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EVALUATION OF PERFORMANCE OF THE MIXTURE OF RICE RIND AND COAL PARTICLE SIZE BETWEEN 100 TO 200 MESH FOR ITS INJECTION IN BLAST FURNACES[1]

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Abstract

Energy is the basis for the development of humankind. Most of the energy used worldwide comes from fossil fuels and their heavy consumption is presented as primarily responsible for the environmental impacts nowadays. In this context it is interesting to think about renewable energy sources in order to reduce these environmental impacts, specifically speaking, the use of biomass as a fuel. The trends of industry to replace the coal used in the production of hot metal indicates the necessity to think of new alternatives to using these types of materials, called biomass, in processes related to the blast furnace. This work studies the PCI (pulverized coal injection) with the addition of rice rind with particle size between 100 and 200 mesh as well being injected through the tuyeres of the blast furnace. The equipment used for this simulation takes into account the peculiarities of a blast furnace. Considering this context, it can be seen that the effect of the mixture of rice rind and coal, correlated with different injection rates and different rates of combustion, can be an efficient choice of clean development, ecological and economic development in the steel industry.

Keywords: Blast furnace; Injection; Rice rind; Energy.

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1 INTRODUCTION

The trend of the steelmaking industry is to substitute the coal for other substances. For hot metal production the need of thinking alternatives for this fuel in the current blast furnaces process is very important. This Paper studies the PCI (Pulverized Coal Injection) with the addition of rice rind in different particle sizes to the fines of coal used in the hot metal production.
This article is divided in two stages. Firstly a characterization of rice rind "in natura", by some tests performed in samples of powder material with particle size varying between 100 and 200 Mesh. The second stage is the study of behavior of the mixture when injected through tuyeres of blast furnace. For this, more tests will be done in a equipment that simulate the injecting process, with mixtures of rice rind and coal in the same particle sizes aforementioned, varying the percentage of rice rind from 0% till 100% and consequently, percentage of coal from 100%, 75%, 50%, 25%, 0%.
The simulator used must consider the peculiarities of the coke blast furnace. Considering this context, the effect of the mixture coal and rice rind were correlated with combustion rate and injection rate.

2 LITERATURE REVIEW

Nowadays, corresponding to the need of an increasing international steel market, together with the demand of production cost reducing, became constant topic in the metallurgical environment. That is why it is extremely important to develop techniques capable to improve the performance of hot metal production, seeking to reduce the costs without negative effects over the quality of the products.
The present Paper shows a specific technique which can make the costs of hot metal production lower, by using the injection of rice rind and coal mixture in blast furnaces. The coal injected comes from a previous sector of production and has a small size of the grains, which would impair the introduction in the top of the furnace. So, the injection through the tuyeres gives a good destination to the material and also reduces the burden that would be introduced in the top of the blast furnace, consequently reducing the production costs.

2.1 Pulverized Coal Injection (PCI)

The main aim of this technique is to substitute part of the grained reducer material, charged in the top of the blast furnace, for a lower cost fuel injected directly through the tuyeres. Indirectly there are other benefits, like the increase of productivity, higher operational stability of the reactor, due to the efficiency of its thermal control. [(1)]
Coal is the product most commonly used for injection through tuyeres, but there are other ones whose feasibility of implementation has been widely studied, such as plastics, tires, vegetable waste, and others.[(1)]
The material must be submitted to some processes that adjusts it to the injection into the combustion zone (or "raceway zone"). Those processes consist in milling, to adequate grain size and drying, to reduce its moisture. After that, the coal is fluidized through the addition of gases (generally Air or Nitrogen) is pneumatically transported through the ducts, and properly distributed through the tuyeres. Figure 1 shows the process of PCI.[(1)]

