STUDY CONCERNING THE INFLUENCE OF ADDING BIOMASS AND INCREASING THE COAL BLENDING BULK DENSITY OVER THE QUALITY OF HARD COKE PRODUCED IN THE PILOT COKING OVEN[1]

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Abstract

The herein paper presents the quality results of the coke produced in pilot coking oven by using blends of mineral coal and biomass (carbonized rice hull and charcoal) and varying the bulk density of the charging. On the first stage of the herein referred study, it was applied coal blends containing briquettes of charcoal fines, in the proportion of 2%, besides varying the charging bulk density from 34.7 to 52.4 lb/ft3. The quality results of the produced coke indicated a rise on the Drum Index from 80.4% to 84.1% and a fall on reactivity from 27.3% to 22.7%. In blends with up to 4% of charcoal addition and charging density established at 52.7 ± 0.1 lb/ft3, it was observed a rise on the Drum Index from 83.9% to 85.%, and an increase on the coke reactivity from 23.2% to 27.5%, as well as an increase on the coking pressure from 1.59 to 4.84 psi. On the second stage of such study, it was assessed the effect of using briquettes made from charcoal fines and rice hull coal over the quality of the produced coke. The results indicated a rise on the D.I. from 77.9% to 81.1%, and a reduction on the coke reactivity from 36.4% to 25.4%, besides an increase on the coking pressure from 0.89 to 2.99 psi.

Key words: Coal; Coke plant; Coke; Biomass; Reactivity; Coking pressure; Drum index; Bulk density.

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1 Introduction

Brazil is a great importer of mineral coal and it presents a high potential concerning the use of biomass for steelmaking purposes. The sustainable reforestation, besides bringing benefits to the environment, such as contributing with the reduction on the production of gases that cause the greenhouse effect, also give room to an increase on the international competitiveness of the domestic industry, as long as the appropriate technologies are available.

The numerous options for applying the biomass and the possibilities that show up due to new alternatives of production shall make the use of the available resources feasible, yet in compliance with the sustainability and efficiency criteria applicable to each region of the country. In a large steel plant, the consumption of mineral coal is around three million ton a year. The mineral coal is the raw-material that answers for 40% of the pig iron production cost in the blast furnace. Another important factor that occurs in such mineral coal burning process is the emission of CO_2 to the atmosphere, contributing to an increase on the environmental pollution. The partial replacement of such non-renewable raw-material by a non-polluting renewable source on the pig iron production cycle at a steel plant will always be welcome, once besides reducing the production cost due to its lower cost and to the receiving of carbon credits, it will also contribute with the reduction of the greenhouse effect and, hence, of the global warming.(1)

2 MATERIALS AND METHODS

2.1 Biomass Characterization

The first stage of the study aimed at characterizing the materials received at the laboratories of the Steelmaking Process General Management Dept., which in such case were charcoal fines (biomass 1), carbonized rice hull (biomass 2), mineral coals and blends of mineral coal with biomass, as well as the coke produced on the pilot coking oven.

The analyses were accomplished based on the application of worldwide known reference Norms. The pieces of equipment applied on the process are shown as follow:

Thermogravimetric Analyzer LECO - TGA - 501.

- Total Sulfur Automatic Analyzer LECO - SC 132.
- YOSHIDA Plastometer Model YM1092-F.
- PRIZE Electric Oven (F.S.I.).
- Analog Electric Oven NA 3400 (establishment of the reactivity index).
- Rotary Drum (establishment of the Drum Index-150/15).
- Muffle to dry the coke.
- Electric Sieves for determining the coke medium grain size.
- Coking Pilot Oven heated by natural gas.
- Self-generating Combustion Oven.
- Electronic Scanning Microscope (MEV).

2.1.1 Char coal fines characterization

The samples of charcoal fines sent by the Ecobriquetes Reciclagem company were characterized at the central laboratory and the obtained results are shown in the Table 1.

Table 1 - Characterization of the charcoal fines.

Volatile Matters (%)	Ashes (%)	Fixed Carbon (%)	Total Sulfur (%)	Fluidity (ddpm)	FSI
27.5	3.3	69.2	0	N.D.	N.D.

2.1.1 Rice hull coal characterization

The carbonized rice hull presents low density, making its transportation in great amounts quite burdensome. So as to facilitate its handling and application in the blend with charcoal, the biomass was subjected to an agglomeration and briquetting process, as per shown on figures 1a and 1b. The briquettes produced with carbonized rice hull have made its application on the mineral coal blends easier.

