a solution that satisfies the current demands for environmental control "CONAMA, (1999)", because it is possible to take advantage of the thermal energy contained in the residues, avoiding the unnecessary burn of non renewable fossils, besides giving an appropriate destination of them.

The use of residues as fuels in the cement production is not new. This process is used thoroughly in Europe and in the United States, and every day is being more used in Brazil. In the USA, since 1969, several cement industries has been using residues as alternative inputs obtaining an annual economy around a million tons of coal "SITIVESP, (2002)".

With the co-processing, 100% of the industrial residues are destroyed without generating any liquid or solid effluent due to the burn. Also, the organic compositions are destroyed in the process due to the high burn temperature. The solids are kept in high temperature by several minutes, the necessary time for the clinker formation. Clinker is the main component of the cement, which is responsible for its hydraulic properties.

The clinker, a basic component of the Portland Cement, is obtained from the grinding, homogenization and burning (high temperatures 1450°C) processes inside the rotary cement kiln starting from a raw mix originating from the raw material: limestone, clay, sand, iron ore. The main chemical elements that constitute the clinker are: calcium oxide (CaO) and silica oxide (SiO_2), which react between themselves forming calcium silicates, which are the main actives components of the cement. A sketch of the manufacture process of the Portland Cement is shown on Fig. 1.

This work presents an arrangement for the mixture optimization of some residual wastes employed as alternatives fuels, such as: mineral coal, petroleum coke and used tires along with raw materials included in the cement process production. This mixture is employed in a rotary kiln, dry via, with four pre-heater stages for clinker production. However, the problem concerning with the mixture of these components is complex. The optimization procedure takes into account process restrictions such as specific heat consumption, cement quality and environmental impact. In this case, the mixture optimization in cement kilns is a problem with nonlinear cost function with linear constraints.

This paper intends to contribute to the study of optimization technique for mixture optimization in cement kilns. CRSA (Algorithm Controlled Random Search).

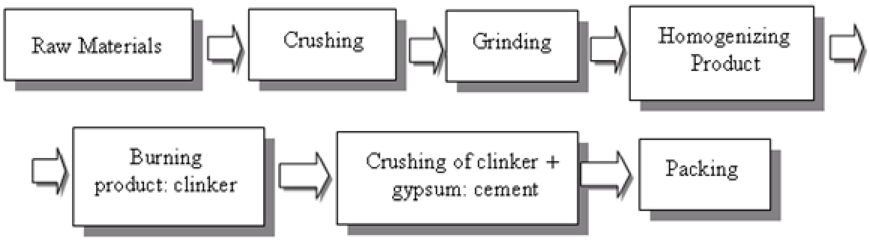


Figure 1. Process steps of the Portland Cement manufacture.

2. RESIDUES USED FOR THE CEMENT INDUSTRIES

The ASTM (American Society of Testing Materials) standards specify tests and procedures to assure the uniformity of the cement produced in the whole world. Before the product can be denominated "Portland Cement", it is necessary to prove that its chemical composition is kept within some specifications along with rigidity and granularity tests. In that way the quality of the cement is proven, regardless the materials and fuels used in its production.

Not all the residues should be used as supplemental fuel. A cement industry production line cannot burn dangerous residues that are highly corrosive, reagents or toxic, for instance, residues that contain chlorine in their composition. These products should be avoided because they can damage some equipments (piping and valves) and generate, most of the time, an acid gas denominated chloride hydrogen (HCl).

Other constraints should be included on the amount of metals incorporated to the clinker. Concentrations of certain metals above 0,1% can also affect cement cohesion and should be strictly controlled. Some examples of residues used in cement industries can be mentioned: the refine waste of lubricant oil, volatile ashes, carbon mill, tyres, tires scrapings, solvents, paints waste, among others "Santi, (1997)".

2.1 Alternative fuels in clinker kilns

A mixture of industrials residues can be used as alternatives fuels in clinker kilns, resulting in economical and environmental advantages, while keeping the quality standards of the final product. In order to use these alternative fuels, an analysis must be performed on the proportions of each residue type to be used. The analysis of the residue components will provide the optimum percentage of each residue type in the mixture.