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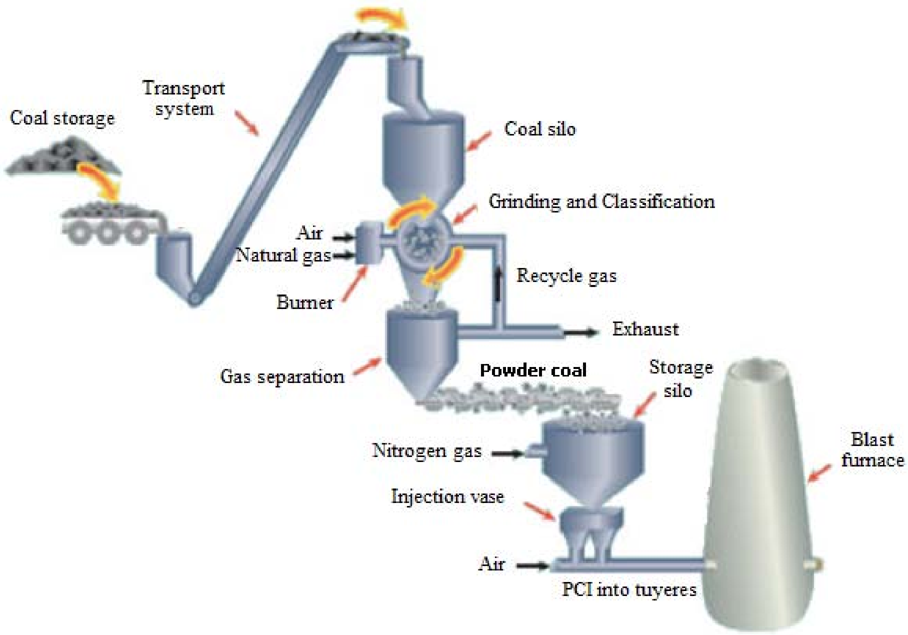

Figure 1: Flowchart of PCI.(1)

Coal is injected in the blast furnace through the tuyeres, in the same region where hot air is also injected. In the raceway zone, the coal suffers devolatilization and burns, producing heat and gases. The heat warms the metallic charge and the gases (CO e H_2), formed in the coal combustion, reduce the metal.(1)

2.2 Coal

Coal is a combustible, sedimentary, organic rock, which is composed mainly of carbon, hydrogen and oxygen. It is formed from vegetation, which has been consolidated between other rock strata and altered by the combined effects of pressure and heat over millions of years to form coal seams. Coal is a fossil fuel and is far more plentiful than oil or gas, with around 118 years of coal remaining worldwide.(2)
Mundial coals reserves are estimated in around seven trillion tons, quantity enough to supply humanity need for some centuries, considering the current consume rates. Figure 2 shows world reserves of coal. Of course for coke making, there is no more than 20 % of the coal reserve that can be used directly in the coke plant, under the actual technology.
Considering that mining is essential to obtain raw material, it is likely to think of alternative ways to optimize the processing in order to reduce the impact over the environment and also the cost of hot metal production. Reusing residual material through incorporation to production processes is one strong trend of study to improve industry processes.

2.3 Rice Rind

Mundial rice production exceeds 625 million tons per year. Brazilian method for rice processing consists in drying, cleaning, pealing and polishing the grains. Among other ways, parboiling is the most commonly used. According to “Instituto Rio Grandense do Arroz”, in Rio Grande do Sul – Brazil, conventional industrial production of 100 kg rice generates around 68 kg grains, 10 kg bran e 22 kg rind.

