SOFTWARE FOR CALCULATING OF COMBUSTION GAS FLOW AND MIXTURE OPTIMIZATION

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Abstract. *Lime industries of the Central-West region of Minas still operate with low technology. This results in low energy efficiencies, high fuel consumption and large environmental impacts. The software developed was aimed at optimizing the dosage of the mixture of raw materials and fuels, as well as the calculation of combustion gas flow in requirements of product quality and environmental constraints. With this software it was possible to carry out a case fuels used traditionally for alternative fuels.*

Keywords: *optimization, calcination, lime industry*

1 INTRODUCTION

Occupying the fifth position in the ranking of countries producers of lime, with a production of 7,425 thousand tons/year, Brazil is one of the largest producers of lime in the world (ABPC, 2014).

Despite the production of lime being very old, still there is little documentation about the lime production process. This causes companies to operate following empirical knowledge of the owners (OCHOA, 2000; OCHOA et al, 2010).

The lime was used for different purposes, in accordance with its type it can be applied in different sectors like construction, sugar, paper, water and wastewater treatment, calcium carbide, bleaching powder, etc. (SARMAH et al., 2005).

The State of Minas Gerais has the main industries of Brazil. In the Midwest region of Minas Gerais, are concentrated approximately 140 industries that mostly fall into small and medium-sized enterprises. Midwest region industries of Minas Gerais still require technology investments. The lack of technology applied to production process of these companies makes these companies operate with low efficiencies, with a high fuel consumption, large CO_2 emissions (SILVA, 2009).

The lime is the product of dissociation reaction of calcium carbonate ($CaCO_3$) calcium oxide (CaO). This reaction usually occurs in blast furnaces, whose temperature is above 1173 K. The main fuel normally used by the industries of the Central-West region of Minas Gerais is the eucalyptus. However, alternative fuels as a coffee husk, rice husk, bagasse, can be used. The approximate chemical reaction for this process is:

$$CaCO_3 + heat \rightarrow CaO + CO_2 \tag{1}$$

The production of lime is among one of the most polluting activities of the environment. It was estimated that the production of 1 ton of lime implies 1.2 ton of the CO_2 emission. This large CO_2 emission is a global effect of lime production. Sulphur dioxide and nitrogen oxide emitted during the calcination contribute to acid rain, which is a regional effect. In addition, a local scale effect is the emission of particulate matter resulting from the mining of limestone, as shown in Fig. 1 (SAGASTUME, 2012).

Figure 1. Particle matter originated from the production of lime.

The temperature of dissociation depends on factors such as origin and composition of limestone, crystal structure, grain size and partial pressure of CO_2 in the atmosphere surrounding (BOYNTON, 1980).

The lack of control in the oven temperature input of raw materials and fuels can cause scaling calcine completely, originating in a shoddy product, as shown in Fig. 2. This is why the present work has the purpose of the development of a software, which should help in minimizing the cost of production of lime production. The software will optimize the fuel mixture to enter the high-lime kiln, whereas the cost of fuel, chemical composition, CO_2 emissions among other parameters.

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Figure 2. Shoddy product originated by lack of control of the parameters of the lime kiln.

2 MAJOR REGULATORY STANDARDS

The main Brazilian standards governing the sector of lime are prepared by the ABNT and INMETRO, being recorded in them:

- NBR 6453/1985 – Lime for construction;
- NBR 6473/1996 – Quicklime and Hydrated lime – chemical analysis;
- NBR 7175/1992 – Hydrated lime for mortar;
- NBR 9289: 07/2000 – Hydrated lime for mortar – definition of fineness.

3 THE CALORIFIC VALUE OF FUEL

CORTEZ et al., 1997 defined the calorific value as the amount of heat that escapes during the complete combustion of the fuel mass unit, the difference between the lower calorific value (LCV) and high power calorific (HCV) is the energy required to evaporate the moisture present in the fuel and energy from oxidation of hydrogen present in the same.

The Tab. 1 shows the chemical composition and calorific value of different types of biomass on a dry basis.

Table 1. Technical characteristics of different types of biomass on a dry basis.

Types of biomass	Elemental composition [%]					
	C	H	O	N	S	LCV [MJ/Kg]
Eucalyptus	49,00	4,87	43,97	0,30	0,01	19,42
Coffee pods	35,5	5,5	57,80	1,25	0,00	15,91
Rice husk	40,96	4,30	34,86	0,40	0,02	16,40
Bagasse	44,80	4,35	39,55	0,38	0,01	17,33
Coconut shell	48,23	4,23	33,19	2,98	0,12	19,04
Corn cob	46,58	4,87	44,46	0,47	0,01	18,77
Branches of cotton	47,05	4,35	40,97	0,65	0,21	18,26
Pine	49,29	4,99	44,36	0,06	0,03	20,03

Source: Adapted from SHIRMER, 2006; ORSINI, 2012.

