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CHARACTERIZATION OF MIXTURES OF SUGARCANE BAGASSE AND COAL FOR INJECTION THROUGH TUYERES OF BLAST FURNACES[1]

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Abstract
This paper aims the study and the characterization of a mixtures of sugarcane bagasse and coal for their injection through tuyeres of blast furnaces, in order to a possible replacement of fossil fuels commonly used for injection into coke blast furnaces. The methodology applied can be divided in two steps. Firstly a characterization of the sugarcane "in natura" by chemical analysis, B.E.T: nitrogen adsorption and scanning electron microscopy performed on samples of the powdered material with the particle size ranging between 48 and 100 mesh. The second part consists of the study of the behavior of a mixture of sugarcane bagasse with coal when injected through the tuyeres. For this, were performed tests using a device that simulates the injection process, using a mixture of coal and bagasse varying only the percentage of sugarcane bagasse from 0% till 100%. Therefore, this paper shows that the mixture of sugarcane bagasse and coal can be an effective alternative for a clean development in the steel industry.
Key words: Sugarcane bagasse; Injection; Energy; Clean development; Blast furnace.

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1 INTRODUCTION

Energy is the basis for Humankind development. Most of the energy used in the world comes from fossil fuels and its intense consumption is the main responsible for most of the environment problems of nowadays.
In this context, it’s interesting to think about sources of renewable energy, in other to reduce impacts and guarantee continuity of energy offer to future generations.
This Research aims the study and characterization of mixtures of sugarcane bagasse and coal for injection through tuyeres of blast furnaces, indicating a possible replacement of part of fossil fuels, commonly used in the coke blast furnaces, by a renewable energy source, the biomass. The work can be divided in two stages. Firstly a characterization of sugarcane bagasse 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 behaviour study of the mixture when injected through tuyeres. For this, more tests have been done in equipment that simulates the injecting process, with mixtures of sugarcane bagasse and coal in the same particle size aforementioned, varying the percentage of sugarcane bagasse from 0 to 100%.
The results of the work led to the observation that injection of mixtures of coal and bagasse is technically viable. So, it is likely to conclude that biomass utilization as reducer at the pig iron´s production may be an efficient choice to a clean development in the siderurgical sector.

2 REVIEW OF LITERATURE

2.1 Sugarcane Bagasse and Energy

Brazil is the country with the largest production of sugarcane in the world. 2010 harvest reached a record number of over 624 million tons sugarcane,[1] which means more than 200 million tons bagasse.
Sugarcane bagasse is a fibrous substance generated in the cane milling process to extract the juice and produce sugar, alcohol (anhydrous or hydrated), stillage, among others. Bagasse fibber composition is about 40% cellulose, 35% hemi-cellulose and 15% lignin.[2] This product has been widely studied because of its economic importance in the use as raw material for many industrial sectors.

2.2 Pulverized Coal Injection (PCI)

The main objective of this technique is to substitute part of the grained reducer material, burdened in the top of the blast furnace, for a lower cost fuel injected directly through the tuyeres. There are also other derivate benefits, like the increase of productivity, higher operational stability of the reactor, due to the efficiency of its thermal control.[3]
Coal is the product most commonly used for injection through tuyeres, but there are others whose viability of implementation has been widely studied, such as plastics, tires, vegetable waste, etc.[3]
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 eliminate humidity. After that, the coal fluidized through the addition of gases (generally air or nitrogen) is pneumatically transported through the pipes, and properly distributed through the tuyeres. Figure 1 shows the process of PCI.[3]

