# EVALUATION OF THE USE OF ALTERNATIVE FUELS IN MIXTURES OF MINERAL COALS FOR INJECTION IN THE BLAST FURNACE[1]

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## Abstract

Brazilian iron and steel plants that use pulverised coal injection in the blast furnaces are facing great difficulties to keep the levels of injection rates that had being practised. These difficulties are associated mainly with fuel costs, and seasonal problems of supply as for example flooding occurrence in Australia, which delayed the coal shipment. In this context, the objective of this study was to evaluate the viability of the use of anthracite and/or petroleum coke in mixtures of mineral coals. Ternary and quaternary mixtures of these solid fuels were made, and subsequently analysed in terms of chemistry, physical characteristics and combustibility, so as to predict the solid fuel behaviour in both the preparation plant and the blast furnace process. Although the results have shown that the use of anthracite and petroleum coke in mixtures with mineral coals tends to worsen their quality, especially the combustibility, it was observed that their use in contents up to 20% in ternary mixtures will cause only a slight deterioration in combustibility. Instead, for the simultaneous use of both solid fuels in quaternary mixtures, the content of both fuels shall be limited to 5%.


**Key words:** Blast furnace; Alternative fuels; PCI.

### AVALIAÇÃO DO USO DE COMBUSTÍVEIS ALTERNATIVOS EM MISTURAS DE CARVÕES MINERAIS PARA INJEÇÃO NO ALTO-FORNO


**Resumo**

As usinas siderúrgicas nacionais, que utilizam a injeção de carvão pulverizado em seus altos-fornos, estão enfrentando grandes dificuldades para manter os níveis de taxas de injeção que vinham sendo praticadas. Essas dificuldades estão principalmente associadas ao custo destes combustíveis, além de problemas sazonais de abastecimento, como por exemplo o ocorrido com os carvões da Austrália, em função de inundações naquele país. Neste contexto, o objetivo desse estudo foi avaliar a viabilidade de uso de antracito e/ou coque de petróleo em misturas com carvões minerais. Foram formadas misturas ternárias e quaternárias desses combustíveis sólidos e, através das análises física, química e de combustibilidade, realizou-se a previsão do seu comportamento nas instalações de preparação e no processo de alto-forno. Apesar dos resultados mostrarem que o uso de antracito e coque de petróleo em misturas com carvões minerais atuam no sentido de deteriorar a qualidade, especialmente quanto à combustibilidade, observou-se que o uso de até 20% em misturas ternárias, ocorre apenas uma ligeira redução nesse parâmetro. Já para o uso simultâneo de antracito e coque de petróleo em misturas quaternárias, a participação desses combustíveis alternativos deve ser reduzida para 5% de cada.


**Palavras-chave:** Alto-forno; Combustíveis auxiliares; PCI.

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## 1 INTRODUCTION

The pulverised coal injection (PCI) system in the Usiminas' Blast furnaces (BF's) started in 1993. Since then injection of either individual coal or a mixture of coals with low and high rank has been used. The pulverised coal injection practice aims at partially substituting the coke, which is charged on the BF's top. Moreover this practice can adjust the coke balance in the plant and prolong the service life of the coke ovens, bringing about in turn a cost reduction of pig iron production.

Like others Brazilian iron and steel plants that use pulverised coal injection in the blast furnaces, Usiminas is facing great difficulties to keep the level of injection rate that used to be practised (130 kg/tHM in BF's #1 and #2 and 140 kg/tHM in BF#3). These difficulties have arisen mainly due to fuel costs, and seasonal problems of supply as for example flooding occurrence in Australia, which delayed the coal shipment.

In this context, the objective of this study was to evaluate the viability of the use of anthracite and/or petroleum coke in mixtures of mineral coals, using the methodology that has been applied to the selection of auxiliary fuels in Usiminas.(1)

## 2 GENERAL CONSIDERATIONS

### 2.1 Injection of Auxiliary Fuels in the Blast Furnace

In coke operated blast furnaces, the coke plays the physical role of permeating, and that is considered to be of paramount importance, since it determines the production of pig iron and the fuel efficiency in the oven. This role cannot be assigned to any other fuel as the coke is the only charged material in the blast furnace that is capable of keeping the permeability of the ascending gas as well as of the descending liquid slag and hot metal. This behaviour is due to the coke characteristics of remaining solid even under conditions of high temperatures existing in the oven, as well as keeping its resistance level regarding the varied thermo-mechanical stresses in the oven. The above-mentioned characteristics allow the coke to keep a proper size and size distribution to provide a good permeability.

