INFLUENCE OF DIFFERENT TYPES OF SOLID FUELS ON THE QUALITY OF IRON ORE PELLETS[1]

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Abstract
Due to petroleum crisis, In the 80's, the solid fuel addition in the iron ore pelletizing process became an essential technology for pellets producers to minimize the production costs and to increase indurating machine productivity and reduction of cost. Since then, few studies were focused on the effect of different characteristics of solid fuel on physical and metallurgical properties of pellets. In this study, fourteen different types of solid fuels were investigated. Solid fuels were characterized at LASID-UFRGS (RS/Brazil) laboratories and pot grate tests were carried out at Tubarão Pelletizing Complex in Vitoria (ES/Brazil). The results showed correlations among solid fuel characteristics such as volatile matter, thermal analysis parameters and physical and metallurgical qualities of pellets. The results will be helpful for Vale's Pelletizing Department technical team to optimize the process and purchase solid fuel.
Key words: Pellets; Solid fuels; Quality and pelletizing process.

INFLUÊNCIA DE DIFERENTES TIPOS DE COMBUSTÍVEIS SÓLIDOS NA QUALIDADE DA PELOTA QUEIMADA DE MINÉRIO DE FERRO

Resumo
Devido à crise do petróleo, na década de 80, a adição de combustível sólido no processo de pelotização de minério de ferro tornou-se uma tecnologia essencial para produção de pelota para minimizar os custos de produção e aumentar a produtividade. Desde então, poucos estudos foram focados no efeito das diferentes características dos combustíveis sólidos nas propriedades físicas e metalúrgicas das pelotas queimadas. Neste estudo, quatorze diferentes tipos de combustíveis sólidos foram investigados. Os combustíveis sólidos foram caracterizados nos laboratórios LASID-UFRGS (RS/Brasil) e os testes de pot grate foram conduzidos no Complexo de Pelotização de Tubarão (Vitória/ES). Os resultados mostraram correlação entre algumas características como matéria volátil, parâmetros de análises térmicas e a qualidade física e metalúrgica da pelota queimada. Esses resultados serão úteis do time técnico do Departamento de Pelotização da Vale para otimizar o processo e para adquirir combustíveis sólidos.
Palavras-chave: Pelota queimada; Combustível sólido; Qualidade e processo de pelotização.

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1 INTRODUCTION

Due to petroleum crisis, in the 80's, solid fuel addition in the iron ore pelletizing process became an essential technology for pellets producers to minimize production costs and increase indurating machine productivity. Since then, although many studies have been done, few were focused on the effect of different characteristics of solid fuel on the physical and metallurgical properties of pellets.
In this study, different solid fuels were investigated such as, anthracite, bituminous coals, pet coke and coke breeze. They were characterized at LASID-UFRGS (RS/Brazil) laboratories and the pot grate (pilot plant) tests were carried out at Tubarão Pelletizing Complex in Vitoria (ES/Brazil). During pot grate tests, all the process parameters were kept constant e.g. pellets chemical composition, thermal profile and mixture carbon content.
The objectives of this work are (1) to develop technical knowledge on solid fuels to the pelletizing process and (2) to assess the influence of various solid fuels in the pelletizing process and quality of pellets.
The quality of pellet depends on not only different process parameters but also raw material and additives (fluxant, additives and binders) used. Solid fuel is one of the most important additive used because it is responsible for improvement on pellet quality, indurating machine productivity and oil or gas consumption during firing.
Different solid fuel addition and dosage are usually the milestone for pellet producers in order to guarantee customers needs and optimize production costs.
Before added, solid fuel must be ground – at least 65% < 0,045mm, in order to guarantee heat homogeneity during firing leading to overall quality improvement. Coarse solid fuel added has a negative impact on physical quality by increasing the porosity of pellets.
Physical and metallurgical qualities of pellets were evaluated according to ISO standards, e.g, abrasion, compressive strength, degree of reduction, static disintegration and swelling index.