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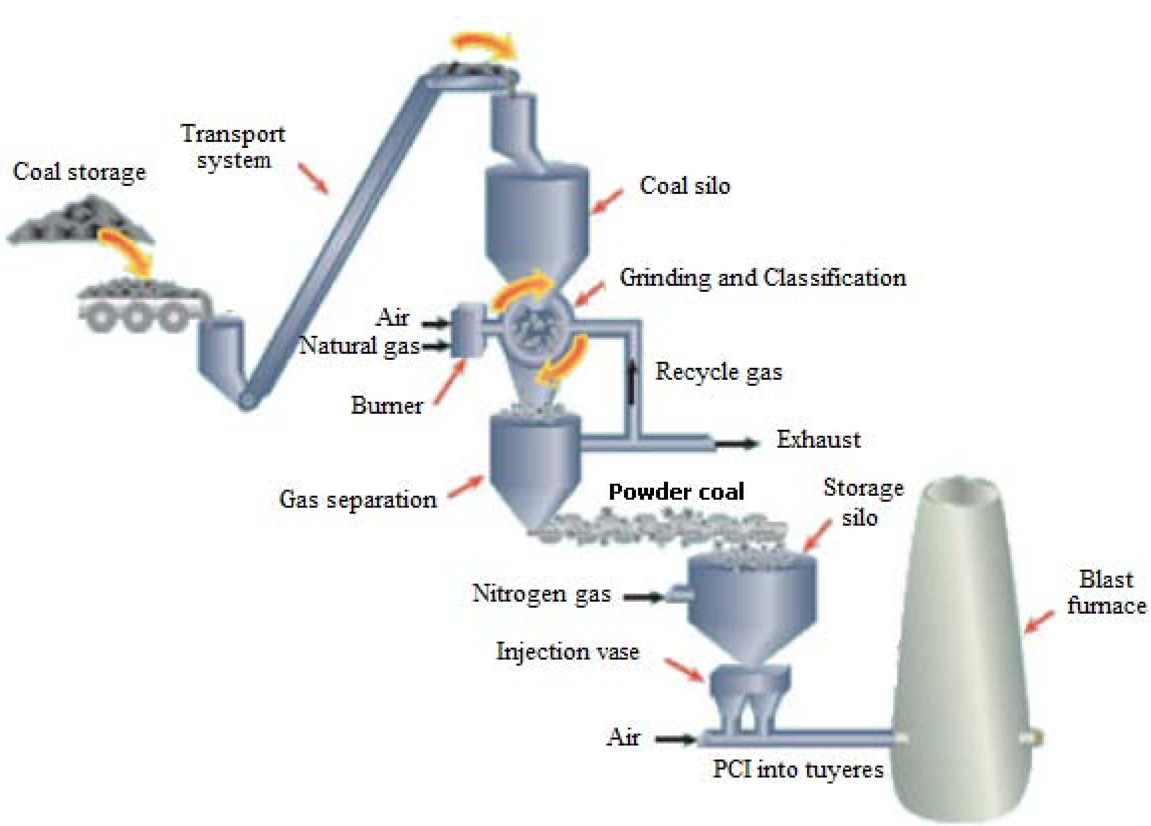

Figure 1 – Overview of PCI.[3]

Coal is injected in the blast furnace through the tuyeres, in the same duct where hot air is also injected. In the raceway zone, the coal suffers devolatilization and burns, producing heat and gases. The heat heats the metallic charge and the gases (CO e H_2), formed in the coal combustion, reduce the metal.[3]

3 PROCEDURE

To process the mixture of sugarcane bagasse and coal it's adopted a procedure that is analogous to PCI technique. To adequate the material for injection, characterization of bagasse and coal were done separately. Afterwards, the application through the tuyeres of the blast furnace simulator was evaluated.
For characterization of sugarcane bagasse, samples of residual bagasse were collected, just after milling. The material was donated by a company that produces sugar, located in the city of Ponte Nova, Minas Gerais, Brazil. The samples were taken from a pile (Figure 2) divided in 4 areas around itself, from each ¼ of the volume were collected. The final volume collected was approximately 8 kg, which was stored for 30 days (Figure 3).

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Figure 2 - Residue from grinding mill.

Figure 3 - Material stored in plastic bag.