The pollutants present in the residue, basically inorganic materials and heavy metals, combine with the silicates form the clinker in cement factories. The recycling process, in the form of co-processing in these kilns, assures that secondary residue will not be formed. However, these pollutants should be studied with criteria, in order to investigate the influence of the heavy metals incorporated by these pollutants might have on the characteristics and properties of Portland cement "Trezza and Scian, (2000)".

2.2 Chemical composition of fuels used for feeding clinker kilns

In order to establish the basic parameters for feeding the fuels in rotary clinker kilns, some essential parameters to formulate the optimization model must be obtained. For this purpose, initial data were gathered, related to the chemical composition of commonly used fuels (coal) and of alternative fuels (petroleum coke, and used tires). The ashes chemical composition was also obtained, especially the ones that are also part of the raw materials used in the clinker production. The chemical composition information, together with the calorific power (Lower Heating Value, LHV) of each one of these fuels and residues, is presented in Table 1.

3. MODELLING BUILDING

The modeling will employ optimization algorithms aiming to assure a better kiln operation stability, a reduction in the energy consumption and an environment impact minimization. The modeling will contemplate two aspects as described below:
a) the effects that the alternative fuels employment can cause:
1) at the clinker quality through the raw material and fuels chemical composition;
2) at the environment through the raw material and fuels CO_2 and SO_2 emissions;
3) at the human health through the heavy metals emissions comprised in the raw materials and fuels;
4) at the manufacture cost taking into account the raw materials and fuels cost, obtaining as a result raw materials and fuels optimum composition for the clinker manufacture.

Table 1. Chemical composition in mass % of main fuels used as primary and alternative fuels in clinker kilns

Component	Coal $^{(a)}$ %	Petrolum Coke $^{(b)}$ %	Tires uses$^{(c)}$ %
C	63.9	8 - 100	72.15
H	3.6	3.5	6.74
S	4.6	0.5 - 0.7	1.23
O	0.9	-	9.67
N	1.8	1.5	0.36
Cl	-	-	0.149
Ash	24.9	1 - 4	8.74
CaO	1.03	-	10.64 *
SiO_2	9.32	-	22.0 *
Al_2O_3	5.8	-	9.09 *
Fe_2O_3	7.21	-	1.45 *
MgO	0.44	-	1.35 *
Alkalis	0.85	-	-
Zn	0.04	1 - 85 **	-
Cd	0.001	1.0 **	0.0006
Cr	0.008	1 - 23 **	0.0097
Ni	0.008	30 - 420 **	-
Pb	0.027	1 - 10 **	0.0065
TI	0.0004	-	1.45 *
Hg	-	0.1 - 10 **	-
As	0.00017	0.1 - 10 **	-
V	0.0648	130 - 2300 **	-
LHV (kJ/kg)	25392	32447 - 36425	32100

Sources: $^{(a)}$"Carvalho, Silva and Menon, (1997)"; $^{(b)}$"ABCP (1984)"; $^{(c)}$"Trezza and Scian (2000)"

b) the cost and energy consumption required to the clinker grinding for the Portland cement manufacture "Tokyay, (1999)". The grinding product must be limited through its fineness in order to create better conditions to the hardening process "Duda, (1997)". The equation which represents the grinding electric energy required must be express in function of the specific surface and mixture control modulus. In order to carry out the modeling as it described above, it is necessary to know the inlet parameters data such as raw materials, fuels, raw materials cost, etc. These parameters must be managed according to the objective function previous defined, which will have as a result the cost and environment minimization among others. The structure necessary to model the problem may be summarizing as shown Fig. 2.

3.1 Optimization Techniques

Controlled Random Search Algorithms are optimization methods suitable for searching of global minimizers of a continuous real function (objective function), $f : \Re^n \rightarrow \Re$, not necessarily differentiable, defined on a hyper-box $S = \{\mathbf{x} \in \Re^n : x_j^L \leq x_j \leq x_j^U, j = 1, ..., n\}$ where x_j^L and x_j^U represent, respectively, lower and upper bounds for the n coordinates of **x**. A point $\mathbf{x}^*$ is said to be a global minimizer of f if $f(\mathbf{x}^*) \leq f(\mathbf{x}), \forall \mathbf{x} \in S$. Besides, the lateral constraints used in the definition of *S*, other types of constraints could be, in principle, imposed by means of a penalization scheme on the objective function or by any other constraint-handling technique "Oyama, Fujii, Shimoyama and Liou, (2005)".