However, thermal and chemical roles can be exerted, in part, by other tuyere injected fuels such as: liquid fuels (oil and tar of mineral coal); gaseous fuels of high calorific value (reducing gas, natural gas and coke oven gas); solid fuels (mineral coal, anthracite, petroleum coke and biomass). Thus, these auxiliary fuels take part also as sources of heat and reducing gas for the process.(2,3)

The establishement of the kind of fuel to be injected takes into consideration the price (for example, oil injection in the blast furnaces havs been substituted by pulverized coal injection because of the substantial increase in oil price by the end of 70's), besides other factors that direct or indirectly affect the savings in the coke substitution. Table 1 indicates the main factors considered for coal, oil and natural gas utilization.

**Table 1** - Comparison of different types of fuels for injection.[2]

| Injectant | Coal | Oil | Natural Gas |
|---|---|---|---|
| Amount of preparetion Required | Most | → | Least |
| Quantity Injectable with minimum tuyere level changes | Most | → | Least |
| Combustion in raceway | Slowest | → | Fastest |
| Nature of Uncombusted carbon | Char | soot | none |
| Effect on hot metal | Ash, Sulpur | Low sulphur | no ash, sulphur |

## 2.2 Theoretical Aspects in the Combustion of Auxiliary Fuels

Auxiliary fuels are injected at low temperature through the tuyeres, and partially substitute the coke that is preheated during its descending along the shaft of the oven. As a result of the combustion of auxiliary fuels carbon monoxide and hydrogen are generated. The heat released by the combustion of coke is always higher than that of whatever hydrocarbon used, and the higher the ratio hydrogen/carbon the lesser the heat released. The direct effect is on the flame temperature, which is reduced when whatever fuel is injected. Table 2 shows the hydrogen/carbon ratio for usual auxiliary fuels.[3]

**Table 2** – Elementary analysis of auxiliary fuels (mass percent).

| Hydrocarbon | $H_2$ | C | $N_2$ | $H_2/C$ |
|---|---|---|---|---|
| Natural Gas | 22.5 | 69.4 | 8.1 | 0.32 |
| Bunker "C" oil | 9.3 | 88.6 | 0.3 | 0.10 |
| Tar | 7.1 | 91.4 | 1.1 | 0.08 |
| Bit. Coal | 5.0 | 80.1 | | 0.06 |
| Anthracite | 2.8 | 80.6 | | 0.03 |

Auxiliary fuel injection in the blast furnace provokes several modifications in the process, when compared to the all-coke operation, as for example[4]: i) increase in the ratio metallic burden/coke in the charging; II) increase in the volume of gases in the blast furnace, mainly with the use of high volatile coal; III) increase in the hydrogen entrance and IV) decrease of flame temperature. Figure 1 shows the decrease of the flame temperature as a function of the ratio hydrogen/carbon.[3]

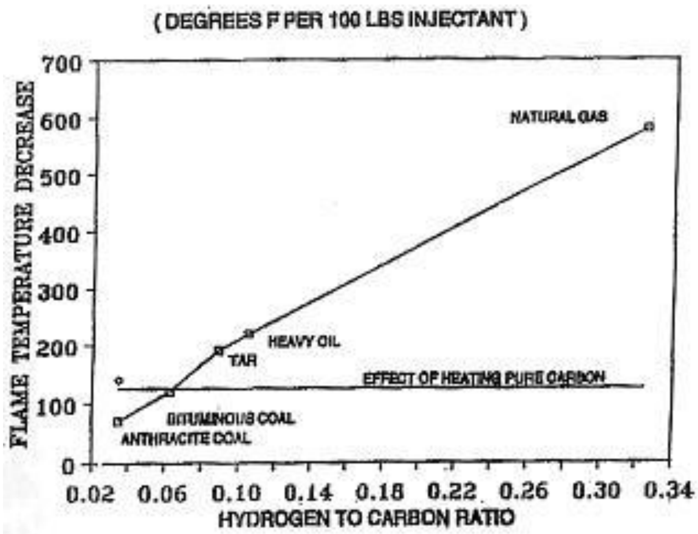



**Figure 1** – Effect of the ratio hydrogen/ carbon for auxiliary fuels in the decrease of flame temperature.

It is important to point out that the productivity of hot metal in the blast furnace will drop if the auxiliary fuel injection is implemented without any operational modification. Therefore, the main measures that are being adopted to minimize the reduction of productivity in the oven, specifically for the coal injection, are[4]: i) alteration in the burden distribution; II) increase in the efficiency of coal combustibility in the combustion zone; III) increase of oxygen enrichment in blown air; IV) optimization of the blown air speed; v) improvement of coke quality and vi) improvement in the quality of metallic burden.