After that, a 110.26 g sample was collected for moisture determination. The material stayed in a stove for 3 days at 100 ºC. 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 6) and processing it for 4 minutes (Figure 4). The process was followed by the separation into a sieve set (200, 100 e 48 Mesh), placed in a vertical shaker (Figure 5) for 25 minutes. After sieving, the sugarcane with grain size between 100 and 200 Mesh was stored in hermetically closed recipients, like Figure 7 represents.

Figure 4 – Material ready to be powdered.

Figure 5 – Vertical sieve shaker.

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Figure 6 – Pulverizer.

Figure 7 - Powdered material.

With the sample properly separated, other sample of 150 g was taken from the container, after quartering. Three samples named from BC1 to BC3, were conduced to Immediate Chemical Analysis, Nitrogen Adsorption (BET isotherm) and MEV or SEM (Scanning Electron Microscope).
The samples were identified according to Table I.
The sample of coal was obtained by sampling following the NBR 8291 (Sampling of raw coal and / or benefit) of ABNT. It was supplied by a company in Brazil that produces coke from imported coal.
Three samples with grain size between 100 and 200 Mesh were taken and named from CM1 to CM3, as listed on Table I, for chemical analysis, BET and SEM.
Samples of mixture of coal and sugarcane bagasse were collected, weighting till 150 mg. They were sent to trial in the simulator of high thermal gradient, varying the injection rates among 50, 100 and 150 kg/t hot metal. Samples were numbered from 1 to 5, according to the characteristics shown in the Table II.

3.1 High Thermal Gradient Simulator

It's an equipment that simulates the similar 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". [3,4]

Table 1 – Identification of samples for chemical and physical analysis

SAMPLE	Grain size (x)	Immediate Chemical Analysis	BET	SEM
BC1	100# > x >200#	X		
BC2	100# > x >200#		X	
BC3	100# > x >200#			X
CM1	100# > x >200#	X		
CM2	100# > x >200#		X	
CM3	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.)

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Table 2 – Identification of the samples for trial in the simulator

SAMPLE	Grain size (x)	% Sugarcane Bagasse	% Coal
1	100# > x >200#	100	0
2	100# > x >200#	75	25
3	100# > x >200#	50	50
4	100# > x >200#	25	75
5	100# > x >200#	0	100

The 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 lower pressure zone.
In Figure 8 there's a picture of the high thermal gradient simulator found at the laboratory of Universidade Federal de Ouro Preto.[3,4]
Figure 9 shows the flowsheet of the simulator. For injection, the gas used was pure oxygen stocked in 13 m^3 cylinder, coupled to the simulator through hoses. Coal is introduced through an opening in the form of "S", using a glass funnel. Furnaces are previously heated at a temperature of 800^0C, for preheating and over 1200^0C for combustion furnace.[3,4]
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 furnace where it is heated to a temperature of blow similar to that achieved in a blast furnace. [3,4]
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 4 times. The pressure in the gas regulators (P1) and (P2) are respectively 5 and 2 kgf/cm^2. [3,4]
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. [3,4]