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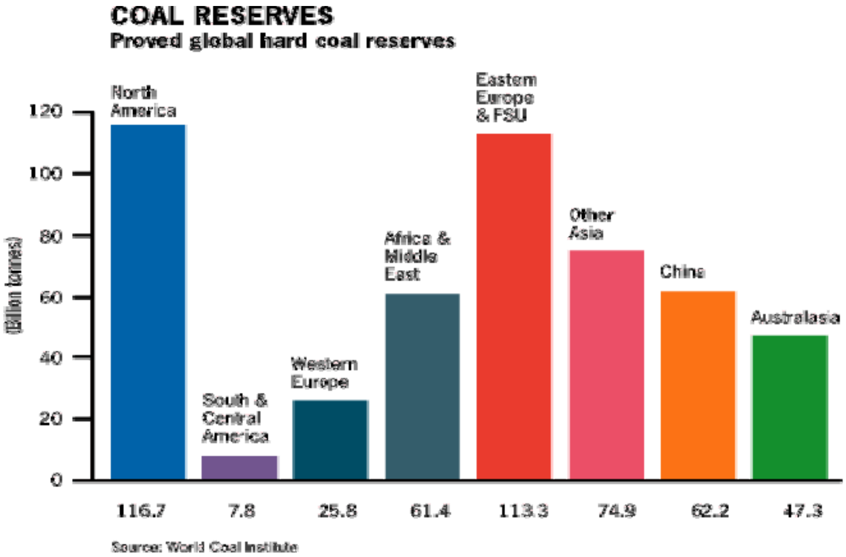

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Figure 2: World Coal reserves.(2)

Storing rice rind is an impracticable process due to its low density, and the discharge or uncontrolled burning can cause serious damage to health and environment.
In Table 1 there's information about rice rind production in the world, in 2009-2010
The a ratio between the amount of heat generated by rice rind and petroleum is 500 kg rice rind for each barrel of petroleum, based in LCV of the petroleum and the rice rind.

Table 1 Rice Production in 2009-2010(tons of rice)(3)

Country	**Production(tons of rice)**	**Percentage %**
China	166,417,000	26.7
India	132,013,000	21.1
Indonesia	52,078,832	8.3
Bangladesh	38,060,000	6.1
Vietnam	34,518,600	5.5
Thailand	27,000,000	4.3
Myanmar	24,640,000	3.9
Philippines	14,031,000	2.2
Brazil	10,198,900	1.7
Japan	9,740,000	1.6
Others	*116.302.668*	*18.6*
Total	*646.000.000*	*100*

3 METHODOLOGY

The processing of the mixture of rice rind and coal is analogous to PCI technique. Samples of rice rind and coal were separately characterized to fit the injection and then its implementation was evaluated in the blast furnace simulator.
The study was conducted at the Laboratory of Iron making of the group of Iron, Steel, Environment and Energy [ISEE] in the Department of Metallurgical Engineering Materials, Escola de Minas, Universidade Federal de Ouro Preto,

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First, samples of rice rind were collected, recently benefited, coming from a company in the state of São Paulo. The samples were taken from a pile (Figure 3) choosing random points to collected portions using a container of 2 liters, approximately (Figure 4). The final volume collected was approximately 30 liters of material, stored for a period of 30 days.


Figure 3: Pile of rice rind.


Figure 4: Collection of material.


Figure 5: Volume collected.

After this period the material was taken to the Mineral Processing Laboratory of Mining at UFOP where a sample of 105.3 g was taken for moisture analysis and, along with the rest of the material it stayed in a stove for three days at a temperature of 100 °C. Then, the sample was weighed again and kept in a plastic bag.
In another laboratory, the pulverization was done, inserting the material in the pulverizing machine (Figure 7) and processing it for 4 minutes (Figure 6). The process was followed by the separation into a sieve set (200, 100 e 48 Mesh), placed in a vertical shaker (Figure 8) for 25 minutes.


Figure 6 : Material ready to be powdered.


Figure 7: Pulverizer.

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Figure 8: Vertical sieve shaker.

After sieving, the rice rind sample was divided according to the grain size classes and stored in hermetically closed recipients, like in Figure 9.
With the samples properly separate, other samples of 150 g were taken from each container, after quartering. Twelve samples named from CA1 to CA6 (doubled), were selected for the grain sizes. They were conduced to Immediate Chemical Analysis, Nitrogen Adsorption (BET technique). The samples were identified according to Table 2.

