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Application of Response Surface Methodology for Study of Fluxes Effects in Fusion of Ashes from Mineral Coal

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Abstract: The present study uses RSM (Response Surface Methodology) to verify the fusibility of bottom ash from coal industry, and efficient flux between, calcium oxide (CaO), lithium oxide (Li_2O) and sodium oxide (Na_2O). The bottom ashes, have demonstrated the possibility to be used in the development of glass-ceramics, and glassy materials, due to the presence of high concentrations of aluminum silicates. Different oxides agents were added to enhance the manufacturing process. However, selecting the best combination between these agents is a need. After using this RSM methodology it was found that the mixture of 50% by mass of sodium and lithium oxide the most significant for reducing the melting and softening temperature.

Keywords: Coal bottom Ash (CBA), Glassy Materials, Process Modeling

1. Introduction

The industrial waste transformation into byproducts is an alternative, which is becoming one of the solutions to reduce the environmental impacts, caused by engineering activities. However, with the growing of the environmental protection awareness, and mitigation of potential impacts associated with the production and consumption process, developing methods to better manage and cope with negative impacts to the environment is extremely needed.

Coal is one of the major worldwide sources of energy, there is a continued interest in the efficient use of coal. The bottom ash, generated by the combustion of coal in power plants, have composition characteristics favorable for use as raw materials in manufacturing glassy, and glass-ceramic materials [1-4]. It is estimated that, the world production of coal ash currently reaches more than 500 million tons per year, of which only about 20% are exploited [5].

The bottom ashes from a power plant are usually disposed of in landfills or abandoned mine sites close to the power plant. Uncontrolled bottom ash dumping may leach and release to the environment a number of trace pollutants. Only a few studies have been carried out to assess the environmental impact of the ash dumping [6, 7, 8]. The coal is a heterogeneous material with properties differing significantly with variations in rank, type, and grade. The presence of mineral matter in coal may result in a number of several technological and environmental problems related to mining, preparation, and combustion of the coals [6, 9-14]. In addition, the large amount of ash produced by coal combustion in Brazilian thermal plants renders disposal of the ash as a serious economic and environmental issue [15].

The bottom ashes, have demonstrated the possibility to be used in the development of glass-ceramics, and glassy materials, due to the presence of high concentrations of aluminum silicates.

On this line, this work aims to study, the better combination of oxides fluxes between Na_2O, Li_2O and CaO in fusibility of bottom ashes and the visibility to be used as raw materials.

2. Materials and Methods

2.1. RSM (Response Surface Methodology)

RSM is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes [6]. The most extensive applications of RSM are in the particular situations where several input variables potentially influence some performance measure or quality characteristic of the process. The performance measure or quality characteristic are called the response. The input variables are called independent variables, and they are subject to the control of the scientist or engineer.

However, in ceramic-vitreous process, the variables system is quite wide. Three manipulated variables (X_1=CaO; X_2=Na_2O and X_3=Li_2O) were assigned. The response function was set to analyze the melting and softening temperatures.

2.2. The Case Study

The bottom ash used was collected from the grid thermal unit at Jorge Lacerda which is located in Santa Catarina, Brazil.

The Jorge Lacerda power plant has 7 pulverized fuel units. The power plant is fed with a coal blend. The total power plant generates approximately 857 MW/h of electricity. The incineration temperature in the boilers can vary between 1000–1500^{o}C. The resultant ash that formed after combustion about 40%. The fly ash is captured by electrostatic precipitators and sometimes utilized to be recycled in the cement industry.

The ash samples were subjected to drying in the oven for 3 hours at a temperature of 105°C followed by the addition of portions from the flux as in the table 1. It should be noted that in all the experiments were used 85% ash and 15% flux, as showed in Table 1.

The samples were melted in zirconium-alumina-silica crucible at 1530°C furnace for 3 hours. Finally, the obtained glass is grinded for optical analysis to determine the theoretical melting and softening temperatures. Furthermore, for XRD and XRF to determine composition.

Table 1. *Formulation of samples according to mixture experimental design for three (3) components.*

No.	Samples	Components [w/w]			Pseudo-Components [g]		
		X_1	X_2	X_3	X_1	X_2	X_3
1	VD1	1	0	0	0.15	0	0
2	VD2	0	1	0	0	0.15	0
3	VD3	0	0	1	0	0	0.15
4	VD4	0	0.5	0	0.075	0.075	0
5	VD5	0.5	0	0.5	0.075	0	0.075
6	VD6	0	0.5	0.5	0	0.075	0.075
7	VD7	0.33	0.33	0.33	0.050	0.050	0.050

3. Results

Considering the composition of the bottom ash from Jorge Lacerda; the study shows the great possibility of these ashes to be transformed into ceramic glassy material. Figure 1 shows the presence of amorphous material, responsible for the transformation of ashes in vitreous materials. Table 2, present the composition of bottom ash from Jorge Lacerda, enormous silicate exists.

