Quality evaluation of metallurgical coke produced with sawdust and different mixtures of coal

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Abstract

The present research is dedicated to analyzing the addition of sawdust biomass, which is a carbonaceous raw material that may be used in coal blends for the production of metallurgical coke, preserving the required quality, with lower cost. The quality of metallurgical coke may be determined by the efficiency of its chemical, physical and thermal functions inside the blast furnace. For the production of hot metal, any modification in the constituents of the raw materials may have a direct influence on the blast furnace productivity and in the final quality of steel. From the thermal degradation analyzes such as coke reactivity index (CRI) and coke strength reaction (CSR), cold resistance (DI) and immediate analyzes, it may define the quality of metallurgical coke produced with biomass aiming at relating the parameters that interfere in the particularities of the material function in the blast furnace. Some results show that it is possible to use 2% of eucalyptus sawdust in the coal mixture.

Keywords: Coke; Cokemaking; Biomass; Sawdust; Steelmaking.

1. Introduction

Steel is the most used metal in the world, and its production is associated to the economic development of a country. However, it is known that steel production generates a lot of solid and liquid waste, as well as emitting a large amount of gases. However, its processes may be at the forefront of recycling and reusing, not only its waste, but also of other process waste. Steel production accounts for about 4-7% of all carbon dioxide emissions in the world and most of these emissions may be associated to the use of fossil fuels, mainly using coke and coal (Wang, 2015).

The introduction of the concept of sustainable energy points to the increasing use of clean and renewable energy sources (biomass, wind and solar). Today there is an international consensus to reduce pollutant gas emissions by reducing fossil fuels. The steel industry therefore needs to redouble its efforts to adjust its operational processes to the commitment to protocols and conferences of recent years. The combination of more energy efficient technologies, such as biomass use, energy cogeneration, material life cycle optimization and eventually carbon sequestration may result in significant reductions in energy consumption and the amount of carbon dioxide emissions. It is noteworthy that the use of this potential may present high costs, as this scenario is still under development in the world and still requires research and investment (Suopajärvi, 2017).

Due to the intense competitiveness in the steel market, advancing production processes, reducing costs and minimizing environmental impacts are fundamental requirements today. These factors stand out for being paramount in the steel research sector (Souza, 2016).

With a growing imposition to reduce CO_2 emissions in the steel mills, mainly because of using metallurgical coke, since it is a product derived from fossil fuels, the use of alternative materials in this process is now being analyzed in several aspects (Silva, 2016).

The cost of producing coke represents approximately 40% of steel production costs, and it is essential for the hot metal production process in the blast furnace (Osório, 2008).

Compared to plastic and related waste, biomass is a source of perspective for replacing fossil fuels in the future, as it is abundant, renewable, clean and carbon neutral (Quan, 2016).

In this way, the insertion of sawdust biomass as a new carbonaceous raw material used in coal mixtures for the production of metallurgical coke, as long as it preserves the required quality for its application in the blast furnace, mainly CSR (Coke Strength after Reaction), CRI (Coke Reactivity Index), and DI (Drum Index), while maintaining a lower productive cost, is a viable possibility for the steel market. As well as the cost of this raw material being lower, its abundance and its high carbon content are significant factors that contribute to the productivity and the good functioning of the blast furnace.

The quality of the coke may be determined through its performance in the blast furnace, being defined from the analysis of its performance, and the factors that influence it during the process in the reactor (Souza, 2016).

In this sense, this study sought to evaluate the influence of the addition of wood biomass and sawdust in the production of metallurgical coke. The CSR, CRI and DI tests performed are shown herein, comparing the different mixtures produced in a pilot coke oven.

2. Development

The experiments in order to characterize the metallurgical coke produced with mixtures of mineral coal and sawdust were carried out as follows:

- Sampling of raw materials for the formulation of mixtures for metallurgical coke production on a pilot scale;
- Physical and chemical characterization of coal and additives, sawdust and wood, used in the mixtures;
- Production of metallurgical coke in a pilot oven;
- Immediate analysis of metallurgical coke produced with different mixtures and additives;
- Analysis of reactivity and degradation after reaction to CO_2 (CRI and CSR).