Figure 1a – Briquette made from rice hull coal

Figure 1b – Briquette containing 3% of charcoal fines and 2% of rice hull coal

Table 2 shows the analysis results of the carbonized rice hull quality parameters, hull which have being applied on the coal blends.

Table 2 - Characterization of carbonized rice hull quality.

Volatile Matters (%)	Ashes (%)	Fixed Carbon (%)	Total Sulfur (%)	Fluidity (ddpm)	FSI
6.3	90.7	3.0	0.01	N.D.	N.D.

For checking the carbonized rice hull structure it was used an electronic scanning microscope, where it was determined the existence of voids in all of the analyzed section. Illustration 2 shows the rice hull structure.

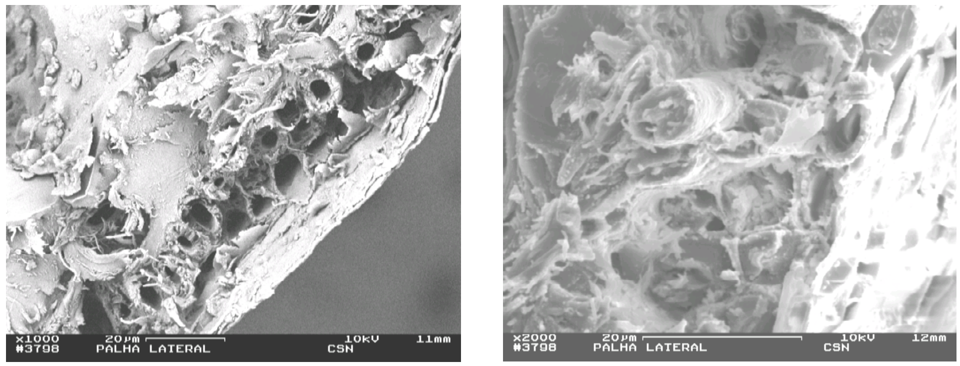

Figure 2 – Rice hull structures analyzed on MEV.

2.1.2 Coal and blend characterization applied on the tests

For developing the blends, it was selected four mineral coals of low, medium and high volatile matter content, which are frequently applied on the coal blends at CSN – Companhia Siderúrgica Nacional (National Steel Company) upon producing hard coke. Table 3 shows the quality of the coals applied on the tests.

Table 3 - Characterization of the cokeable coals quality.

Coal Type	Volatile Matter Content (%)	Ashes Content (%)	Sulfur Content (%)	Fixed Carbon Content (%)	Fluidity Log (ddpm)	FSI	Reflectance (Re)
HV	30.76	7.96	0.84	61.28	4.18	7.5	0.88
MV1	23.17	8.64	0.63	68.19	3.64	9.0	1.15
MV2	20.26	9.03	0.57	70.71	2.42	9.0	1.39
LV	16.66	7.15	0.90	76.19	1.447	8.5	1.51

At the central lab six blends containing biomass were developed and characterized and than charged into the coking pilot oven for producing and characterizing coke in pilot range. The compositions and parameters of the coal blends quality are shown on the Table 4.

Table 4 – Characterization of the coals blends with biomass.

Blend Number	Applied Blends	Content in Volatile Matter (%)	Ashes Content (%)	Fixed Carbon Content (%)	Sulfur Content (%)	Fluidity (log ddpm)	Reflectance (Re)
M-1	100% MV	23.17	8.64	68.19	0.63	3.64	1.15
M-2	98% MV+2% CH	23.26	8.53	68.21	0.62	3.59	1.13
M-3	97% MV+3% CH	23.30	8.48	68.22	0.61	3.57	1.12
M-4	96% MV+4% CH*	23.34	8.43	68.23	0.60	3.55	1.10
M-5	10%AV+60%MV+30%BV	21.69	8.16	70.15	0.73	2.91	1.26
M-6	10%AV+57%MV+30%BV+3%PRC**	21.20	10.63	68.17	0.71	2.80	1.22
M-7	10%AV+55%MV+30%BV+3%CV+2%PRC	21.49	9.65	68.86	0.69	2.77	1.20

**   CH = charcoal; ** PRC = carbonized rice hull*

2.1.3 Method

The preparation of the briquettes made from carbonized rice hull and the briquettes made from the blend of charcoal fines with carbonized rice hull was performed at the company named Ecobriquetes reciclagem ME. The referred company is located in Volta Redonda – RJ and its expertise is the development of briquetting processes and equipment, that is to say:

Sprayers
1. Intensive Mixers
2. Piston Briquetting Machines
3. Hydraulic Briquetting Machines
4. Drying Kilns

In association with the briquetting, a number of different organic binder was developed so as to provide enough mechanical resistance in order to allow both, handling and charging of the material. The charcoal grinding took place with no granulometric size adaptation. After the homogenization with the binder in an intensive mixer (hydrolyzed corn starch), the blend was inserted into the briquetting machine, which in response to the impact, forced the passage of the material through a cylindrical die. The resulting briquettes were subjected to forced drying in kilns at 130º C, and after 5 hours of such a drying process, they were left to cool at ambient temperature.

The production of coke at the coking pilot oven was performed in compliance with the following conditions:

Temperature of the oven:	1050º C.
Coking time:	16 hours
Moisture content:	1.3%
	6.0%
Bulk density:	555.8 kg/m3

	752.9 kg/m3
	842.6 kg/m3
	844.2 kg/m3
	845.8 kg/m3
Blend grain size:	→80 to 84% smaller than 3.2 mm
	→70 to 75% smaller than 3.2 mm

3 RESULTS

The first charging sequence was accomplished with a blend containing 2% of charcoal and 98% of coal of medium content of volatile matter. At this stage it was considered a variation of the charge bulk density from 34.7 to 52.4 lb/ft3 and the blend grain size in the range of 80 to 84% smaller than 3.2 mm. The moisture content in the blend was varied from 1.3 to 6.0%. The bulk density effect over the coking pressure and the quality of the coke produced at the coking pilot oven are shown in table 5.

Table 5 – Effect of the bulk density on the coking pressure and on the quality of the coke produced in the coking pilot oven.

Oven number test / blend	Bulk Density (lb/ft^3)	Coking Pressure (psi)	D.I. (150/15) (%)	Reactivity (%)
1/ M-2	34.7	0.59	80.4	27.3
2/ M-2	47.0	1.28	81.9	22.8
3/ M-2	52.4	1.59	84.1	22.7

For performing the second sequencing of tests, the blend bulk density was maintained practically constant around 52.7 ± 0.1 lb/ft^3 and the content of charcoal fines in the blend varied. Table 6 shows the achieved coke quality results.

Table 6 – Coke quality produced with the charcoal elevation in the coal blend.

Oven number test / blend	Charcoal in the blend (%)	Bulk Density (lb/ft^3)	D.I.(150/15) (%)	Reactivity (%)
4/M-1*	0	52.8	83.9	23.2
5/M-2*	2	52.7	84.1	22.7
6/M-3*	3	52.6	84.3	25.8
7/M-4*	4	52.7	85.1	27.5

On the third sequencing of tests, it was added M-1 biomass briquettes to the blend (carbonized rice hull) besides varying the blend bulk density. The results concerning the achieved coke quality are shown on Table 7.

(*) On M1, M2, M3 and M4 blends only one mineral coal was applied (MV1).

Table 7 – It shows the quality results of the coke produced on the pilot oven by using blends containing carbonized rice hull.

Oven number test / blend	Briquette of Carbonized Rice Hull Coal (%)	Bulk Density (lb/ft^3)	Coking Pressure (psi)	D.I. (150/15) (%)	React ivity (%)
8/M-5	0	48.6	2.95	79.1	32.5
9/M-6	3	48.6	2.72	80.0	35.8
10/M-6	3	50.1	4.39	81.0	33.2
11/M-6	3	52.2	7.76	81.2	34.4

For the tests final sequencing it was applied M-3 blends, in addition to the biomass briquettes containing charcoal fines and carbonized rice hull coal. At this stage it was kept a biomass percentage of 5% and the furnace charging bulk density was varied. Table 8 shows the obtained results in terms of both, coke quality and coking pressure.

Table 8 – It shows results in terms of both, quality and coking pressure of the coke produced with M-7 blend and with bulk density variation.