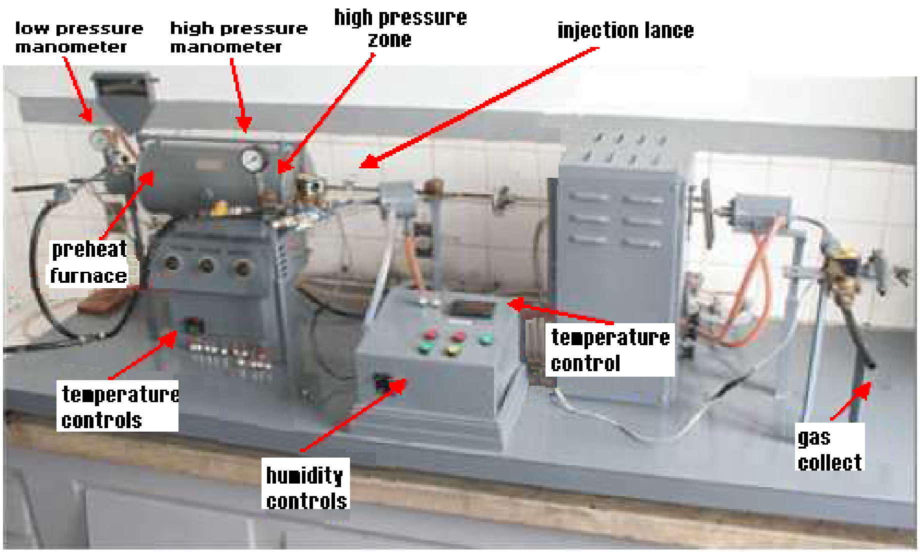

Figure 8 - High thermal gradient simulator of Universidade Federal de Ouro Preto.[3]

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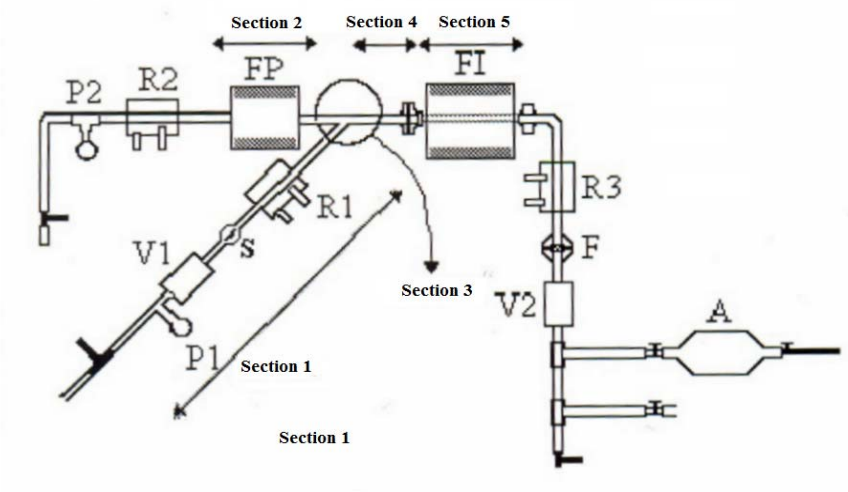

Figure 9- Scheme of the simulator regions.[3]

The ampoules are made of glass with two openings one at each end and an internal volume varying between 200 and 500 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. [3,4]

3.2 ORSAT

Ampoule with the collected gas is coupled through a rubber hose to ORSAT (Figure 10). 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 potassium hydroxide for CO_2.[3,4] The H2 and CH4 can be analysed using a system connected with a furnace that burns the both gases, permitting afterwards to determine these ones.
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.[3,4]
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 choose 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.[3,4]

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Figure 10 - ORSAT.[3]

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.

$$IC = K\ (\%CO + \%CO_2)*ng\ /\ [(ma*\%Cf\ /\ 1200000) - (\%CH_4*ng\ /\ 100)] \quad (1)$$

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 = depending on the conditions of experiment and simulated blast furnace

4 RESULTS

4.1 Physical and Chemical Characterization

The first density test conducted on the sample of sugarcane bagasse had humidity rate of 37.61%.
Chemical analysis of sugarcane provided the values shown in Table 3.

Table 3 – Immediate chemical analysis of sugarcane bagasse

SAMPLE	Humidity (%)	Volatiles (%)	Ashes (%)	Fixed Carbon (%)
BC1	6,403	69,456	12,079	12,062

Considering that the analysis was performed on a dry basis, it's suitable to affirm that the values obtained match the ones from literature (Table 4).

Table 4 - Proximate chemical analysis of sugarcane bagasse[6,7]

	Humidity (%)	Volatiles (%)	Ashes (%)	F. Carbon (%)
Bagasse	50	35	4	11
Bagasse	50	37	1,5	11,5

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Chemical analysis of coal provided the values shown in Table 5.