## 3 METHODOLOGY

### 3.1 Methodology of Characterization for Auxiliary Solid Fuels

An adequate methodology for selection of auxiliary solids fuels to be injected has to be based on the knowledge of their characteristics, so that their behaviour in the preparation plant, during their transport to the blast furnace and the consequent injection, could be predicted.

In Usiminas, the main analyses and tests used are: i) physical characterization (grain size analysis, moisture and hardgrove grintability index); II) chemical characterization (direct analysis, elementary analysis and ash composition); III) petrography analysis (maceral composition and determination of rank); IV) coking properties (Gieseler maximum fluidity) and v) combustion parameters (calorific value and combustibility index).

#### 3.1.1 Simulator of raceway in Usiminas

The raceway simulator in Usiminas is composed by two ovens (figure 2), the first being for preheating the oxygen until the blow temperature in the blast furnace is reached (850 ~ 1100°C). The second is used to simulate the thermal conditions in the combustion zone (1600°C).

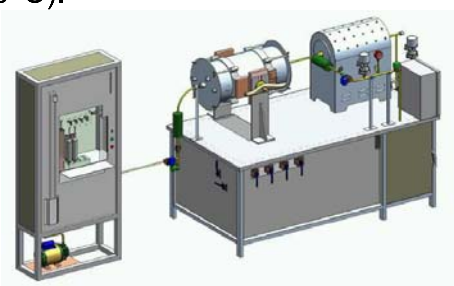


**Figure 2** – Simulator of raceway in Usiminas.

The determination of the combustibility index of the solid fuel is carried out by an indirect method that considers the contents of CO and $CO_2$ in the combustion products, the mass and the elementary analysis of coal, and the amount of oxygen used in the burning.

#### 3.1.2 Sampling of fuels and making of the mixtures

Four kinds of fuels were used: two kinds of Australian coal, being one a medium-to-high volatile coal (MH AUS) and the other a low-to-medium volatile (ML AUS), a South African originated anthracite (AK AFR) and a Brazilian petroleum coke (CP BRA).

The samples of the coals were collected while they were received and piled up in stacks in Usiminas' yards, according to a standard procedure of sampling in the conveyor. The sample container was a drum of 200 litres. The samples of anthracite and petroleum coke were collected from the stacks. It is worth mentioning that the anthracite was that used in the sintering plant and the petroleum coke was that used in the coke oven plant.

Initially a binary mixture with the Australian coals was made (for Reference) using a weight percent ratio of 50%. The ternary mixtures were constituted by the two Australian coals with the addition of anthracite and/or petroleum coke in the ratios of 10%, 20% and 30%, in weight. The quaternary mixtures were formulated by the two mineral coals and the simultaneous addition of anthracite and petroleum coke in ratios of 5%, 10% and 15% of each. Table 3 shows the composition of the binary mixtures (Reference), and ternary and quaternary mixtures.

The assays of combustibility of the mixtures were carried out by simulating injection rates of 150 kg/tHM. Similar conditions practised in the Blast Furnace #3 were applied to the tests, namely blown air temperature of 1100°C, air specific flow rate of 1150 $Nm^3$/tHM, air moisture of 20 g/$Nm^3$ and 5% of oxygen enrichment. The granulometry used for both the fuels and the mixtures was of 80% < 200 mesh.

**Table 3** - Composition of the coals mixtures with addition of anthracite and/or petroleum coke.

| Mixtures | | MH AUS | ML AUS | AK AFS | CP BRA |
|---|---|---|---|---|---|
| Binary | Coal Mixture (Reference) | 50% | 50% | --- | --- |
| Ternary | TM-10% AK | 45% | 45% | 10% | --- |
| Ternary | TM-20% AK | 40% | 40% | 20% | --- |
| Ternary | TM-30% AK | 35% | 35% | 30% | --- |
| Ternary | TM-10% CP | 45% | 45% | --- | 10% |
| Ternary | TM-20% CP | 40% | 40% | --- | 20% |
| Ternary | TM-30% CP | 35% | 35% | --- | 30% |
| Quaternary | QM-5%AK+5%CP | 45% | 45% | 5% | 5% |
| Quaternary | QM-10%AK+10%CP | 40% | 40% | 10% | 10% |
| Quaternary | QM-15%AK+15%CP | 35% | 35% | 15% | 15% |