Oven number test / blend	Biomass Briquette in the Coal Blend (%)	Bulk Density (lb/ft^3)	Coking Pressure (psi)	D.I. (150/15) (%)	React ivity (%)
12/M-7	5	48.4	0.89	77.9	36.4
13/M-7	5	50.0	2.08	79.5	33.9
14/M-7	5	52.1	2.99	81.1	25.4

5 RESULTS ASSESSMENT AND COMMENTS

The influence of the bulk density increase from 34.7 to 52.4 lb/ft3 on the coke quality and on the coking pressure was determined in the coal blend that have included charcoal fines, leading to an increase on the coking pressure from 0.59 to 1.59 psi. Such an increase was also encountered at the paper developed by Khan et al.[(2)] As to the coke quality, it was verified a rise on the D.I. from 80.4 to 84.1%, fact which has also been verified by Nomura et al.,[(3)] giving room to a reduction on the coke reactivity from 27.3% to 22.7%. Figures 3, 4 and 5 show such a behavior.

The hold of the bulk density between 52.7 ± 0.1 lb/ft^3 and the increase on the biomass participation (charcoal fines) at the coal blends have lead to a rise on the Drum Index and on the coke reactivity, as well as on the coking pressure. Figures 6, 7 and 8 show the occurred variations.

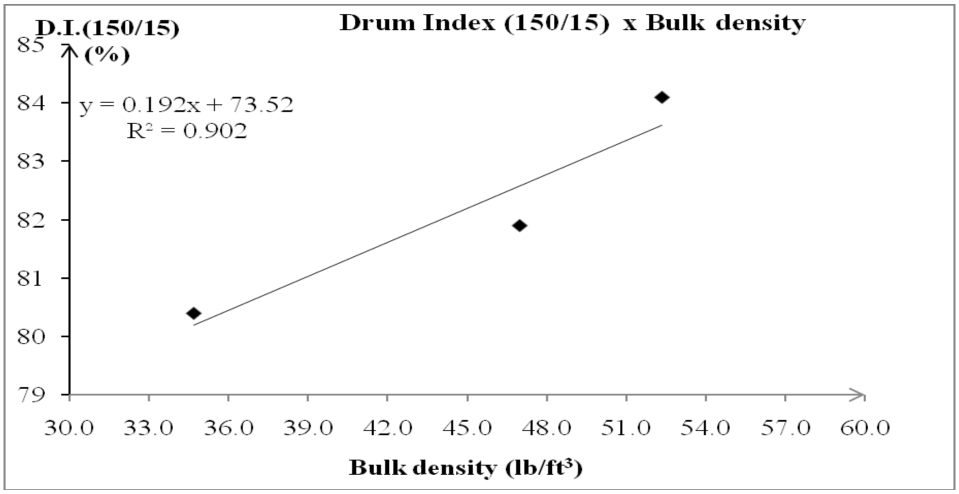

Figure 3 – It shows the correlation between the Drum Index and the Bulk Density.

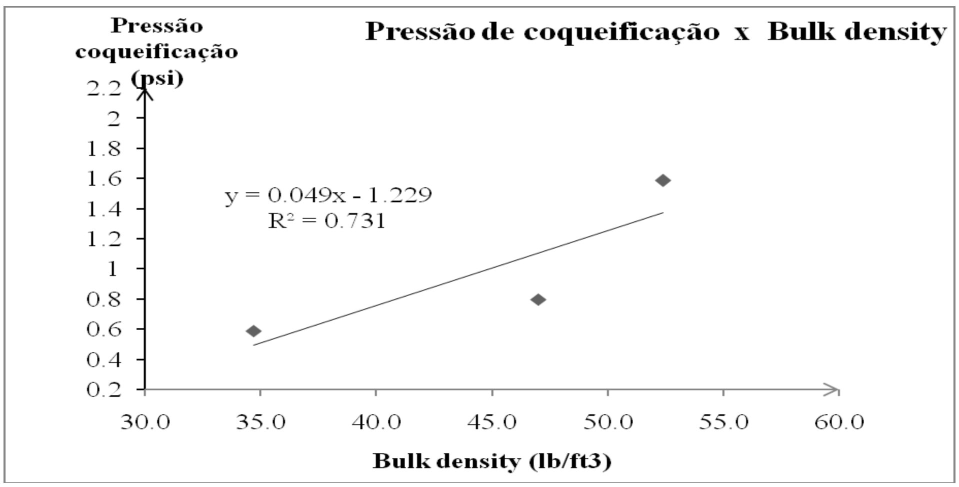

Figure 4 – It shows de correlation between the coking pressure and the bulk density.