Figure 9: Properly identified and sealed containers

Table 2: Identification of samples for chemical and physical analysis

SAMPLE	Grain size (x)	Immediate Chemical Analysis	BET	Combustion test
CA1	100# > x >200#	X		
CA2	100# > x >200#		X	
CA3	100# > x >200#			X

("#" is the symbol for Mesh, sieve opening nomenclature. A sieve with 48 Mesh opening (48#), for example, has 48 holes per square inch.)

A sample of coal donated by a local factory was analyzed, according to Immediate Chemical Analysis. Additionally samples of mixture of coal and rice rind were separated, weighting around 60 mg. They were sent to trial in the simulator of high thermal gradient at ISEE, varying the injection rates among 50, 100 and 150 kg/t hot metal.
Samples were numbered from 1 to 15, according to the characteristics of Table 3.

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Table 3: Identification of the samples for trial in the simulator

SAMPLE	Injection rate (kg/t hot metal)	Rice Rind %	Coal %
1	50	100	0
2	50	75	25
3	50	50	50
4	50	25	75
5	50	0	100
6	100	100	0
7	100	75	25
8	100	50	50
9	100	25	75
10	100	0	100
11	150	100	0
12	150	75	25
13	150	50	50
14	150	25	75
15	150	0	100

3.1 High Thermal Gradient Simulator

It's an equipment that simulates the submission conditions of the material injected in the tuyeres of an industrial blast furnace. It's possible to divide it in two parts, high pressure and low pressure zone. Low pressure zone consists in a preheating furnace that simulates the conditions of heat regenerator in the conventional blast furnace, the coal injection point and combustion furnace, which represents the "raceway zone".

Figure 10 is a picture of the simulator found at ISEE in Universidade Federal de Ouro Preto. High pressure zone has a manometer and injection lance, which is activated by an electromagnetic valve. All the zones together represent the physical conditions of operation and combustion in a blast furnace. The charge of pulverized material is done in the low pressure zone.

For injection, the gas used was pure oxygen stocked in 13 m^3 cylinder, coupled to the simulator though hoses. Coal is introduced through an opening in the form of "S", using a glass funnel. Each furnace is previously heated at a temperature of 800^0C, to preheating and till 1500^0C to combustion furnace.

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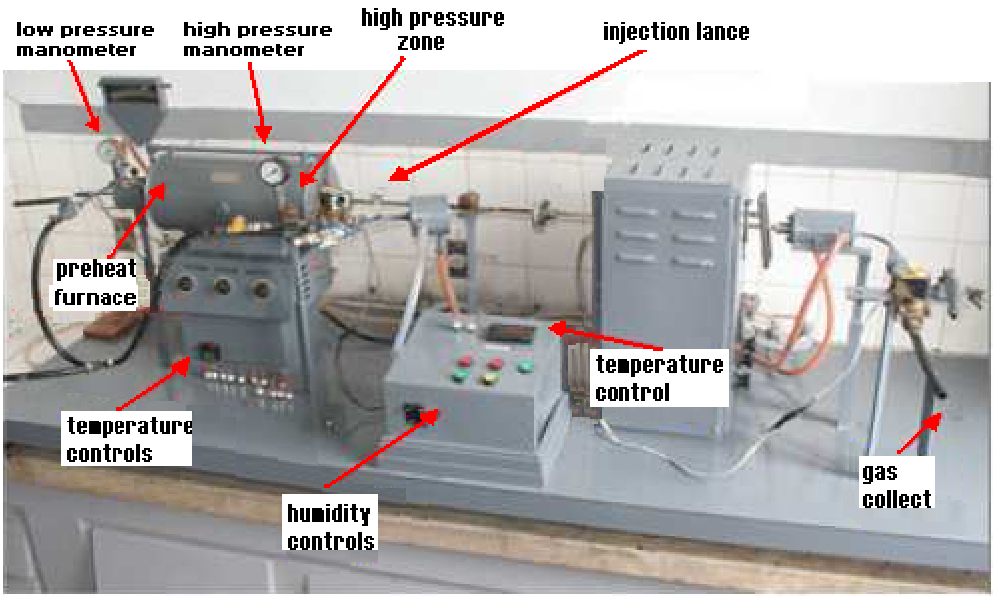