2 IMPORTANT PARAMETERS OF REACTIVITY AND COAL RANK

The degree of alteration (or metamorphism) that occurs as a coal matures from peat to anthracite is referred to as the "rank" of the coal. Main parameters to ranking the solid fuels were carbon content, heating value and vitrinite content. This study considered solid fuels with different rank, e.g., high volatile bituminous coal to meta-anthracite.
The reactivity depends on coal characteristics and genesis. Differences in macerals physical and chemical properties reflect on their behavior during combustion and/or gasification. The liptinite group is more reactive and has a low ignition point, yielding a greater part of volatile matter. The next more reactive group is vitrinite and the inertinite is less reactive due to its more aromatic chemical nature. In turn, the coal char (residue of C after pyrolysis) and inertinite have a similar reactivity. [1]
The higher is the coal rank, the lower is the volatile matter and the reactivity, although some bituminous coals, due to high plasticity, can show lower reactivity than anthracite.[2] The changing in chemical structure and physical properties according to the increase of coal rank promotes a decrease in aliphatic chains and an increase in aromaticity, lowering the reactivity.
The coal mineral matter can also affect its reactivity. The mineral matter changes the reactivity of char not only by the catalytic effect (case of low rank coals), but also

affects the reactivity by changes introduced in the chemical structure (concentration of C active sites) and physical property (accessibility to reactant gas) of the chars of coal.[3] Studying the influence of different clays on the coal combustion it was concluded that the improvement in the reaction rate was due to the macroporosity increase (and not in surface area) and the reactant gas accessibility of during decomposition.[4]

High heating rates increase the volatile release temperature, therefore increasing the coal ignition temperature and the devolatilization rate.[5]

Thermogravimetric analysis (TGA) evaluates combustion behavior of solid fuels in low heating rates, considering characteristic parameters of thermal profile (reactivity and temperatures). The combustion profiles obtained are so distinct for different coal ranks and can be used to classify the coals by its combustibility. [6,7]

3 MATERIAL AND METHODS

Solid fuels were characterized considering chemical, physical, petrographic and thermal analysis. Chemical analysis considered ash, volatile matter, fixed carbon content, lower and higher heating value. Ash content of solid fuel affect the heating values as well as the higher the ash content the lower heating value. During solid fuel combustion part of the heat released is used to heat the inorganic matter (ash).

Considering the petrographic analysis, the coal microscopic organic constituents (macerals) are: vitrinite, inertinite, liptinite. Vitrinite is measured by different ash vitrinite coloring.

Firing conditions as well as firing profile, total firing time and carbon addition (1,0%) were kept constant for all solid fuels samples tested. It means that any optimization had been done.

The solid fuels tested can be seen in Table1, considering their rank according to ASTM. They were characterized at LASID-UFRGS (RS/Brazil) laboratories and the pot grate (pilot plant) tests were carried out at Tubarão Pelletizing Complex in Vitoria (ES/Brazil).

Table 1: Solid fuels selected to the study.

Sample	Types
A	High volatile coal
B	Medium volatile coal
C	Anthracite
D	Low volatile coal
E	Anthracite
F	Anthracite
G	Anthracite
H	Anthracite
I	Anthracite
J	Anthracite
K	Anthracite
L	Petroleum coke
M	Petroleum coke
N	Coke

Tests to characterize solid fuels were: chemical, ultimate, petrography, thermal, physical analysis and heating value. Tests of pellets quality parameters were abrasion, strength compression, RDI, GI, redutibility and chemical analysis of pellet.
The characteristics of solid fuel samples were evaluated according to ASTM and ISO standards and by thermal analysis. The proximate analysis, such as ash, volatile matter and fixed carbon, was carried out using ABNT NBR 8293, NBR 8289 and NBR 8290 standards. The higher heating and lower heating values were determined by ASTM 5865, and HGI was used the ASTM D 409 standards.
The maceral content of natural solid fuels was determined by petrography analysis whose sample preparation was based on regular procedure including cutting, mounting, grinding and polishing. Coal petrography was used to identify and quantify macerals groups, minerals, impurities and to measure vitrinite reflectance index.
Thermo-gravimetric tests were performed in a Netzsch STA 409C apparatus in which 30 mg of sample were spread at the bottom of the crucible. Temperature was increased from 25 to 1000^{o}C at a heating rate of 25^{o}C min^{-1} and the airflow rate was 50 ml min^{-1}. The combustion profile is the first derivative of the weight loss curve (DTG) and the reaction rate at any point is defined as $R=-(1/m_o)dm/dt$ where m_o is the dry-ash-free initial sample mass. The maximum reaction rate or maximum reactivity is denoted as $R_{máx}$.
Some relevant temperatures can be determined from the combustion profiles. Initial burning temperature (T_i) is defined in this work as that at which reactivity is 1/5 of the maximum reactivity.[6] Final or burnout temperature (Tf) is that at which combustion ceases and peak temperature (Tp) is that at which maximum reaction rate occurs [5].
The standard Tubarão Blast Furnace pellet mixture (iron ore pellet feed and additives) was prepared at pilot plant in Vitoria (ES) and different solid fuels were added considering 1,0% of fixed carbon in the mixture. The binary basicity of the pellets was kept constant by burnt lime addition.
The quality of pellets was evaluated according to ISO physical and metallurgical standards.