Table 5 - Proximate chemical analysis of coal

SAMPLE	Humidity (%)	Volatiles (%)	Ashes (%)	Fixed Carbon (%)
CM1	1,04	20,2	7,95	70,81

4.2 Metallurgical Characterization

The results of Nitrogen Adsorption (BET isotherm) and the images of MEV or SEM (Scanning Electron Microscope) are shown on Table 6 and Figure 11. Considering the specific surface, its values are of great importance as regards the burning rate of materials in the reactor under study. The greater the surface area contact of the reducing gas with the material, higher the combustion rate, since the residence time of material in the combustion zone is approximately 20ms.

Table 6 – Tests for Nitrogen Adsorption by BET isotherm.

SAMPLE	Density	Specific Surface BET	Volume of Micropores	Area of Micropores
	(g/cm^3)	(m^2/g)	(cm^3/g)	(m^2/g)
BC2	1,419	0,454	0,00026	0,745
CM	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)
BC2	201,40	2,560	0,00114	1581,20	100,60
CM	52,65	6,4660	5,59E-03	1829,30	115,10

The burning of the samples in the simulator of high thermal gradient has been done for particle size classified between 100 # and 200#, varying the percentage of the mixture and injection rate of 50, 100 and 150 kg/t hot metal.
The values obtained are shown in Table 7. Figure 12 relates the combustion rate with the percentage of bagasse in the mixture. Y-axis represents the combustion rate range and x-axis the percentage (by weight) of bagasse in the mixture.

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

		% of bagasse in the mixture				
		0	**25**	**50**	**75**	**100**
Injection Rate	**50**	85,1	85,95	84,2	83,7	83,8
	100	84,45	85,6	83,9	82,9	82,35
	150	78,95	80,3	79,1	75,2	73,35

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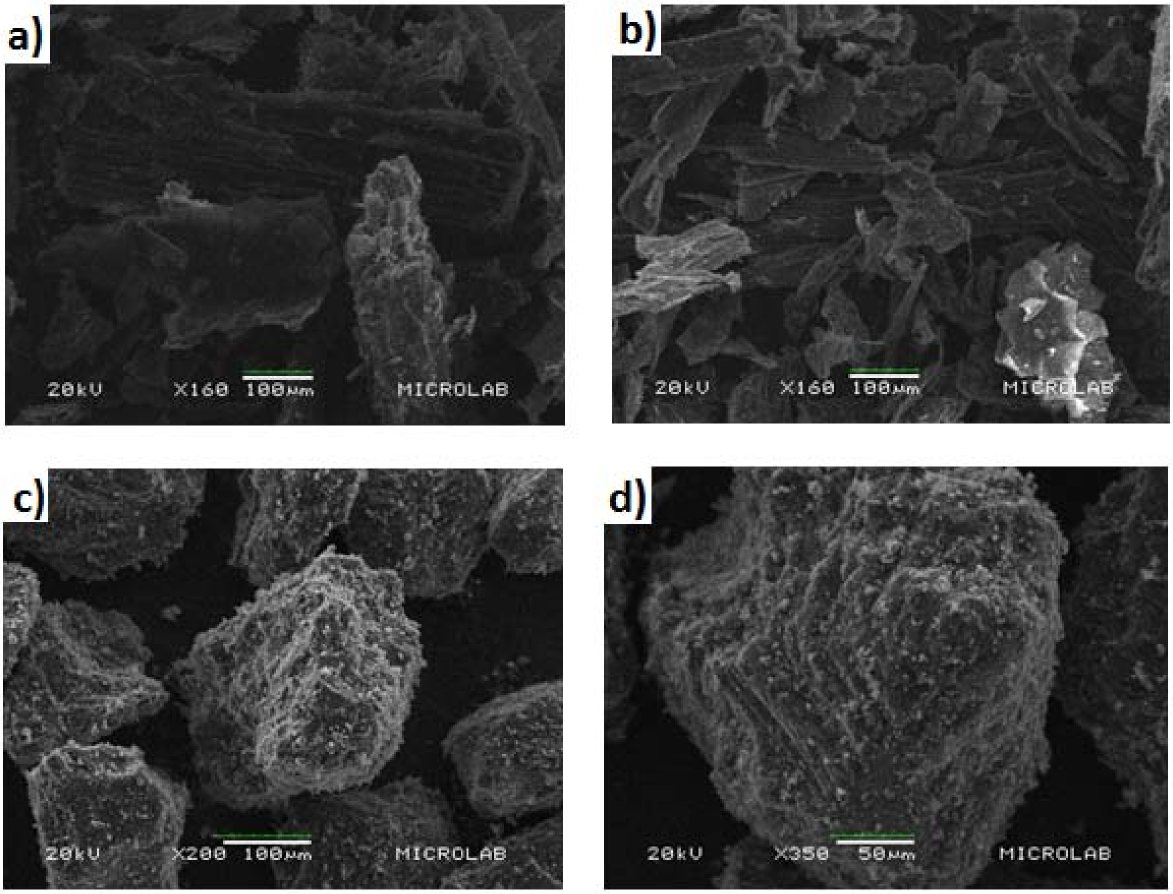