The CRSA's were proposed as an improvement to simple random search methods in which only the point with the lowest function value is retained in each iteration "Price, (1977)". Like Genetic and Differential Evolution Algorithms, a CRSA is a population set-based algorithm that starts with an initial set *P* of *N* points randomly chosen over S and then carries out an iterative contraction process towards a global minimizer by means of purely heuristic procedures. Further, the population size N is maintained throughout the optimization process. Unlike the other mentioned global optimization algorithms, the CRSA replaces a single point of the population (its current worst objective value point, **h**) by a better point **p** in each iteration (i.e., a trial point **p** so that $f(\mathbf{p}) < f(\mathbf{h})$). Thus its implementation is more straightforward.

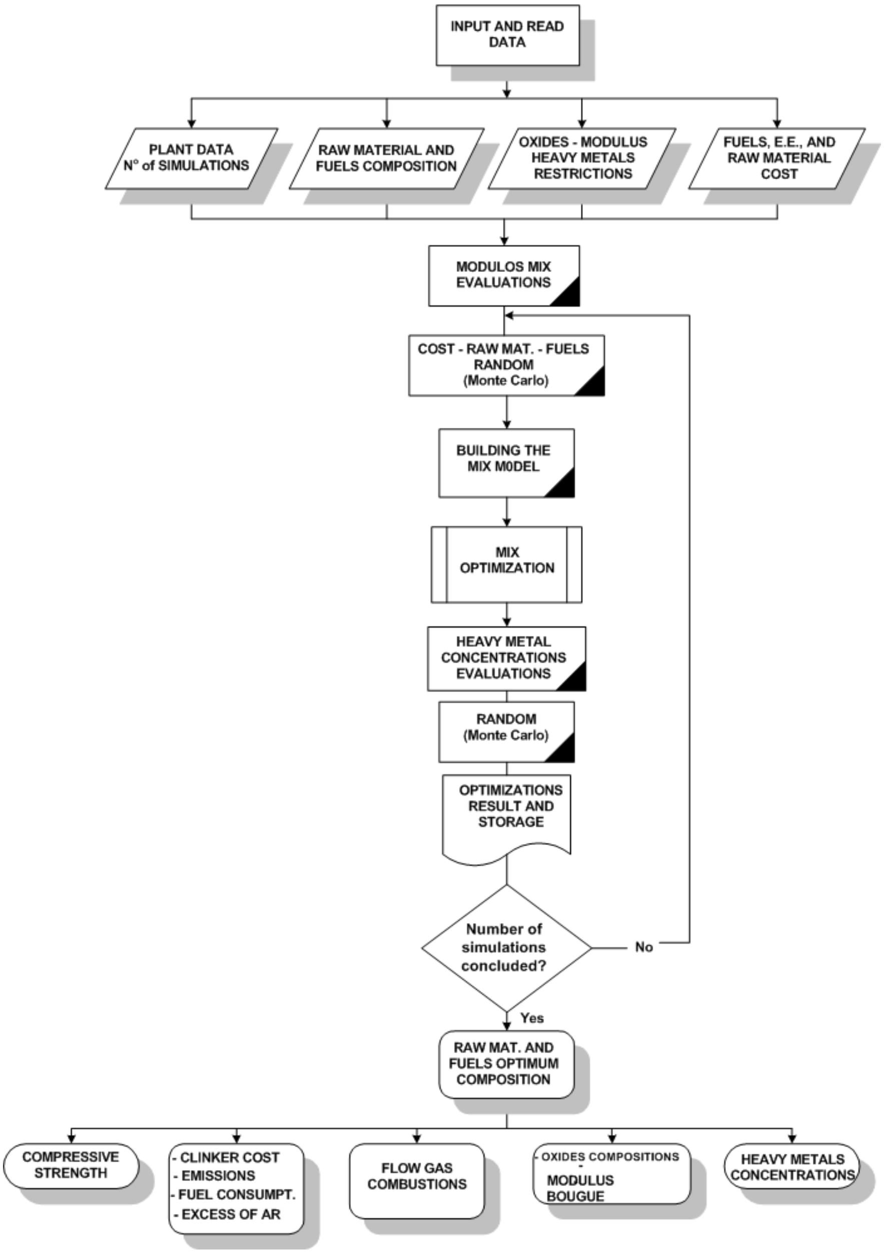


Figure 2. Flowchart when the industrial wastes co-processing is employed.