4 RESULTS AND DISCUSSION

Table 2 shows the characterization of the solid fuels through proximate analysis, heating values and grindability index.

Table 2: Proximate analysis, heating values and grindability index of the solid fuels.

Sample	Ashes (%)	Volatile Matter (%)	Carbon fix (%)	LHV	HHV	HGI
A	7.25	34.61	58.14	7500	7760	57
B	9.15	25.22	65.63	7560	7795	90
C	8.71	19.71	71.58	7210	7405	*
D	4.90	18.37	76.73	8060	8280	*
E	7.26	11.39	81.35	7720	7910	87
F	16.04	10.92	73.04	6700	6860	67
G	10.29	8.43	81.28	7390	7550	65
H	16.92	6.51	76.57	6865	7005	46
I	15.81	5.14	79.05	6385	6435	51
J	11.43	4.04	84.53	7030	7100	42
K	16.42	2.98	80.60	6695	6750	46
L	0.02	11.08	88.90	8435	8635	111
M	0.02	12.24	87.74	8455	8655	*
N	13.48	2.18	84.34	6555	6565	*

** The quantities of samples aren't enough to make the HGI test.*

According to proximate analysis, samples F, H, I and K showed high ash content (16,04%, 16,92%, 15,81% e 16,42%, respectively), whereas samples D, L, M showed low ash content. It can be seen in Table 3 that heating values are mainly affected by ash content in these coal rank.
Samples A and B showed the higher volatile matter content in comparison with other samples. These samples burn faster compared to lower volatile ones. Considering pelletizing process, low volatile matter has a positive impact on green pellet firing.
Samples H, I, J and K showed low HGI leading to high-energy consumption during grinding. Samples L, M, D showed the highest heating value and N sample showed the lowest.
The ash chemical analysis for all the samples can be seen in Table 3. Ash chemical analysis of petroleum coke was not determined due to its low content.

Table 3. Ash chemical analysis.

Sample	SiO_2	Al_2O_3	Fe_T	CaO	MgO	Mn	K_2O	Na_2O	P
A	48.22	32.69	5.64	2.15	0.98	0.02	1.95	0.25	0.12
B	49.30	28.26	6.22	2.55	1.46	0.02	2.20	0.64	0.32
C	50.38	34.44	4.68	1.84	0.69	0.04	0.95	0.17	0.27
D	34.41	20.43	12.68	11.9	2.24	0.07	1.57	0.27	0.03
E	60.96	25.92	4.52	1.68	0.75	0.05	0.89	0.33	0.25
F	47.51	28.06	4.96	4.25	1.19	0.05	1.77	0.88	0.18
G	45.21	35.74	3.34	5.09	1.47	0.02	0.54	0.45	0.02
H	56.06	27.47	3.90	1.13	1.58	0.03	4.4	0.20	0.05
I	54.39	18.56	4.78	8.38	1.83	0.09	3.20	0.58	0.11
J	57.63	24.06	6.07	2.91	1.39	0.11	2.17	0.46	0.08
K	50.33	20.02	8.44	4.49	2.06	0.29	3.34	1,00	0.06
N	43.18	22.37	16.25	4.09	1.27	0.14	1.14	0.25	0.21

Sample E showed the highest SiO_2 content and sample D the lowest. Sample I showed the lowest Al_2O_3 content and sample G the highest.
Table 4 shows the ultimate analysis of the solid fuels. Considering bituminous coals, the carbon content increases when volatile matter decreases. Samples D, M, N and O showed high carbon content. Basically hydrogen content decreases with volatile matter. Table 5 shows the results of maceral analysis and the reflectance index.