TM – Ternary Mixture; QM – Quaternary Mixture

# 4 RESULTS

## 4.1 Characterization of Individual Fuels

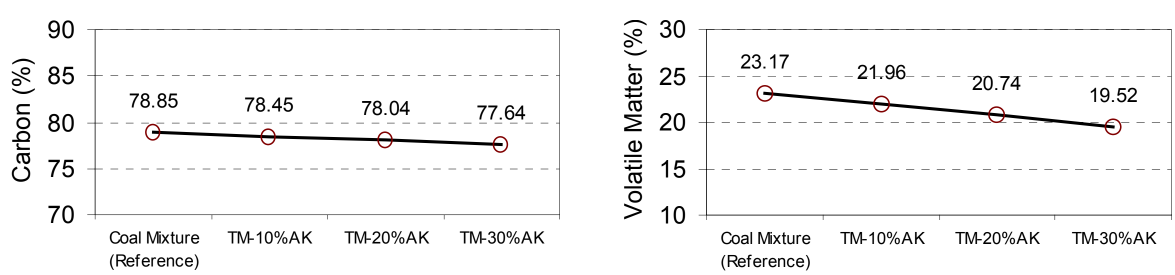
The results of the analyses and tests for characterization of auxiliary fuels are shown in Table 4.

**Table 4** - Results of the analyses and tests for characterization of auxiliary fuels.

| ANALYSIS | | Unit | Auxiliary Fuels | | | |
|---|---|---|---|---|---|---|
| | | | MA AUS | MV AUS | AK AFS | CP BRA |
| | | | 100% | 100% | 100% | 100% |
| Elementary | Carbon | (%) | 77.00 | 80.70 | 74.80 | 91.50 |
| | Hydrogen | (%) | 3.49 | 2.91 | 2.10 | 2.92 |
| | Oxygen | (%) | 6.03 | 4.01 | 5.35 | 1.04 |
| | Nitrogen | (%) | 1.77 | 1.44 | 1.67 | 2.38 |
| | Sulphur | (%) | 0.58 | 0.42 | 1.02 | 0.81 |
| Proximate | Moisture | (%) | 10.39 | 9.25 | 9.27 | 11.58 |
| | Ash | (%) | 9.55 | 10.41 | 14.37 | 0.35 |
| | Volatile Matter | (%) | 25.92 | 20.42 | 11.01 | 14.72 |
| | Fixed Carbon | (%) | 64.53 | 69.17 | 74.62 | 84.93 |
| Ash Composition | $SiO_2$ | (%) | 54.69 | 50.37 | 51.03 | 36.91 |
| | $Fe_2O_3$ | (%) | 7.49 | 4.60 | 9.19 | 15.27 |
| | CaO | (%) | 4.12 | 2.18 | 4.89 | 10.75 |
| | $Na_2O$ | (%) | 0.41 | 0.35 | 1.12 | 1.84 |
| | $P_2O_5$ | (%) | 1.13 | 1.19 | 0.86 | 0.31 |
| | ZnO | (%) | 0.013 | 0.020 | 0.017 | 0.304 |
| | $Al_2O_3$ | (%) | 26.75 | 38.03 | 26.61 | 12.31 |
| | $TiO_2$ | (%) | 1.17 | 1.51 | 1.34 | 1.56 |
| | MgO | (%) | 0.98 | 0.95 | 1.13 | 1.78 |
| | $K_2O$ | (%) | 1.69 | 1.03 | 2.55 | 0.87 |
| | MnO | (%) | 0.03 | 0.01 | 0.07 | 0.40 |
| | $SO_3$ | (%) | 0.01 | 0.01 | | 0.06 |
| Alkali in the Ash | | (%) | 2.10 | 1.38 | 3.67 | 2.71 |
| Alkali in the Fuel | | (%) | 0.20 | 0.14 | 0.53 | 0.01 |
| Hardgrove | HGI | (-) | 80 | 78 | 57 | 113 |
| Calorific Value | PCI | (kcal/kg) | 7206 | 7506 | 6668 | 8495 |
| | PCS | (kcal/kg) | 7386 | 7656 | 6776 | 8695 |
| Combustibility | Combustibility Index | (%) | 67 | 64 | 39 | 49 |
| Coking Properties | Platometry Gieseler | (ddpm) | 13.0 | 2.50 | | |

## 4.2 Characterization of the Ternary Mixtures Made by Coals and Anthracite

The results of characterization for the mixtures of coals with the addition of anthracite in the ratios of 10%, 20% and 30% are shown in Figure 3.