Figure 10: Simulator of high thermal gradient of ISEE Group - Universidade Federal de Ouro Preto.(1)

Figure 11 represents the scheme of simulator regions. In the injection lance, the gas drags the particulate material under the command of the electromagnetic valve (V1) that operates simultaneously with the valve (V2) by just 2 seconds repeating this activation for "n" times. The pressure in the gas regulators (P1) and (P2) are respectively 5 and 2 kgf/cm^2. The regions corresponding to what can be seen in the last figure, as described below: Section 1 – high pressure region, where the shock wave will be generated during the test;
Section 2 – corresponds to the pre-heating of air in the blast furnace; Section 3 – point where the powder will be mixed with the air coming from the wind ring (in the blast furnace); Section 4 – Region before the raceway, where there is mixing of powder and air;
Section 5 – region where the reactions (pyrolisis and combustion) take place)

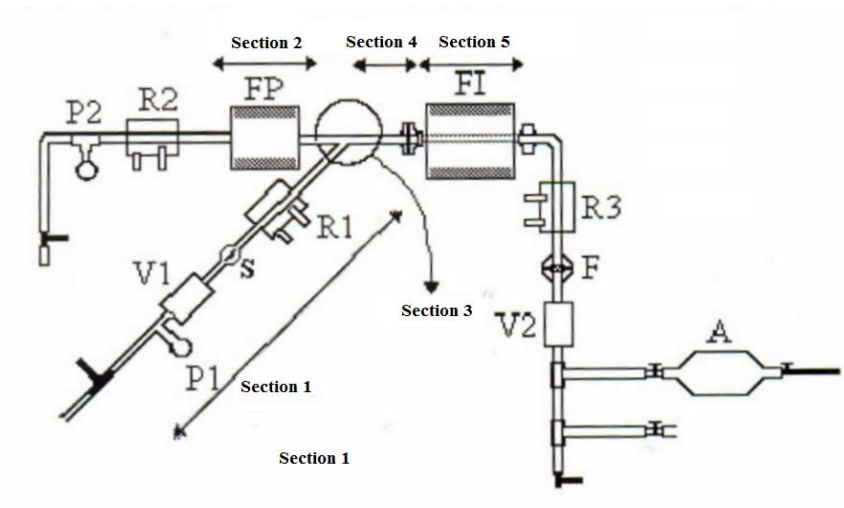

Figure 11: Scheme of the simulator regions.(1)

After open the cylinder valve, the gas is conducted to a branch of the hose that leads to preheat furnace and one that leads to the lance of injection in the preheating

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furnace where it is heated to a temperature of blow similar to that achieved in a blast furnace.[1]
The gas with particles of the injected material comes in contact with the gas from the preheat furnace and they enter the combustion furnace together. After burning, the particles and gas are separate and the gas is collected in ampoules for characterization.
The ampoules are made of glass with two openings one at each end and an internal volume varying between 200 and 250 ml, filled with water that is expelled by the other end as the gas is injected into the recipient. After the gas is collected it is sent to the gas analyzer ORSAT.

3.2 Orsat

The ampoule with the collected gas is coupled through a rubber hose to ORSAT (Figure 12). The equipment consists of support that gathers a set of glass ampoules containing solutions necessary to analyze the gas. This system is connected by glass tubes where the gas is forced, causing a wash that separates the appropriate fractions of CO, CO_2 and O_2. The solutions used are copper chloride for CO, pyrogallol for O_2 and hydroxide potassium for CO_2. (1)
Using a tube containing a saline solution and the level difference between this solution and the ampoules it's possible to measure the percentage of each gas in the sample.(1)
After open the ampoule valve, the gas is driven by the hose to the inlet of ORSAT, where it can be directed to each ampoule, following a certain order. After chose which solution ampoule to be used, the gas is forced through it due to a difference in level between the saline and bulb forcing the separation of gases, this difference is established until the saline solution equilibrates with the solution in the ORSAT ampoule, not allowing more gas to be absorbed thus separating the gas fraction which solution is specified to separate. After this procedure the gas is expelled from this ampoule and closes the valve that provides the path for it, repeating the procedure for the other ampoules.(1)