4 THE MATHEMATICAL MODEL

The mathematical model to evaluate the process of manufacture of lime proposed in this article considers the quality standards of lime, specific consumption, chemical composition of fuels and raw materials, daily production of lime, raw material costs.

The Table 2 shows the results of chemical analyses of the lime industry studied, for the survey of the chemical composition of the limestone, which will serve for the construction of the model.

Table 2. Chemical composition of limestone

Raw material	Calcium oxide content (CaO) [%]
Limestone	51,51

Source: Chemical analyses carried out by the authors.

The variables that represent the composition of the raw material and fuel are limestone (X_1), eucalyptus (X_2), coffee pods (X_3), rice husk (X_4), bagasse (X_5), coconut husk (X_6), corncob (X_7), branches of cotton (X_8) and pine (X_9).

The variables that represent the cost of the raw materials and fuels are: limestone (W_1), eucalyptus (W_2), coffee pods (W_3), rice rusk (W_4), bagasse (W_5), coconut husk (W_6), corn cob (W_7), branches of cotton (W_8) and pine (W_9).

Both the composition of limestone as the calorific value of the fuel can suffer alterations according to each region (CARPIO, 2005).

$$\text{Min } W_1X_1 + W_2X_2 + W_3X_3 + W_4X_4 + W_5X_5 + W_6X_6 + W_7X_7 + W_8X_8 + W_9X_9 \tag{2}$$

Subject to:

$$57{,}514X_1 + 0X_2 + 0X_4 + 0X_5 + 0X_6 + 0X_7 + 0X_8 + 0X_9 \geq 88 \tag{3}$$

$$57{,}514X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 + 0X_6 + 0X_7 + 0X_8 + 0X_9 \leq 100 \tag{4}$$

$$0X_1 + 19420X_2 + 159068X_3 + 16400X_4 + 17330X_5 + 19040X_6 + 18770X_7 + 18260X_8 + 20030X_9 \leq 100 \tag{5}$$

$$1X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 + 0X_6 + 0X_7 + 0X_8 + 0X_9 \geq 0 \tag{6}$$

$$0X_1 + 1X_2 + 0X_3 + 0X_4 + 0X_5 + 0X_6 + 0X_7 + 0X_8 + 0X_9 \geq 0 \tag{7}$$

$$0X_1 + 0X_2 + 1X_3 + 0X_4 + 0X_5 + 0X_6 + 0X_7 + 0X_8 + 0X_9 \geq 0 \tag{8}$$

$$0X_1 + 0X_2 + 0X_3 + 1X_4 + 0X_5 + 0X_6 + 0X_7 + 0X_8 + 0X_9 \geq 0 \tag{9}$$

$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 1X_5 + 0X_6 + 0X_7 + 0X_8 + 0X_9 \geq 0 \tag{10}$$

$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 + 1X_6 + 0X_7 + 0X_8 + 0X_9 \geq 0 \tag{11}$$

$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 + 0X_6 + 1X_7 + 0X_8 + 0X_9 \geq 0 \tag{12}$$

$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 + 0X_6 + 0X_7 + 1X_8 + 0X_9 \geq 0 \tag{13}$$

$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 + 0X_6 + 0X_7 + 0X_8 + 1X_9 \geq 0 \tag{14}$$

The Eq. (2) describes the objective function that is a problem of minimizing costs, which considers the costs of raw materials and fuels.

The Eq. (3) and Eq. (4) represent the restriction on the present of calcium oxide present at lime.

The Eq. (5) represents the restrictions concerning the specific consumption of heat, required by high-lime kiln.

The Eq. (6), Eq. (7), Eq. (8), Eq. (9), Eq. (10), Eq. (11), Eq. (12) e Eq. (13), represent the constraints due to the non-template variables can assume values less than or equal to zero.

5 THE SOFTWARE

To initialize the program, the user must configure the input parameters of the plant, as shown in Fig. 3. This interface the user can change the specific energy consumption, the daily production of lime and the total calcium oxide present in the raw material, plus the option to select one or more types of fuel.