3.2 Basics of CRSA

The basic CRSA for minimization can be described in six steps as follows (adapted from "Ali, Törn and Viitamen, (1997)" and "Ali and Törn, (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, **h**, and the best point, **l**, i.e., those points in P with the highest and the lowest function values, f_h and f_l, respectively. If a stopping criterion is already satisfied, then stop (for example, stop if f_h - $f_l < \varepsilon$, where ε is a given tolerance).
2. Generate a trial point **p** for replacing the worst point, **h**.
3. If **p** is infeasible ($\mathbf{p} \notin$ S), go to step 2 (or alter **p** to be feasible).
4. Evaluate f_p = f($\mathbf{p}$). If **p** is unsatisfactory ($f_p \geq f_h$), 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 **h** and f_h in new P. If $f_p < f_l$, then set **p**, f_p as new **l**, f_l.
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 $f_p < f_l$ in step 5). It should be noted that all versions assume that $N >> n$ and it is typically suggested $N = 10(n + 1)$.

4. JAVA SOFTWARE

Java language creation had begun in 1991, but it didn't get much success then. But, with the advent of internet in 1995 and the Web applications development in Java, the language, finally, was recognized. Nowadays, it is one of most used languages and reached a great popularity for being the first free language of platform.

When a Java program is compiled, an intermediate code is generated called bytecode. This bytecode is interpreted by the Java virtual machines (JVMs) for the most operational systems. The virtual machine is responsible for creating a multiplatform atmosphere, so, if somebody builds a new operational system, it is enough to create a java machine virtual that translates the bytecodes into the native code of that system and the application will be executed without problems.

Besides its portability, the Java language also stood out for other characteristics:

- Object Orientation: the code is organized in classes, which can establish inheritance relationships amongst themselves;
- Net Resources: it holds extensive routines library that facilitate the cooperation between TCP/IP protocols (Transmission Control Protocol / Internet Protocol), as http (Hyper Text Transfer Protocol) and FTP (File Transfer Protocol);
- Similar syntax to the C / C++ Language;
- Automatic memory desallocation by garbage collector;
- Bytecode: interpreted, instead of compiled.

4.1 Why to Choose Java

Due to its great success and functionality, Java is one of the most used language nowadays. It holds an extensive routines library that allows a great easiness to program. It is quite safe, which allows programs to being executed through the internet. Java is a language that is neither arrested to any architecture nor to any company. It is fast and stable. Due to those benefits and because there isn't any software like that in the market, the Java language was chosen to development this project.

5. EVALUATION EXAMPLE

An evaluation example thought the developed program for the model proposed is presented. The program was structured to have a friendly interface with the user, because, at the beginning, it is requested a considerable amount of input data. Among the main program characteristics it can be quoted:

- it can work with a great number of iterations;
- there are no limits for the different input data, which provide to the use to accomplish simulations in critical situations (out of the established limits);
- it is employed a Controlled Random Search Algorithm (CRSA);
- the program builds the main models itself, such as raw materials and fuels, as well as specific surface and mixture modules (Figure 3);
- Concerning to the fuels, it can work with up to seven fuels simultaneously, among solids, liquids and gaseous;

As it follows, it is presented, concisely, the program screens with the input data and results, aiming of giving an idea of how the simulation is done.

On Figure 3, the main plant data are supplied, such as: daily clinker production, specific heat consumption that the kiln needs for the clinker production and the iterations number, regarding that these data can change based on the plant which will be simulated.

Figure 4 display the cost of the main raw materials and employed fuels for the presented model. It is important to mention that the supplied costs values are adopted by the model as an average, being important to supply the deviation-pattern, with the purpose that these prices can vary in each iteration.

The input data regarding to the raw materials and heavy metals are presented concisely in Figure 5. These values are read by the program to form part of the clinker production model.

Even so, Figure 6 presents the proposed model restrictions, which are gathered as it follows: regarding to the presence of the main oxides in the clinker as well as the mixture modules control, which should stay between minimum and maximum values.

It is also possible to model the presence of free oxygen (O_2) in the exhaustion gases, which in the model, it is carried out an stoichiometric combustion reaction with air excess aiming to evaluate the exhaust gas flow and the heavy metal concentration.