Figure 12: ORSAT.(1)

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3.3 Combustion Rate

With the results of the trial, it's possible to calculate the combustion rate using Equation 1 shown in the related literature.

$$IC = k * (\%CO + \%CO_2)*n / [(ma*\%Cf / 1200000) – (\%CH_4*ng / 100)] \qquad (1)$$

Wet basis, where
IC = Combustion Rate(combustibility);
%CO, $\%CO_2$, $\%CH_4$ = Percentage of gases;
%Cf = Fixed carbon in the sample;
ng = Number of moles of gas after the experience;
ma = Sample mass of carbon injected (in milligrams).
K = constant depending on the test parameters and conditions of the simulated blast furnace.

4 RESULTS AND DISCUSSIONS

4.1 Physical and Chemical Characterization

For the sample of coal, Table 4 shows the Chemical Analysis, on a dry basis: ***HGI** (Hardgrove Index Grindability): parameter indicating strength of the material, the higher the HGI, the softer is coal.

Table 4: Results for Chemical Analysis of Coal sample - Dry Basis (%)

S	0.26	Na_2O	0.22
Ashes	7.95	K_2O	0.8
Volatile	20.2	ZnO	0.01
Fe_2O_3	11.03	TiO_2	0.9
SiO2	59.21	S	3.28
Al_2O_3	20.51	C	81.5
CaO	2.25	H	4.12
MgO	1.48	N	2.29
MnO	0.25	O	3.9
P_2O_5	0.45	fixed C	73.71
HGI*****	65	total Fe	7.72
Replacement Rate	0.588	total P	0.17
Inherent Humidity	1.04		

For the sample of rice rind, Table 5 shows the Proximate Chemical Analysis:

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Table 5: Rice rind chemical analysis

Parameter	Grain Size	Density	C	Volatiles	LHV
Unidade	100 #< % < 200 #	kg/dm^3	%	%	$kcal/m^3$
Valor	80	132	16,46	78,28	2095

LHV: Low Heat Value

4.2 Metallurgical Characterization

Table 6 exposes the result of Nitrogen Adsorption (BET isotherm) for the samples of rice rind (CA4) and coal. Considering the specific surface, its values are of great importance as regards the burning rate of materials in the reactor under study. The greater surface area contact of the reducing gas with the material, thus ensuring greater combustion, since the residence time of material in the combustion zone is approximately 20 milliseconds.

Table 6: Nitrogen Adsorption - BET Technique

SAMPLE	Density	Specific Surface BET	Volume of Micropores	Area of Micropores
	(g/cm^3)	**(m^2/g)**	**(cm^3/g)**	**(m^2/g)**
CA2	1.459	1.3070	0.0006213	1.759
COAL	1,3070	1,9420	0,00076	2,158

SAMPLE	Constant C	Average Size of Micropores	Total Volume of Pores	Maximum Diameter of Pores	Average Diameter of Pores
	(ideal range of values: 50<C<200)	**(nm)**	**(cm^3/g)**	**(Å)**	**(Å)**
CA2	52.43	6.247	0.003497	1771.5	107.1
COAL	52,65	6,4660	5,59E-03	1829,30	115,10

Constant C: ideal range of values => 50<C<200

For Proximate Chemical Analysis of rice rind samples, as well as BET technique, more tests will be done as the results found are not enough for explain some results obtained. They will be determined proximately.

The injection tests in the simulator of high thermal gradient has been done for particle size classified between 100 # and 200#, varying the percentage of rice rind from 0%, 25%, 50%, 75% and 100% and consequently, percentage of coal from 100%, 75%, 50%, 25%, 0%.