The nomenclature used for the samples, which is in this study, are described in Table 1.

Table 1 - Description of the base mix composition in the hangings.

Charge	CB(%)	Waste Wood (%)	Sawdust (%)
Coal Base Mixture (CB)	100	0	0
CB with Waste Wood (CBWW2%)	98	2	0
CB with Sawdust (CBS2%)	98	0	2
CB with Waste Wood (CBWW5%)	95	5	0
CB with Sawdust (CBS5%)	95	0	5

A pilot furnace from Gerdau Ouro Branco, manufactured in 1989 by Carbolite Furnace with the Coal Research Establishment in England, was used to implement this research. The dimensions of the pilot furnace are: 455 mm wide x 930 mm long x 830 mm in height, with a useful volume of 0.350 m^3 and a load capacity of 250 kg (dry basis) at a load density of 750 kg / m^3.

2.1 Chemical analysis

Figure 1 presents the results obtained in the analysis of ash and the results of the analysis of sulfur in the coke produced with the addition of biomass, for both wood and sawdust.

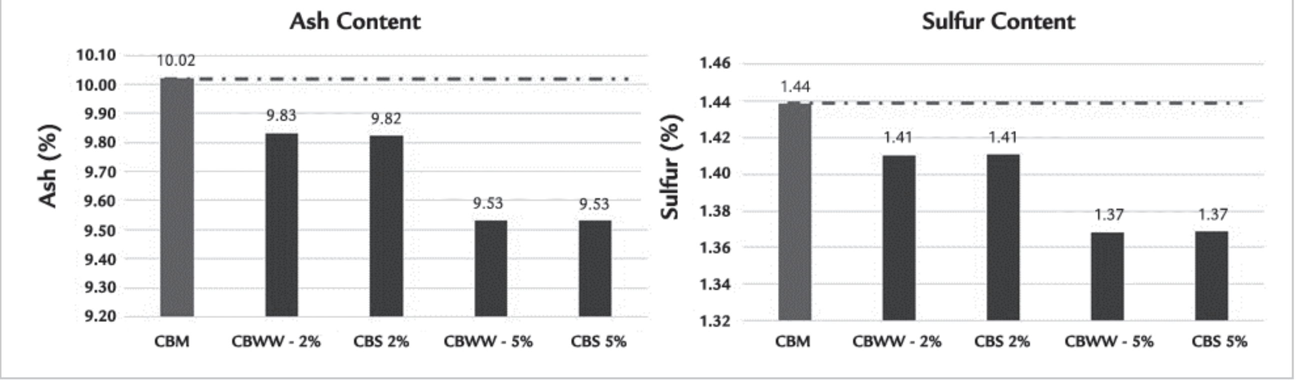

Figure 1 - Ash and sulfur analysis of coke produced with different mixtures.

It is possible to see that there is a reduction in ash and sulfur content with an increase in the share of biomass, due to its low ash and sulfur content. In general, for 1% of biomass addition, a drop of 0.01% in the ash content and 0.02% in the sulfur content of the coke is generated. Low values of sulfur and ash contribute positively to the base mixture that will be turned into coke, culminating in the low variation of ash and sulfur obtained (Montiniano, 2014).

2.2 DI, CSR, CRI

The Drum index is an important indicator to evaluate the quality of the produced coke. Basically, this test consists of placing a sample inside a drum and rotating it with speed and in directions defined by standards. It is a very common test in steel mills to assess resistance to coke drumming. Figure 2 shows the results for the DI of different mixtures.