Table 4: Ultimate analysis of solid fuels.

Samples	%C	%N	%H	%O	%St
A	78.62	1.53	5.05	6.55	1.00
B	79.98	1.80	4.61	3.54	0.82
C	78.58	1.71	3.79	6.73	0.48
D	86.62	1.30	4.27	2.17	0.74
F	83.37	1.66	3.65	3.07	0.99
G	74.00	2.07	3.08	3.30	1.51
H	82.05	1.25	3.13	2.79	0.53
I	76.24	1.01	2.70	2.59	0.54
J	79.07	0.44	0.99	3.47	0.22
K	83.99	1.06	1.35	1.93	0.24
L	80.38	0.75	1.09	0.27	1.09
M	91.59	2.48	3.86	1.27	0.78
N	90.91	2.54	3.89	1.78	0.86
O	84.78	1.14	0.25	0,00	0.46

Table 5: Petrographic analysis of solid fuels.

Samples	Vitrinite	Inertinite	Liptinite	Other Minerals	Reflectance
A	69.8	18.0	6.0	6.2	1.06
B	74.6	19.4	0.4	5.0	1.08
C	67.0	26.0	2.6	4.3	1.77
D	78.9	18.3	nd	2.9	1.51
E	74.0	17.8	nd	8.2	2.00
F	64.4	29.8	nd	5.8	2.07
G	87.6	6.6	nd	5.8	2.41
H	80.2	6.6	nd	13.2	3.04
I	85.0	5.0	nd	10.0	5.99
J	66.2	29.6	0.2	4.0	4.59
K	82.4	9.4	nd	8.2	6.23

Samples G, H, I and K showed the highest vitrinite content. The reflectance index is inversely proportional to the volatile matter, the sample K showed the highest rank compared to other samples.

The samples A and B can be classified as bituminous high volatile coals according to the reflectance index.

Figure 1 and Table 6 show combustion profiles and initial, burning, peak and burnout temperatures of different solid fuels evaluated by TGA. Although this technique do not simulate the real conditions of pelletizing process, such as heating rate, it is possible to carry out a comparative study supporting technical team in process optimizing and predicting the behavior of solid fuels during firing. The combustion profiles are very sensitive to coal rank and can be used to classify the coals according their combustibility.[4]

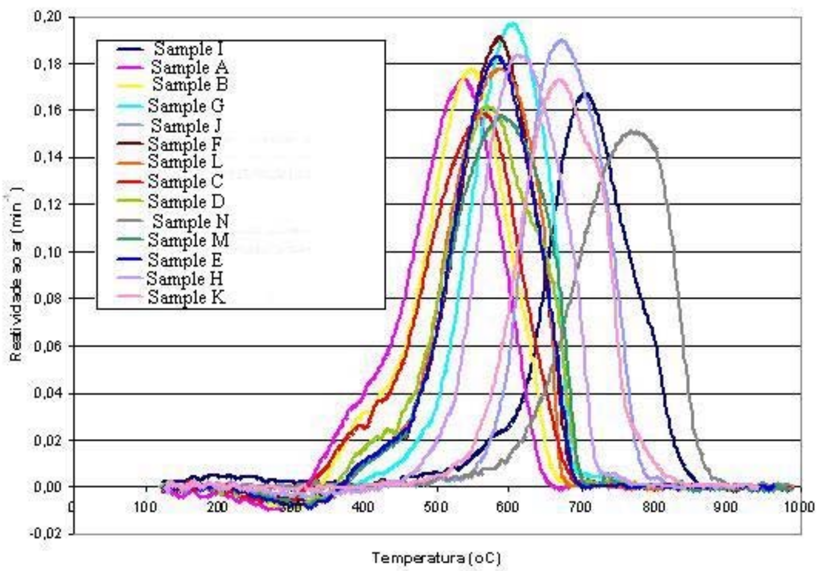

Figure 1: Solid fuels combustion profiles.