In the model it is possible to limit the entrance of some heavy metals such as: zinc, vanadium and chrome as well as controlling the exit of others as cadmium, lead, mercury and thallium, which have a harmful effect to the environment and to the human health.

Figures 7 and 8 presented concisely the accomplished simulation results. Figure 7 present the possible costs that the clinker can adopt, regarding that these values are in function of the costs proposed for the present simulation. On the other hand, it is presented the air excess which participates during the combustion process, being an important parameter to control the CO_2 emissions in the exhaustion gases, raw materials and used fuels.

The raw materials and fuels consumption are also presented in the results screen Figure 7. It is important to mention that all results show the average and the standard deviation, being that these results can vary in each iteration.

Figure 8 shows the main oxides composition present in the clinker structure, regarding that these values must stay inside the adopted limits for the present simulation. Also, Figure 8 presents the main silicate composition values that form the clinker.

As it can be noted, the obtained results answer satisfactorily the restrictions imposed by the model. It is clear that the model itself punishes when some quality restriction, environmental restriction or another is violated, trying to obtain the optimum composition for the raw materials and fuels, used in the process. With these results it is possible to evaluate others parameters which are of great interest for the cement industry, such as: resistance to the compression, combustion flow gases, CO_2 emissions, heavy metals concentration, flame temperature, among others.

Finally, through the presented model, it is possible to foresee the raw composition when it wants to burn residues as secondary fuels in rotary kiln in cement industries. It is also possible to calculate the levels of substitution of the primary fuel by the alternative fuel derived from residues, regarding the acceptable levels of pollutant emissions. This model was shown satisfactory regarding the presented results, such for maintaining the chemical composition values inside of the quality parameters as well as for finding smaller production costs.

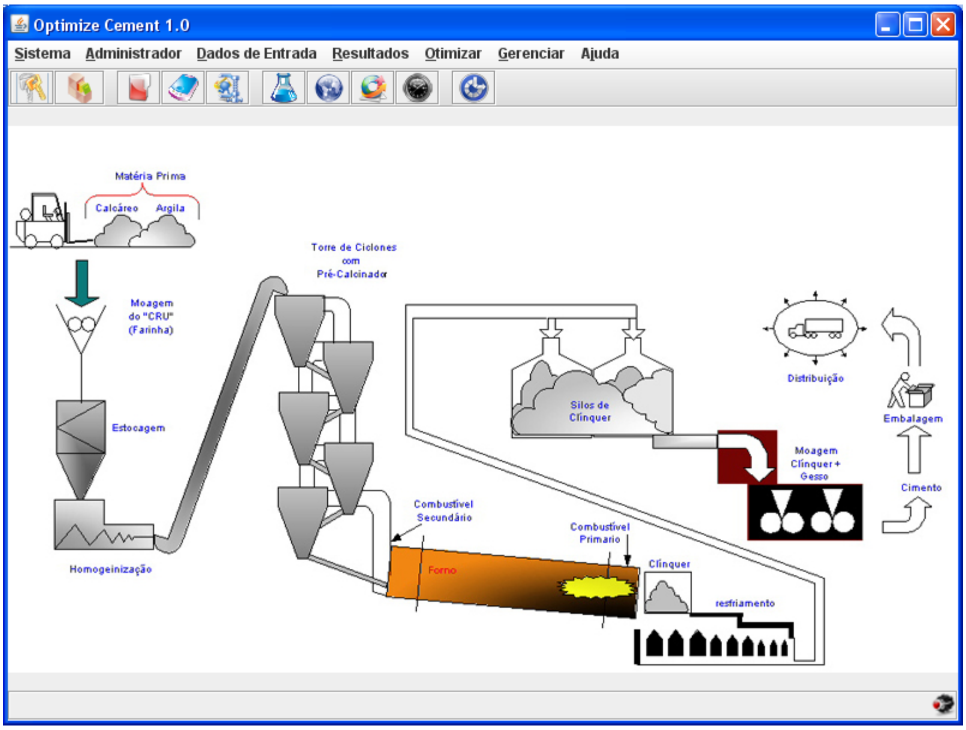


Figure 3. Entrance of data of the plant and number of iterations.