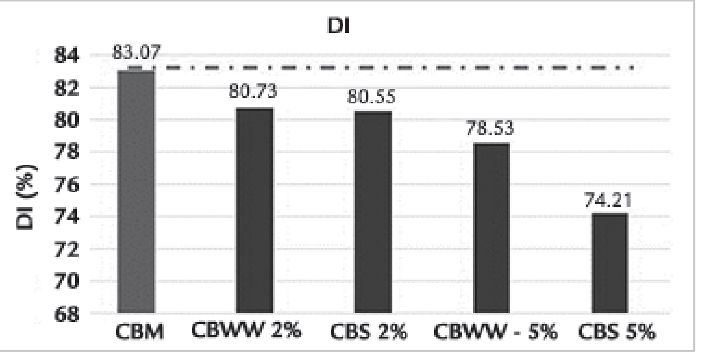

Figure 2 - Drum Index results for coke produced from different mixtures.

As found by Montiniano *et al.* (2014), the addition of sawdust causes an increase in the porosity of the metallurgical coke, and it may influence mechanical strength, which can be reinforced by Quan (2016) conclusions. The increase of inert particles during the plastic state decreases the participation of the necessary components to reach a state of agglomeration. This behavior may be clearly seen in the graph of Figure 2, in which the DI values decrease with the increase in the participation of both wood and sawdust. No significant differences were found between the levels with 2% wood and 2% sawdust, which presented an average reduction of 2.43% in relation to the reference base mixture. For the 5% levels, a significant drop in the values is noted, reaching the value of 8.86% for 5% sawdust and 4.54% for 5% wood.

CRI is defined as the percentage of mass lost during the test by injection of CO_2 under established conditions, whereas the CSR is a known index to evaluate the coke resistance after the CO_2 reaction. Highly reactive coke with a CRI value above that specified (<25%) may promote the generation of coke breeze in the blast furnace, affecting its permeability (Nomura, 2007). The results of CSR and CRI are shown in Figure 3.

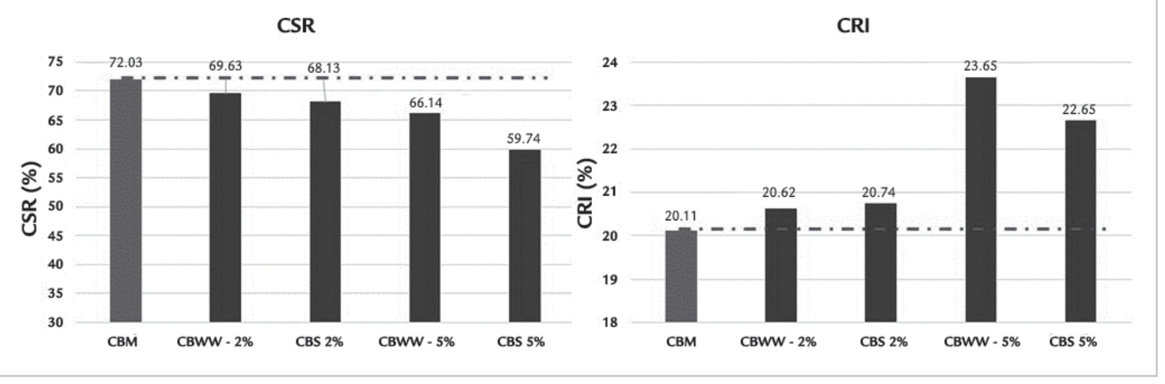

Figure 3 - CSR and CRI of coke produced with different mixtures.

There was an inverse and direct relationship between participation of sawdust and wood in the CSR and CRI, respectively. The addition of 2% sawdust generated a 3.9% drop in CSR and a 0.63% increase in reactivity, against the expressive 12.29% drop in CSR and a 2.54% increase in reactivity for adding 5%. When compared to sawdust 2%, wood 2% showed a lower drop in CSR values (1.5%) and a smaller increase in CRI values (0.12%). Wood 5% showed an even higher CSR value (66.14%) in relation to the sawdust level 5% (59.74%), with an increase in CRI to 23.65% against 22.65 % of sawdust.