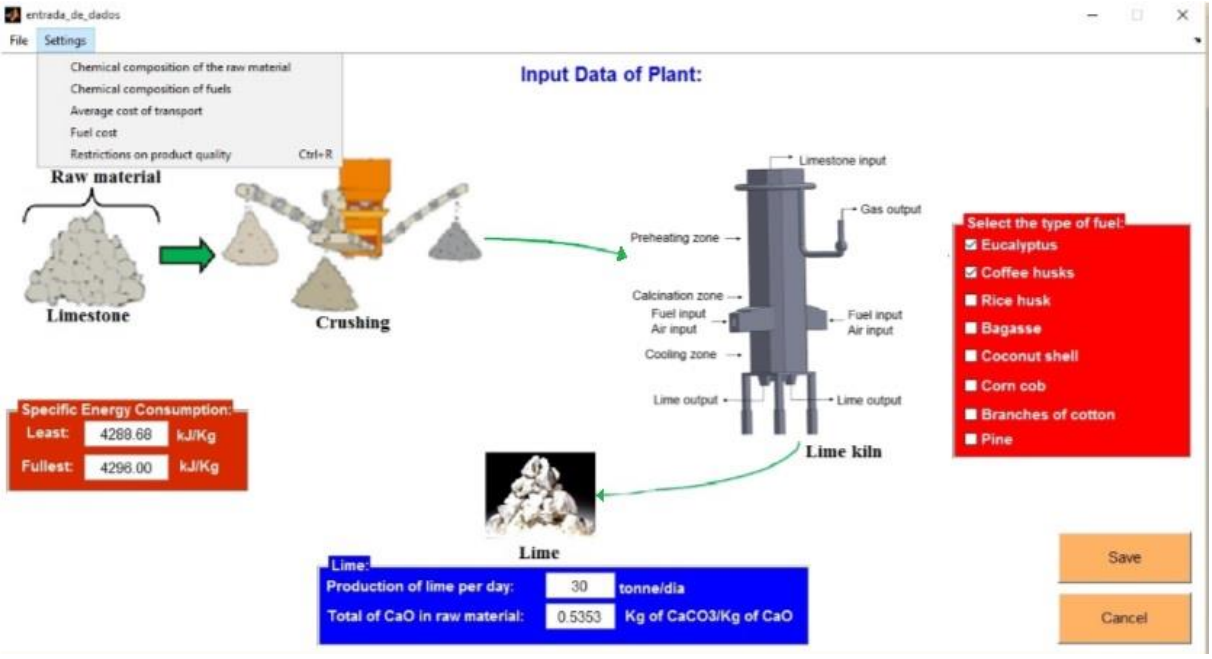

Figure 3. Data entry interface.

As mentioned above, the chemical composition of the limestone can change according to the region, so the user can change it in the interface shown in Fig. 4.

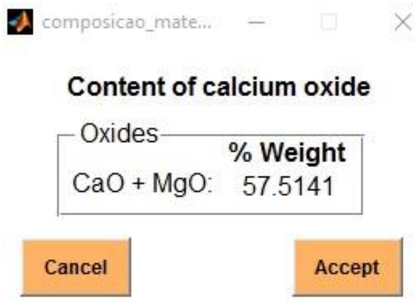

Figure 4. Configuration interface of the chemical composition of the limestone.

Because the cost of raw materials depend on factor such as: location, transportation of raw materials and suppliers. Therefore, the price of the raw material can change from company to company. The user must enter the cost of limestone in dollars per ton. Figure 5 shows the configuration interface of the average cost with raw material.

Figure 5. Configuration interface of the average cost with raw material.

The fuel composition may vary, if necessary, the user can configure the chemical composition of the fuel. Figure 6 shows the configuration interface of the chemical composition of the limestone.