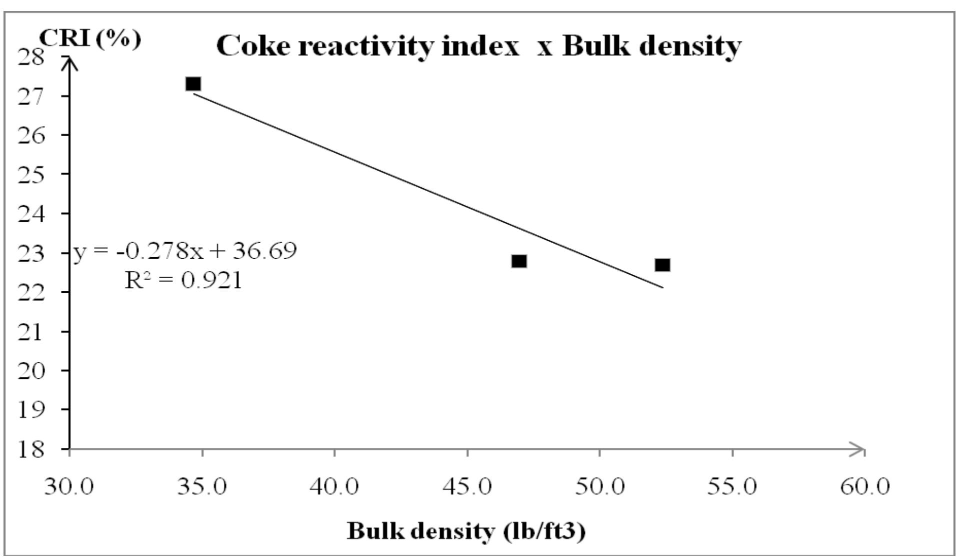

Figure 5 – It shows the correlation between CRI and bulk density.

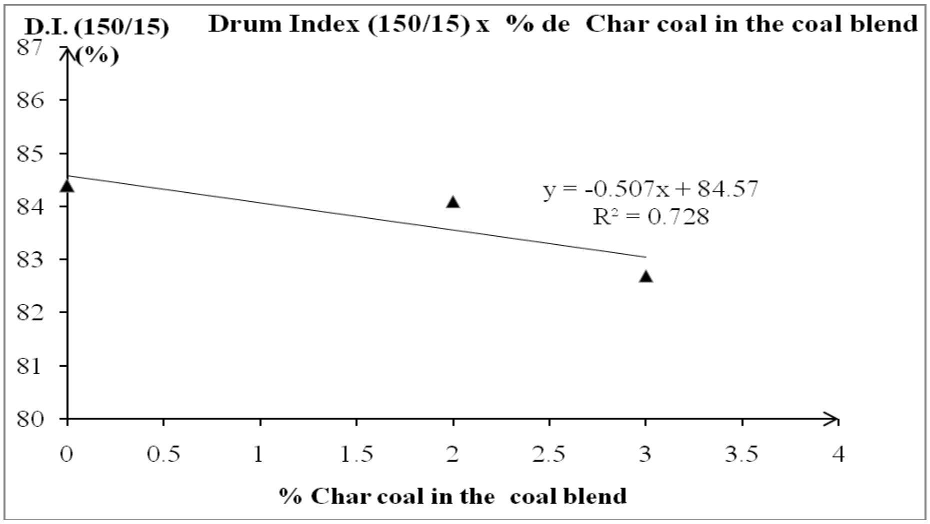

Figure 6 – It shows the correlation between the D.I. and the charcoal % in the coal blend.

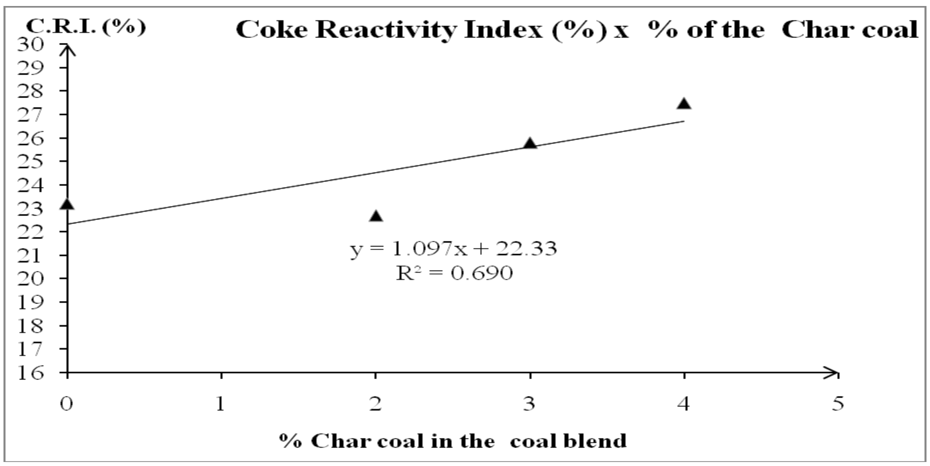

Figure 7 – It shows the correlation between CRI and charcoal percentage.