The values obtained are shown in Table 7.

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Table 7 - Results of burning rates in proportion of rice rind in the mixture and injection rate (kg/t hot metal)

		% of rice rind in the mixture				
Unit	kg/t hot metal	**0**	**25**	**50**	**75**	**100**
Injection	**50**	86,1	88,5	90	90,5	89,1
rate	**100**	78,6	81,5	83,2	84,1	83,1
In BF	**150**	69,2	72	74,1	74,8	72,1

The results obtained using mixtures of coal and rice rind are shown in the Figure 12, where in the X-achse it is shown the rate of injection of mixtures, in the Y-achse it is shown the combustion rate calculated based on the described methodology.

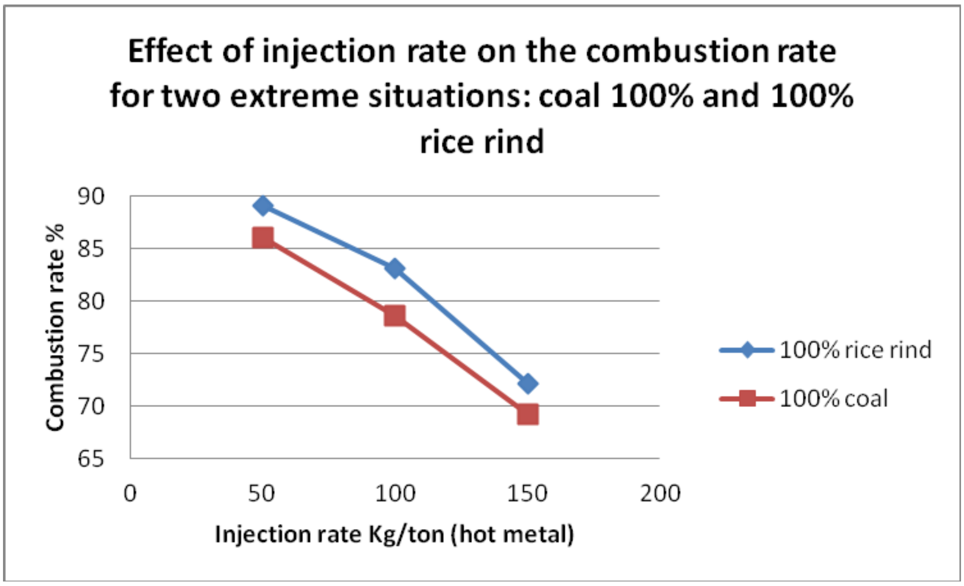

Figure 12: Effect of injection rate on the combustion rate for two extreme situations: coal 100% and 100% rice rind.

For this research it was used CA3 sample. For the coal, it was used a sample with 80 % between 100 and 200 mesh. Figure 11 shows that when the injection rate increases, there is a decrease on the combustion rate, for the three types of practiced materials: 100 % of coal, 100 % of Rice rind and 25 % of Rice crust and 75 % of Coal. These results were explained by other authors[4-6] and make sense, because when the injection rate increases, there is less oxygen available for the combustion, implying a decrease on the combustion rate. Similar results were obtained when mixtures of charcoal and rice crust were mixed.[7] It can be foreseen that higher injection rate can be obtained if some weight percentage of rice crust is mixed into coal. The conditions for that depend on the grain size of both fuels and the conditions of the tuyeres into the blast furnace.