Table 6. Initial burning, peak and burnout temperatures of solid fuels.

Solid Fuels	T_i (^{0}C)	T_p (^{0}C)	T_b (^{0}C)
A	437	536	605
B	457	548	618
C	460	563	631
D	487	569	658
E	506	588	671
F	504	585	650
G	534	604	667
H	550	611	690
I	580	704	788
J	592	670	750
K	606	672	749
L	511	590	652
M	505	588	671
N	667	767	836

Comparing the analyses in Table1 to the characteristics temperatures in Table 6 and the volatile matter content in Table 3, it can be seen that these temperatures decrease as the volatile matter increases.

The sample N burns at higher temperature, while samples A, B and C burn at lower ones. The sample G shows the highest reactivity compared to the other samples (Figure 1).

Samples A and B showed the lowest peak temperatures (536^{o}C and 548^{o}C, respectively). The peak temperature is related to the coal rank and coal combustibility decreases with the increasing of the rank.

Thermal profiles data can support process-engineering team in adjusting the firing pattern of the traveling grate machines in iron ore pelletizing plants.

The pelletizing thermal cycle is divided into updraft drying, downdraft drying, pre-heating, firing, post-firing and cooling. It's important to notice that the carbon should not be burnt at the drying zone, because, in this case, part of its energy should be wasted as exhaust gas. The initial and peak burning temperatures of solid fuels have to fit in the thermal profile of pelletizing in order to provide the best energy efficiency. Thus, the initial and peak temperatures have an impact on the quality of fire pellet. There are other characteristics of solid fuels that impact on quality, for example, fixed carbon, volatile matter and reactivity.

Table 7 shows the results of the quality parameters of pellet. The degree of reduction, swelling and porosity did not show significant difference among them.

Table 7: Quality of pellets tests.

Samples	Abrasion (%<0.5mm)	Compression Strength (daN/p)	Degree of Reduction (%)	Swell (%)	Porosity (%)
A	3.0	235	66.4	11.4	26.1
B	4.4	237	72.5	11.9	27.4
C	3.6	272	70.0	11.8	26.3
D	3.2	269	71.0	10.9	24.5
E	2.8	296	69.0	10.4	25.9
F	3.1	294	70.7	11.6	25.8
G	3.5	263	68.8	11.4	25.4
H	2.5	330	71.9	11.3	26.5
I	3.0	301	70.1	11.2	24.3
J	2.7	315	69.7	11.7	24.2
K	3.1	311	70.8	12.3	24.5
L	3.4	304	68.6	12.1	26.1
M	3.0	323	68.0	11.3	25.4
N	2.3	397	67.4	10.6	22.8

The solid fuels characteristics were correlated with metallurgical, chemical and physical quality of pellets. The results of chemical, abrasion, swell and porosity are within quality specification.
Then, a new approach to Vale's Pelletizing Department purchasing area was established based on the real impact of different solid fuels on the quality of pellets.
Sample N shows the highest compressive strength compared to other samples due to its intrinsic characteristics as vitrinite content and fixed carbon, moreover lower volatile matter content.
Samples A, B, C and D showed low compressive strength, the most important physical parameter of pellets due to their high volatile matter content.

6 CONCLUSIONS

This study shows the influence of different solid fuels, based on high, medium and low volatile matter, on the physical and metallurgical quality of BF standard iron ore pellets produced at Vale's Tubarão Pelletizing Complex in Vitória (Brazil).
Low rank solid fuels (medium/high volatile coal) have shown a negative effect on the quality of pellets, considering same firing profile for all tested samples. An optimization test program can be carried out to improve quality of pellets even with this kind of solid fuel, what is important because medium/high volatile coal generally requires a low acquisition cost and because of the low offer of high fixed carbon.
The biggest impact within different types of solid fuels occurs in the physical properties of iron ore pellets.
This study can support the purchasing area to develop Valor In Use (VIU) of solid fuel acquisition determining its real price based on pelletizing plant performance.
In addition to commercial approach, this study can support pelletizing plant technical team to optimize firing process and to improve overall quality of pellets.

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