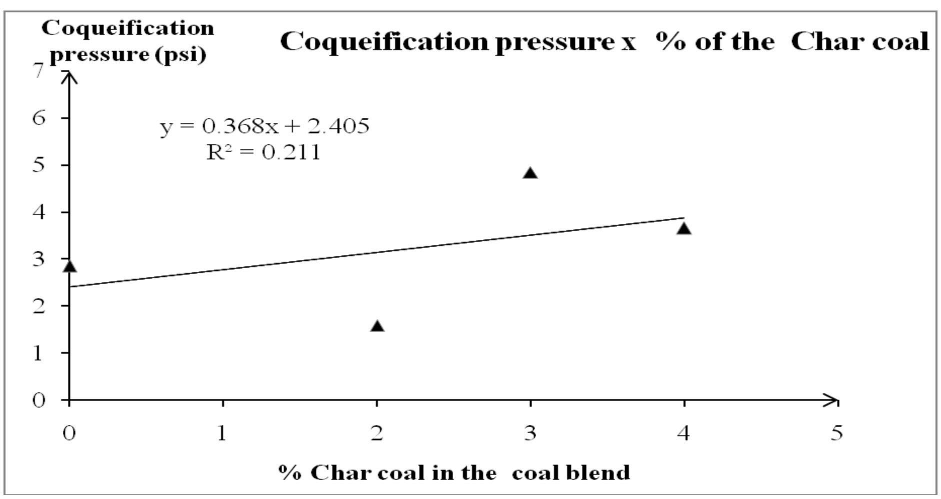

Figure 8 – It shows the correlation between the coking pressure and the charcoal percentage in the coal blend.

On the M-6 blend, besides varying the bulk density, it was added 3% of rice hull coal briquettes. The results showed the rise on the coke D.I., with an increase of the bulk density, fact which has been corroborated on the tests where charcoal was added to the blend. The highly stressed point was the increase on the coking pressure due to the bulk density elevation, fact which has also been previously corroborated. Figures 9, 10 and 11 show the quality behavior of the coke produced with 3% of carbonized rice hull in the coal blend.

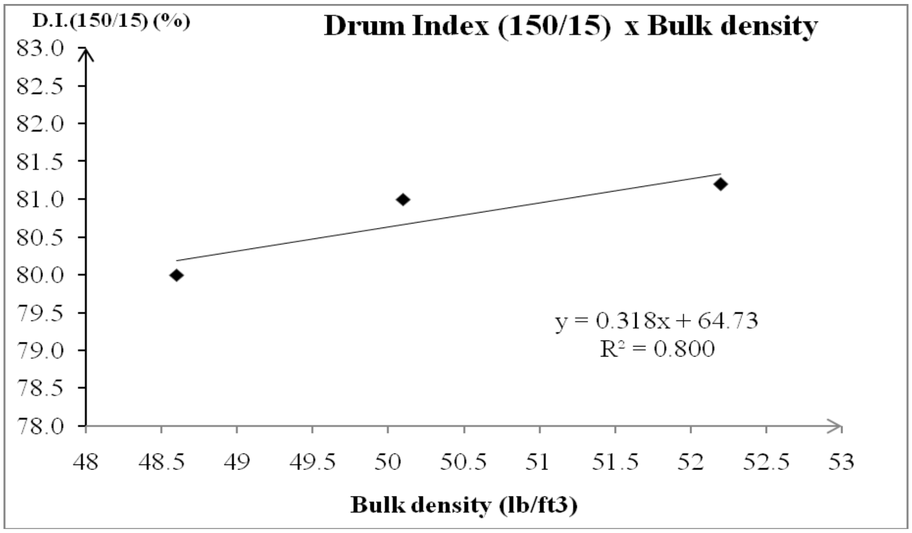

Figure 9 – It shows the correlation between the D.I. and Bulk Density of the quality of the coke produced with 3% of biomass (coal rice hull) in the coal blend.