Custo Médio

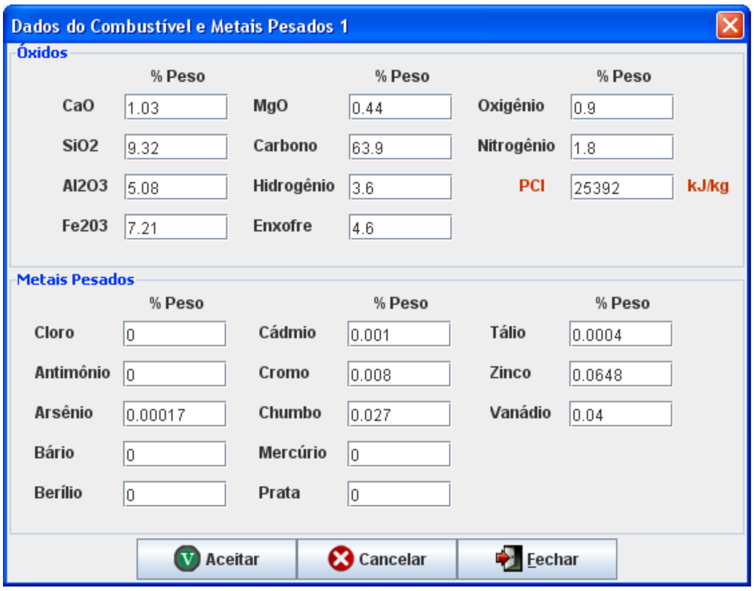
Matéria Prima & EE

	R$ / t	
Matéria Prima 1	0.8526	
Matéria Prima 2	0.5611	
Matéria Prima 3	1.5326	
Matéria Prima 4	0.7430	
Energia Elétrica	0.0268	R$ / KWh

Combustível

	R$ / t
Combustível 1	34.0704
Combustível 2	43.8139
Combustível 3	49.6354
Combustível 4	0

Figure 4. Data of entrance of the costs of the raw materials and fuels.



Dados do Combustível e Metais Pesados 1

Óxidos

	% Peso		% Peso		% Peso	
CaO	1.03	MgO	0.44	Oxigênio	0.9	
SiO2	9.32	Carbono	63.9	Nitrogênio	1.8	
Al2O3	5.08	Hidrogênio	3.6	PCI	25392	kJ/kg
Fe2O3	7.21	Enxofre	4.6			

Metais Pesados

	% Peso		% Peso		% Peso
Cloro	0	Cádmio	0.001	Tálio	0.0004
Antimônio	0	Cromo	0.008	Zinco	0.0648
Arsênio	0.00017	Chumbo	0.027	Vanádio	0.04
Bário	0	Mercúrio	0		
Berílio	0	Prata	0		

Figure 5. Data of entrance of the fuel 1 and heavy metals.

	Mínimo % Peso	Máximo % Peso
CaO	62	67
SiO2	19	25
Al2O3	2	9
Fe2O3	1	5
MgO	6.5	
SO3	0.2	2.07
Na2O	0.03	0.33
K2O	0.31	1.76

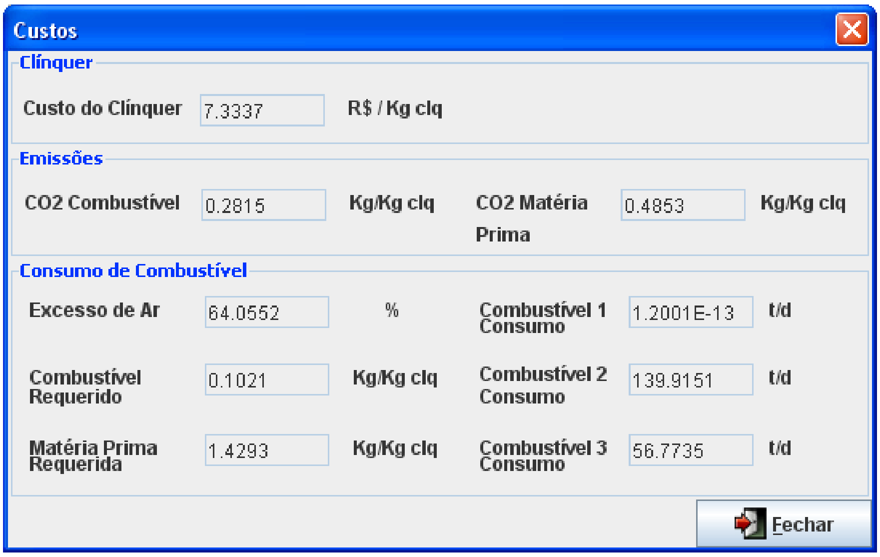
	Mínimo % Peso	Máximo % Peso
Módulo de Sílica	2.3	2.7
Módulo de Alumina	1.3	2.7
Fator de Saturação da Cal	93	98