Figure 11 – a) sugarcane bagasse increased 160x, b) sugarcane bagasse increased 160x, c) coal increased 200x, d) coal increased 350x.

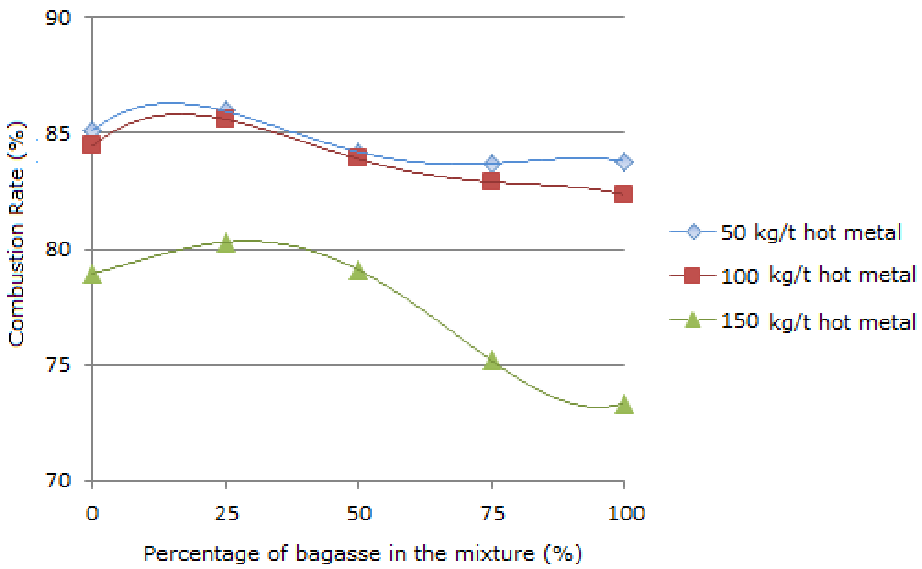

Figure 12 - Effect of bagasse in the mixture of bagasse + coal on the combustion rate

It is observed that the combustion rate increases and reaches a maximum, which oscillates around 20% of bagasse in the blend, when there are two fuels mixed. This increase in combustion rate can be justified by a combination of factors related to the pyrolysis and combustion of volatiles.

As the rate of injection increases, very little variation shows up when it rises from 50 to 100 kg/t hot metal. The variation of the combustion rate would be almost

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insensitive to this variation. But when there's an injection rate up of 150 kg / t hot metal, it's observed an appreciable decrease in the rate of combustion. This can be explained by a mechanism already proposed by Assis et al.[5]
Figure 13 illustrates the effect of injection rate for two extreme situations, ie 100% of coal and 100% of sugarcane bagasse as an agent for injection.