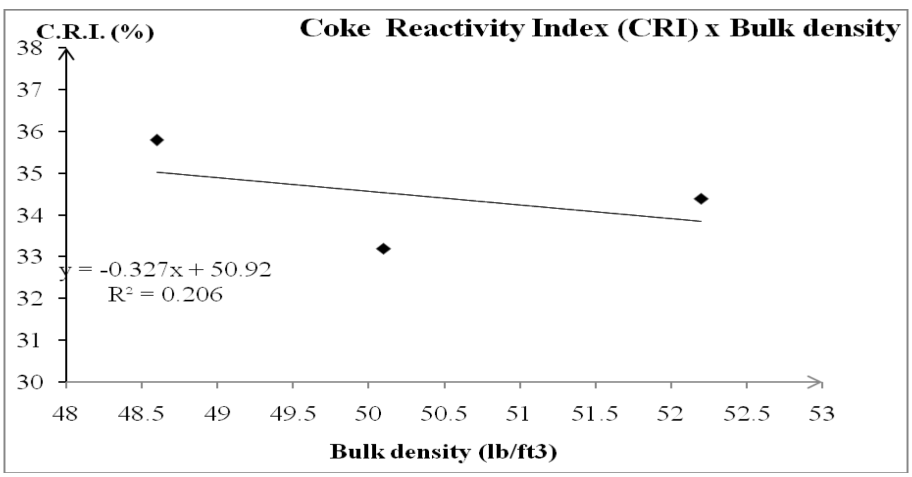

Figure 10 – It shows the correlation between CRI and Bulk Density concerning the quality of the coke produced with 3% of biomass (coal rice hull) in the coal blend.

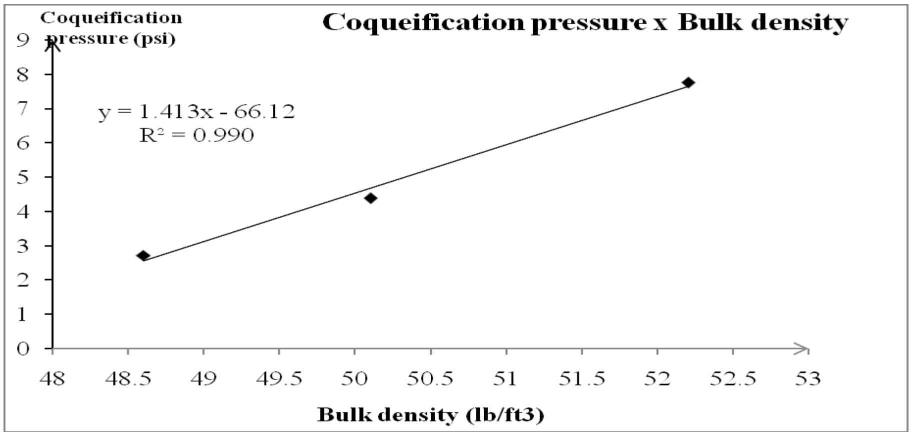

Figure 11 – Correlation between Coking Pressure and Bulk Density

The effect of the bulk density over the quality of the coke produced with coal blend containing 5% of biomass is shown on figures 12, 13 and 14. Correlations were more significant, that is to say, the coke DI presented a rise from 77.9% to 81.1% due to the bulk density increase, corroborating the same behavior obtained from the previous tests. The bulk density increase has significantly reduced the coke reactivity and the coking pressure was linearly increased.

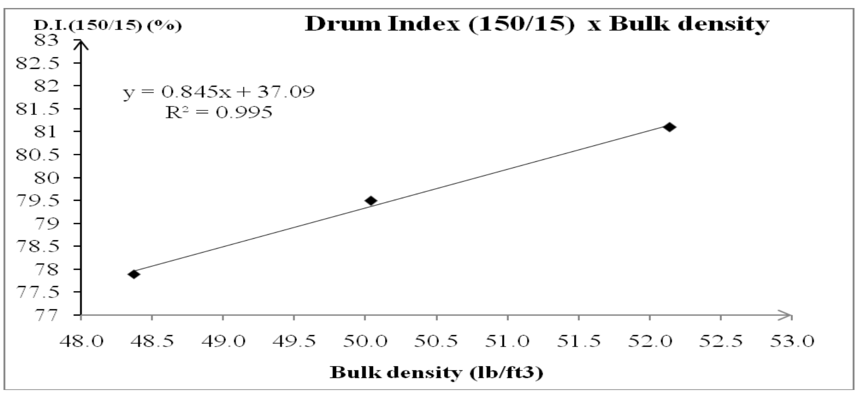

Figure 12 – Correlation between D.I. and Bulk Density (coal blend with 5% of biomass addition)