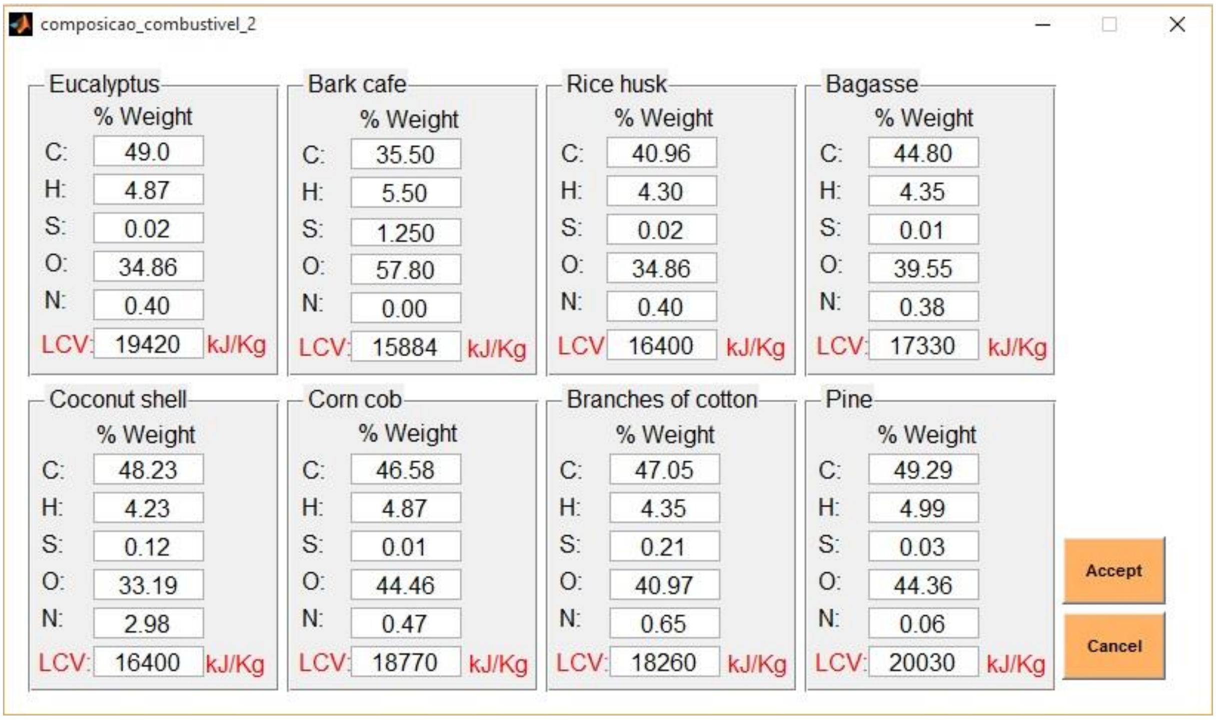

Figure 6. Configuration interface of the chemical composition of the limestone.

The user can configure the fuel cost, as shown in Fig. 7.

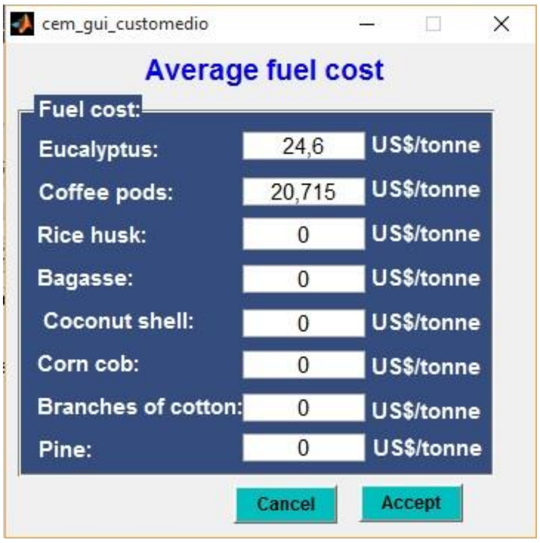

Figure 7. Configuration interface of the average fuel cost.

Finally, the standard model constraints follow the NBR 7175, and can be changed if necessary. It is not advisable to change this parameter, if the boundaries that establishes standard have not been changed. As shown in Fig. 8.

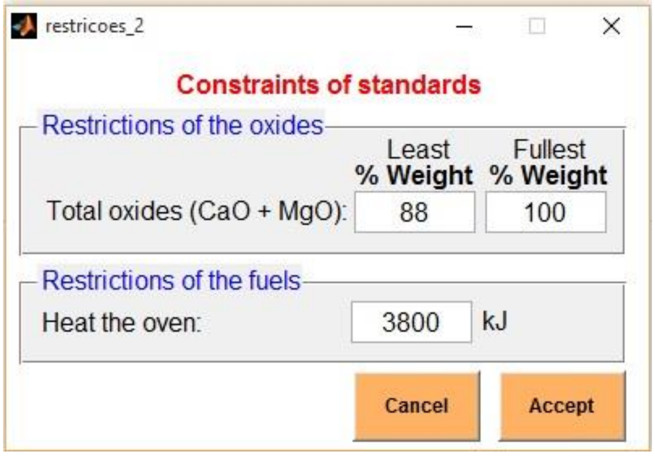

Figure 8. Configuration interface of the constraints of standards.

6 CONCLUSIONS

In this article was developed a software capable of performing the calculation of combustion gas flow and optimization of fuel mixture, and may evaluate various types of fuels in addition to fuels used in the lime industry studied. For industry studied a flow rate of 14.0177 N m^3/s in wet basis and 13.9089 N m^3/s in dry basis. In the calculation of the optimization of the mixture, which was obtained for each 1.53006% lime, must enter 0.195675% of coffee pods. With this result was possible to conclude that the fuel suitable for industry use is the eucalyptus.

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