Table 2. *Composition of bottom ashes from Jorge Lacerda.*

Elements	Bottom ash (%)
SiO_2	54.53
Al_2O_3	22.82
Fe_2O_3	9.96
MnO	0.03
MgO	0.51
TiO_2	1.07
Na_2O	0.16
K_2O	2.40
P_2O_5	0.06
Fire loss	7.07

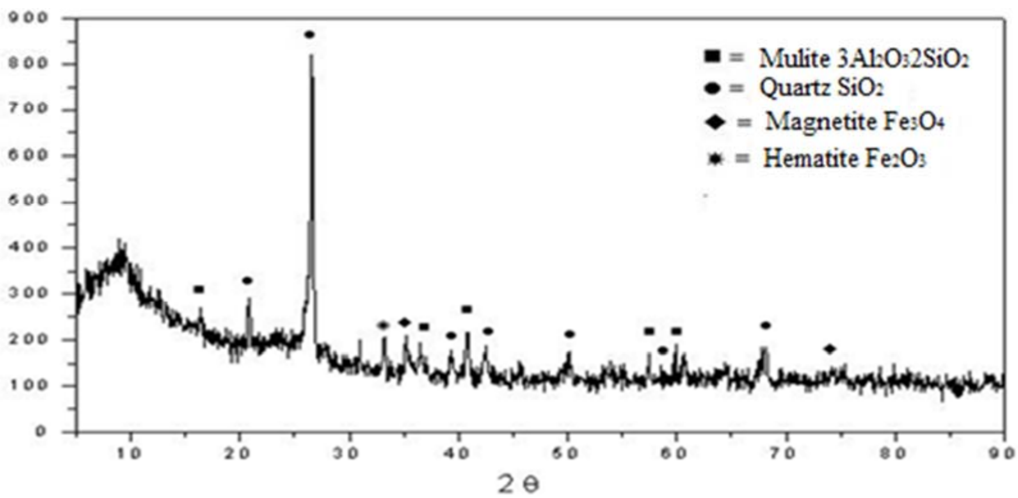

Figure 1. *XRD of bottom ashes from Jorge Lacerda.*

Table 3 shows the result of softening and melting temperatures of samples of glass produced from coal ash. For better understand the result Statist 8.0 software was used to simulate RSM technique, as can be seen in Figure 2. The response surface graphs (Figures 2a and 2b) show a relationship between the value of a given property and mixture composition expressed in weight fraction of components in accordance with the appropriate template. In present study, the model was suitable for the special cubic.

Table 3. *Softening and meltimg temperatures of glass from coal ash.*

No.	Samples	Components [w/w]			Pseudo-Components [g]			Response [ºC]	
		X_1	X_2	X_3	X_1	X_2	X_3	T S*oft.*	T*melt*
1	VD1	1	0	0	0.15	0	0	1290	1372
2	VD2	0	1	0	0	0.15	0	1077	1115
3	VD3	0	0	1	0	0	0.15	1070	1244
4	VD4	0	0.5	0	0.075	0.075	0	1090	1156
5	VD5	0	0	0.5	0.075	0	0.075	1064	1283
6	VD6	0	0.5	0.5	0	0.075	0.075	953	1057
7	VD7	0.33	0.33	0.33	0.050	0.050	0.050	985	1119

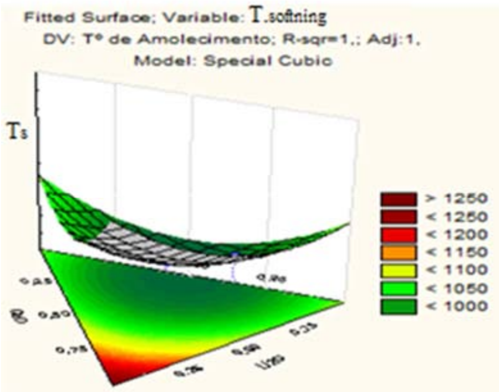

Figure 2a. *Response surface for Softening Temperature.*

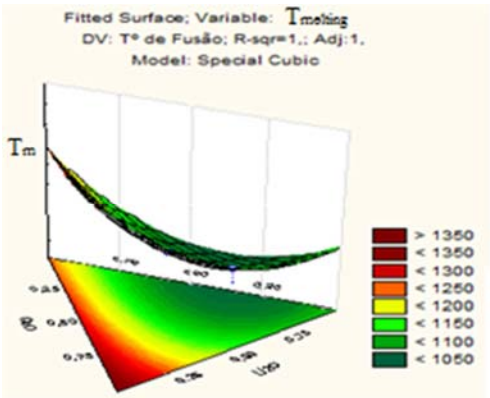

Figure 2b. *Response surface for Melting Temperature.*

Figure 2a shows the increase in mass fraction of CaO leads to higher softening point values. However, there is a concave region, representing the existence of an extreme minimum of T S*oftening*. This region is characterized by the presence of high concentrations of Li_2O and Na_2O, consequently with decrease the percentage of CaO.