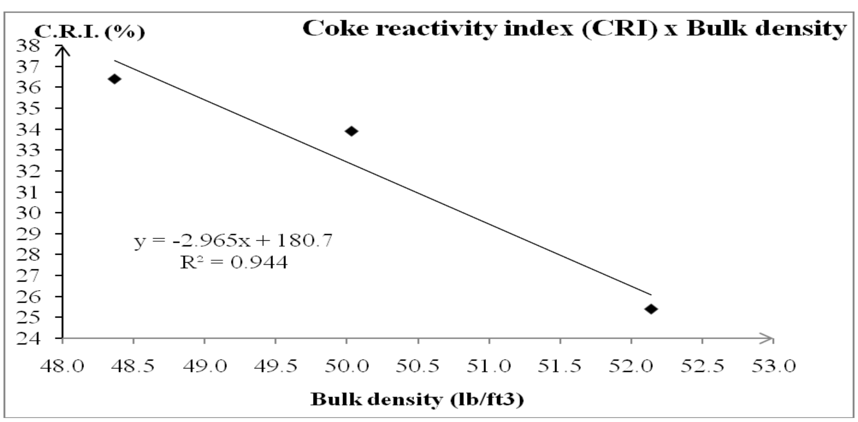

Figure 13 – Correlation between CRI and Bulk Density

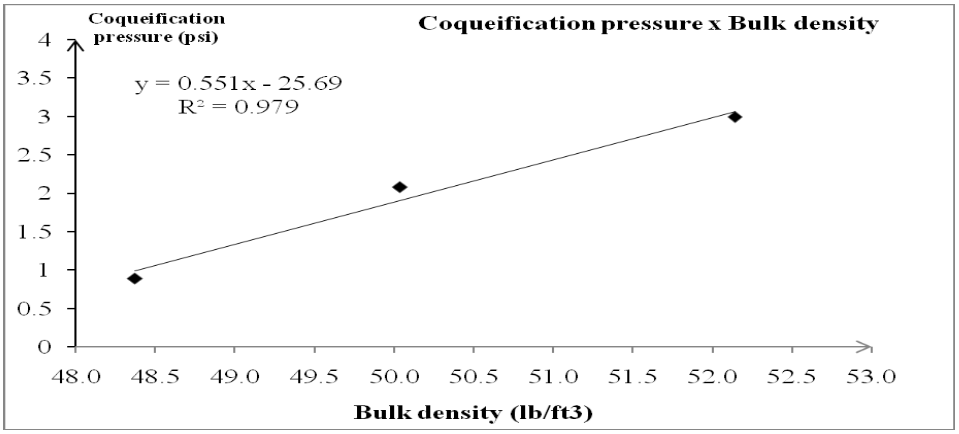

Figure 14 – Correlation between Coking Pressure and Bulk Density concerning the coal blend with 5% of biomass addition**.**

6 CONCLUSION

The biomass addition and the bulk density variation at the coal blends produced the following effects at the coke quality and at the coking pressure:

- The increase on the bulk density from 34.7 to 52.7 lb/ft^3 in coal blends with 2% of charcoal briquettes besides causing a rise on the Drum Index from 80.4% to 84.1%, also reduced the coke reactivity from 27.3% to 22.7% and increased the coking pressure from 0.59 to 1.59 psi.
- Both, the increase of the charcoal fines briquettes content in the coal blends from 0 to 4% and the charging the bulk density of about 52.7 ± 0,1 lb/ft^3 have caused a rise on the coke DI from 83.9% to 85.1%, besides increasing the coke reactivity from 23.2% to 27.5%.
- The increase of the bulk density from 48.6 to 52.2 lb/ft^3 in the coal blends and the addition of 3% of carbonized rice hull briquettes to the mineral coal blends, besides having allowed a rise on the coke DI from 79.1% to 81.2%, have also caused a minor change on the coke reactivity and a major increase on the coking pressure from 2.95 to 7.76 psi.
- The elevation of the bulk density in the coal blends, plus the addition of biomass briquettes containing charcoal fines and carbonized rice hull coal fines, at a 5% proportion, besides having produced a rise on the coke DI from 77.9% to 81.1%, have also allows a reduction on the coke reactivity from 36.4% to 25.4% and an increase on the coking pressure from 0.89 to 2.99 psi.

Note
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