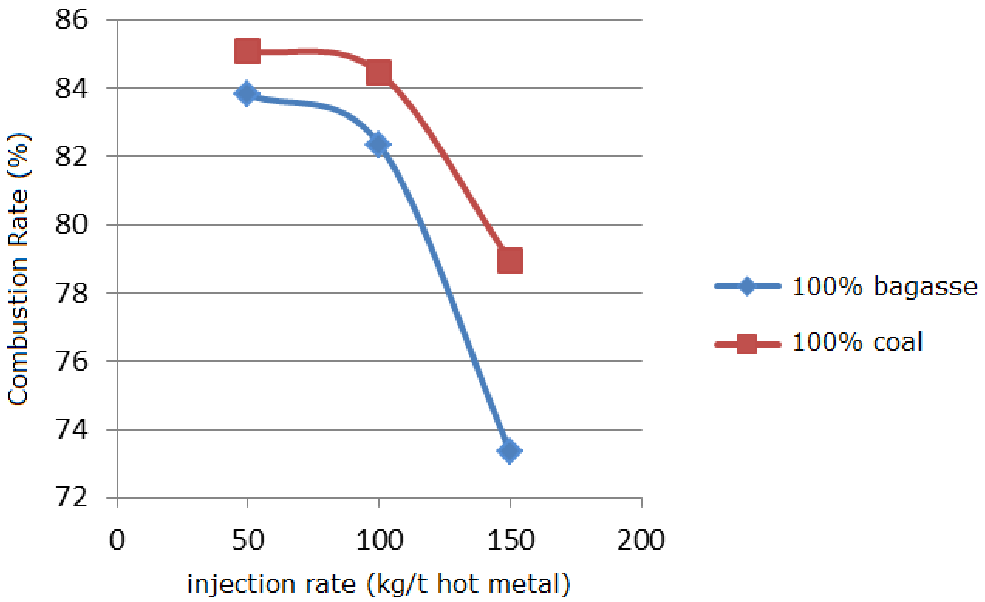

Figure 13 - Effect of injection rate on the combustion rate for two extreme situations: coal 100% and 100% sugarcane bagasse.

As the injection rate increases, there is a decreased on combustion rate. This effect is virtually the same as for coal, as for sugar cane bagasse due to the high volatile content of both fuels. This explains why there is a set rate of injection, from which the combustion rate of the alternative fuel is reduced to a greater extent. But at the same time, demonstrates the possible technical advantage of the use of coal mixed with sugarcane bagasse for injection into the blast furnaces.
It was done a simulation using mixture of sugarcane bagasse and coal. Taking the example of a blast furnace with production capacity of 8000 tons per day, injecting a rate of 150 kg / t hot metal mixing, it would consume about 240 tons per day of sugar cane bagasse, representing an estimated saving of 4 000 000 USD annually (it is considered a gain of USD 35,50 per ton of sugarcane bagasse injected, about 60% of the cost of coal dust injection).

5 CONCLUSIONS

The study allowed the observation of significant increase in combustion rate when sugarcane bagasse is mixed with coal for injection in the tuyeres of blast furnaces.
There is an increase in combustion rate only to the extent around 20% bagasse in the mixture.
The increase in injection rate implies a reduction in the combustion rate for the two fuels. To increase from 50 to 100 kg / t pig iron, there is virtually no change, however when it rises to 150 kg / t pig iron, there is a substantial reduction in the rate of combustion.

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It is intended to achieve more results with tests for particle sizes above below 200# and above 100#.
Taking the example of a blast furnace with production capacity of 8000 tons per day, injecting a rate of 150 kg / t hot metal mixing, it would consume about 240 tons per day of sugar cane bagasse, representing an estimated saving of 4 000 000 USD annually (it is considered a gain of USD 35,00 per ton of sugarcane bagasse injected). Advantages over the greenhouse effect can be generated as well, which could originate additional carbon credits.
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 sugarcane bagasse 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 sugarcane bagasse in a radius of about 200km or even more.

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