This result shows the importance of the combined effect of Li_2O, Na_2O and CaO in the vitreous softening temperature in the bottom ash. There has been a similarity in response to surface melting temperature (T*melt*) in Figure 2b, higher values of CaO provide higher values melting temperature to glassy material developed.

The level curves (Figure 3a and 3b) of the special cubic model as a function of the proportions of components (Li_2O, Na_2O and CaO) show a clear trend of decreasing softening and melting temperature, with decreasing of the weight ratio of CaO.

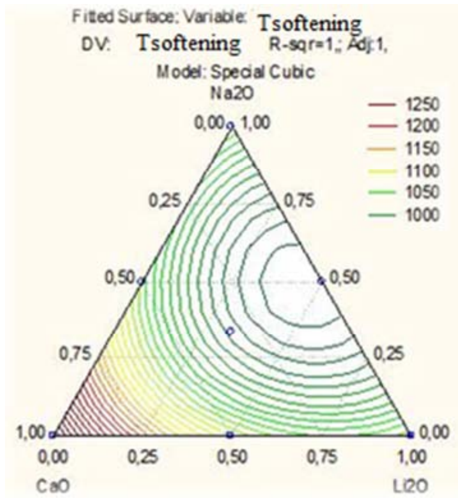

Figure 3a. *Contour line of softening temperature surface.*

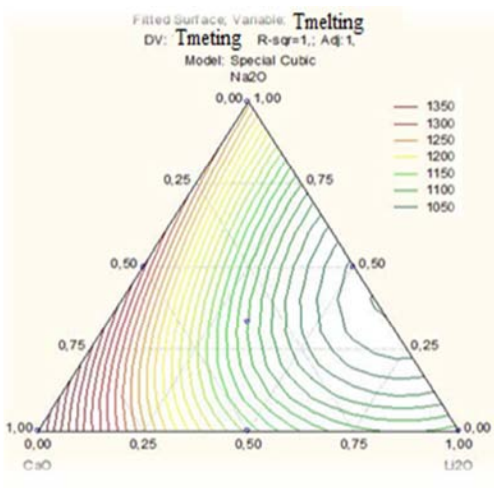

Figure 3b. *Contour line of melting temperature surface.*

All formulations developed have showed for both softening temperature as well as melting temperature, a minimum peak, given by the combination of two components (Li_2O and Na_2O) that is proving the technical feasibility of application of these fluxes in the CBA. The estimated model of softening temperatures response and fusion is represented by the equations (1) and (2) respectively:

$$T_{melt} = 1372X_1 + 1115X_2 + 1244X_3 - 350X_1X_2 - 100X_1X_3 - 490X_2X_3 - 546X_1X_2X_3 \quad (1)$$

$$T_{soften} = 1290X_1 + 1077X_2 + 1070X_3 - 374X_1X_2 - 464X_1X_3 - 482X_2X_3 - 378X_1X_2X_3 \quad (2)$$

Where: $x_1 = CaO, x_2 = Li_2O$ e $x_3 = Na_2O$

The estimated RSM of softening and melting temperatures, represented in equations (1) and (2) show that additions of 7.5% of Li_2O and 7.5% of Na_2O (sample VD6) in formulating the glassy materials is contributing to a reduction both softening and melting temperatures, respectively, to whatever proportion of CaO present. With regard to CaO, the percentage up to 2.5% help to increase the softening temperature. The profiles of the estimates of the properties for softening temperature and melting temperature are almost similar, confirming again validating the model chosen.

4. Conclusions

It was found that the coal bottom ash is an economic and attractive raw materials of alumina silicate (SiO_2 and Al_2O_3) for developing glassy materials; It was possible through the RSM provide the equation that describes the behavior of the flux components (CaO, Li_2O and Na_2O) in the verification process of the coal bottom ash.

Through the experimental the combination of Li_2O and Na_2O (sample VD6) was favorable in reducing the melting and softening temperatures. The bottom ashes, have demonstrated the possibility to be used in the development of glass-ceramics, and glassy materials, due to the presence of high concentrations of aluminum silicates.

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