As in the case of DI, the results may also be interpreted based on the volume of pores present in the coke, which end up facilitating the diffusion of CO_2 in its structure, as related by Montiniano (2014), Quin (2014) and Quan (2016). Bearing in mind that both sawdust and wood have a greater loss of volatiles during the softening phase than coal, in which sawdust has a greater homogeneity of distribution in the coke matrix, with significantly smaller particle size distribution than wood. This generates a different biomass distribution along the structure, with different behaviors of the solid during contraction, providing different amounts of cracks and pores.

2.3 Particle size distribution and yields

The yield of a mixture in coking is defined as the mass of the coking divided by the mass of the coal mixture added in the coking oven. The lower the yield, the higher the volatile content in the coals, since they leave the system in the process. Figure 4 demonstrates the performance of the mixtures for all levels of tests.

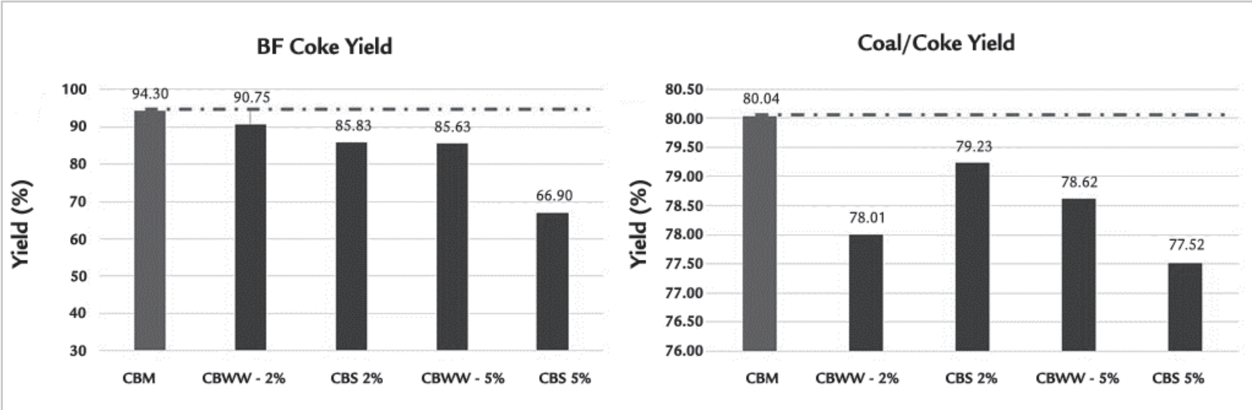

Figure 4 - Results of blast furnace and coke / coal yields.

Seeing these graphs is possible to say that there is an indirect relationship between the participation of biomass in the mixture and the coke yield for the blast furnace; what stands for, the coke mass above the coke breeze granulometry divided by the total mass of coarse coke. The most satisfactory result was obtained with the participation of 2% of wood, presenting a fall of only 3.55%, and the worst of the scenarios with 5% of sawdust, presenting a fall of 27.4%. Regarding coke / coal yields, wood and sawdust showed the opposite behavior, where the participation of 5% (1.42%) of wood generated a smaller drop in yield than the participation of 2% (2.03%), and sawdust showed a smaller decrease for the participation of 2% (0.81%) than for 5% (2.52%). In Figure 5 it is possible to note the yield of metallurgical coke and coke breeze.