O2 livre (%) 7

	Limite Máximo	
Cádmio	0.1	mg/Nm3
Chumbo	0.35	mg/Nm3
Mercúrio	0.05	mg/Nm3
Tálio	0.1	mg/Nm3
Zinco	0.5	% Peso
Vanádio	1	% Peso
Cromo	0.5	% Peso

Enxofre 0.05 %

Figure 6. Restrictions of the oxides, modules of the mixture and heavy metals.

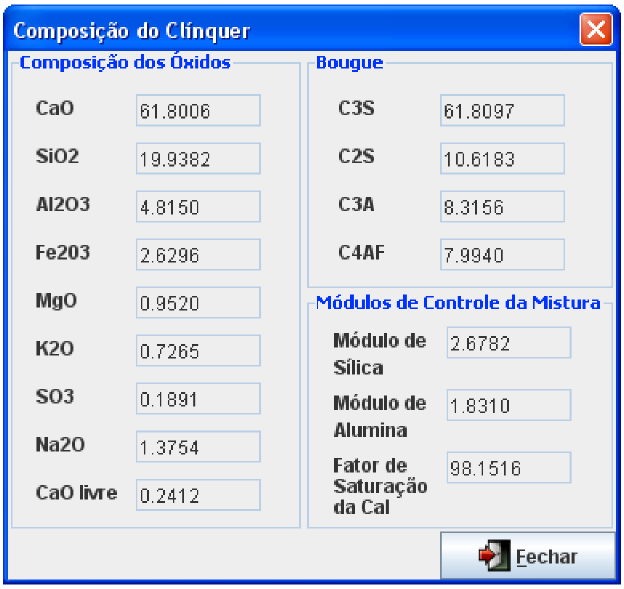


Custo do Clínquer 7.3337 R$ / Kg clq

CO2 Combustível	0.2815	Kg/Kg clq	CO2 Matéria Prima	0.4853	Kg/Kg clq

Excesso de Ar	64.0552	%	Combustível 1 Consumo	1.2001E-13	t/d
Combustível Requerido	0.1021	Kg/Kg clq	Combustível 2 Consumo	139.9151	t/d
Matéria Prima Requerida	1.4293	Kg/Kg clq	Combustível 3 Consumo	56.7735	t/d

Figure 7. Result of the cost of the clinker, emissions and consumption of combustible.



Composição do Clínquer

Composição dos Óxidos

CaO	61.8006
SiO2	19.9382
Al2O3	4.8150
Fe2O3	2.6296
MgO	0.9520
K2O	0.7265
SO3	0.1891
Na2O	1.3754
CaO livre	0.2412

Bougue

C3S	61.8097
C2S	10.6183
C3A	8.3156
C4AF	7.9940

Módulos de Controle da Mistura

Módulo de Sílica	2.6782
Módulo de Alumina	1.8310
Fator de Saturação da Cal	98.1516

Figure 8. Result of the composition of the oxides clinker and modules of control of the mixture.

6. CONCLUSION

The model purpose was to accomplish a sensibility analysis under the main parameters that can affect the quality of the clinker, the environment, the oven stability, and the clinker production cost, such as:

- The fuels and raw materials chemical composition that are used in the process;
- The clinker production and specific heat consumption;
- The raw material and fuel cost, which can be simulated in a certain range determined by the user;
- The emissions limit (heavy metals) and quality established by the current law, which can accomplish simulations in critical situations with the purpose of verifying how it can affect new limits to the final product, i.e., the clinker and the emissions;
- The cement composition wanted, through the specific surface mixture model, among others.

As results reached by the model it can be mentioned:

- The oxides composition, the mixture control modules and the clinker mineralogical composition;
- Fuel consumption, which can be punished by the model when one of them exceeds the established limits by the current law;
- The CO_2 emissions by the raw material and fuels used in the process;
- The combustion gas flow, which the reaction is accomplished by the model;
- The compression resistance for the paste different ages, among others.

7. ACKNOWLEDGEMENTS

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