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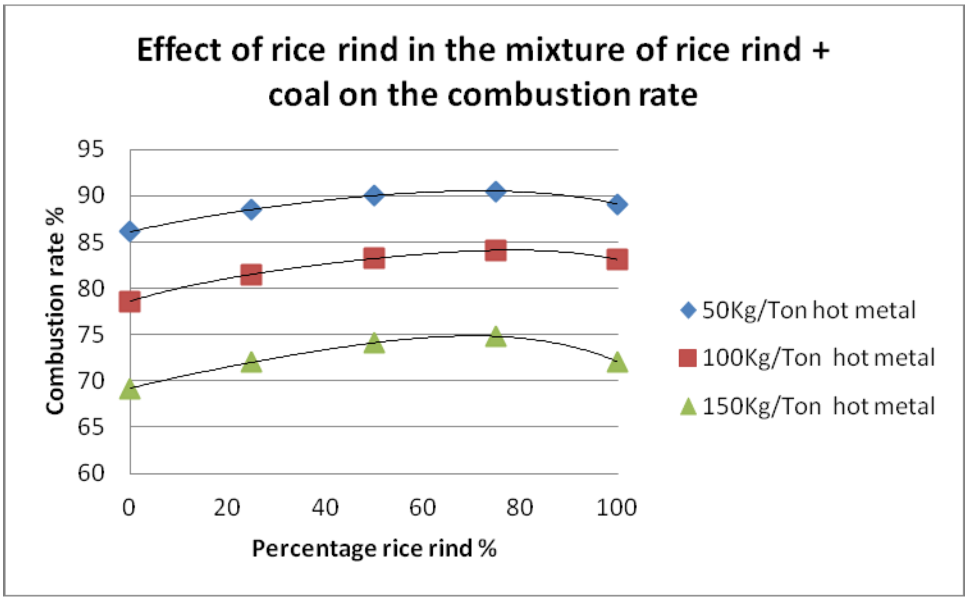

Figure 13: Results obtained showing the combustion effect of mixture of rice rind and coal in the high thermal gradient simulator.

For the grain size considered in this paper, there is an increase in combustion rate using any percentage of rice rind in the mixture but, when uses 75% of rice rind, the combustion rate is the highest as showed in the Figure 13.

The increase in injection rate implies a reduction in the combustion rate for the two fuels: rice crust and coal, and for the mixture too. The first one observation can be explained because there is a symbiosis between the pirolysis and combustion of volatile materials of both materials. The second one can be explained, because when there is an increase on injection rate, then, the O/C decreases, explaining the decreasing of combustion rate.

Considering a blast furnace with production capacity of 10.000 tons per day, injecting a rate of 150 kg / t hot metal with 25 % of rice crust and 75 % of coal, it would consume about 122000 tons per year of rice rind, representing an estimated saving of 5,25 Mio USD annually (it is considered a gain of 80 % of the cost of coal dust injection). Advantages over the greenhouse effect can be generated as well, which could originate additional carbon credits. This is very important point to be considered in the project, because sometimes the problem to get the rice rind depends on the logistic. This case, the Clean Development Mechanism can be used to get financial money for the project.

5 CONCLUSIONS

It can be concluded that the study allowed the observation of increase in combustion rate when rice crust is mixed with coal for injection in the tuyeres of coke blast furnaces.

When there is an increase from 50 to 150 kg / t hot metal, there is a big change in the combustion rate, this reducing the impact of the fuels into the tuyeres of blast furnace.

Best results were obtained using 75% of the mixture composed by rice rind. Other parameters needs to be considered in the blast furnace process, for example, the importance of the reduction gas formed by the coal burning

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Taking the example of a blast furnace with production capacity of 10.000 tons per day, injecting a rate of 150 kg / t hot metal with 25 % of rice crust and 75 % of coal, it would consume about 350 tons per day of rice rind, representing an estimated saving of 5,25 Mio USD annually (it is considered a gain of 80 % of the cost of coal dust injection). Advantages over the greenhouse effect can be generated as well, which could originate additional carbon credits. This is very important point to be considered in the project.

It is clear that these results can be obtained if industrial blast furnace reproduces the lab conditions.

Even being applied in other functions, much of the rice crust generated is not used, so the cost of the product for this purpose can become null. The feasibility would be even greater for blast furnaces located in areas with availability of rice rind in a radius of about 400km or less, but all parameters will be dependent on the price of coal and coke.

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