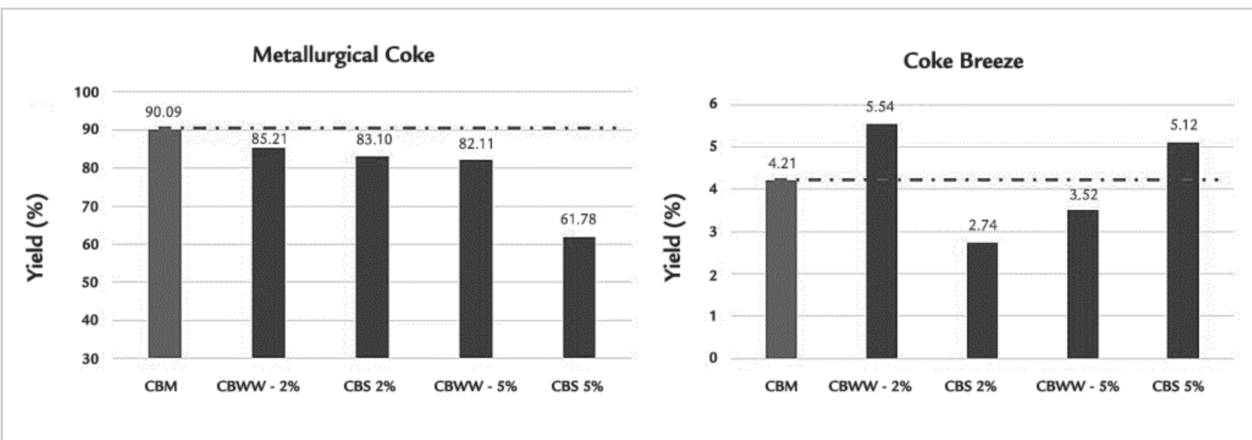

Figure 5 - Results of the fraction of metallurgical coke and breeze produced.

The change in yield may also be evidenced by the change in the production of metallurgical coke and coke breeze. The increase in the share of biomass generated a reduction in the fraction of metallurgical coke due to the increase in the volatile material present in the mixture that was coked, as shown by Quan (2016) and Montiniano (2013). Opposite to the inverse and direct relationship between the generation of coke breeze and participation of sawdust and wood, respectively.

Table 2 - Analysis of the manufacture of metallurgical coke with the addition of biomass.

Metallurgical Coke 2017(t)	Coke Economy -2%(t)	Emission Factor (tCO_2/unit)*	Avoided Emission (tCO_2)
2076.180	41523.6	3.059	127020.69

WSA Factor*

According to the analysis carried out above, there is a significant reduction in CO_2 emissions, and a considerable profit in the economy of mineral coal used in the process, due to the use of 2% sawdust to replace mineral coal.

2.4 The Effect of DI, CRI and CSR parameters on coke-rate

The decrease in DI leads to a reduction in particle size during handling of the coke, and it causes greater fragility to support the load column inside the blast furnace, with a considerable increase in the coke-rate. This may cause caging and load slip.

With the decrease in the CSR, a decrease in the granulometry of the coke occurs during its handling. This weakens the support of the load column inside the blast furnace and increases the coke-rate, as observed. This may also cause caging, load slip and slag return in the tuyeres due to the low permeability of the coke in the hearth.

The increase in CRI accelerates the reduction of coke granulometry in contact with CO_2, having a negative effect on the charge permeability in the granular zone and in the hearth, showing an increase in the coke-rate. This may also cause caging, load slip and slag return in the tuyeres during the caging cutting process due to the low permeability of coke in the hearth (Braga, 2010).

3. Conclusions

The use of eucalyptus wood biomass as an alternative raw material for the production of metallurgical coke proved to be viable only in its composition having ranges of up to 2%.

The CSR reached values of 69.63% and 68.13% for wood and sawdust, respectively, with a small increase in reactivity when compared to the reference coke, with values of 20.62% for wood and 20.74% for sawdust. All values were satisfactory from an industrial point of view. The DI values also showed greater decreases for the 5% shareholdings, confirming their unfeasibility.

The coke / coal yield did not show great variations between the different holdings and biomasses, while the coke yield BF showed better results for the wood share in 2% (90.5%).

There was an increase of 3.55% in the production of coke breeze compared to the reference base mixture.

In general, the participation of 2% granulated wood was more viable than in the form of sawdust.

Acknowledgments

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