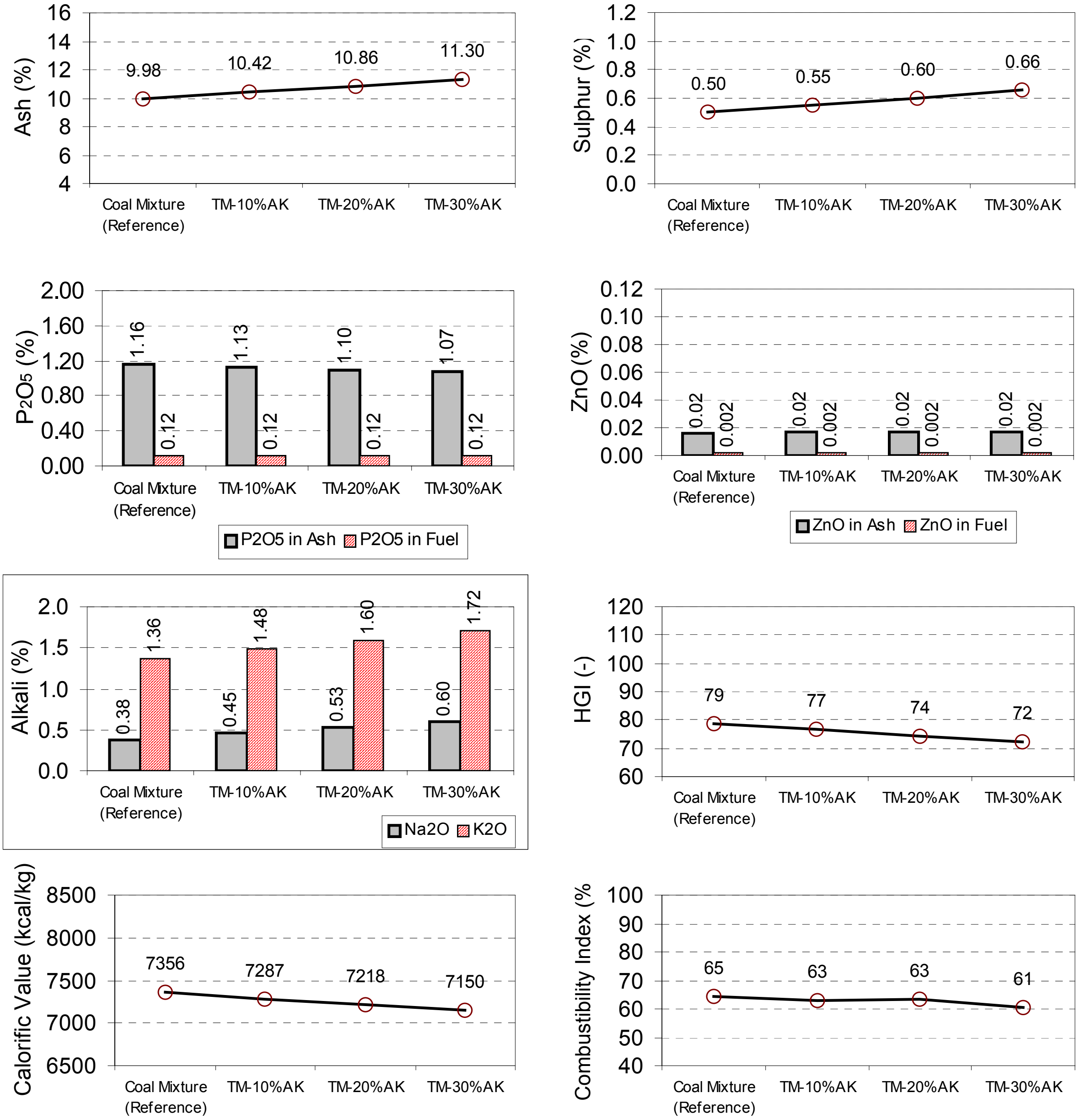
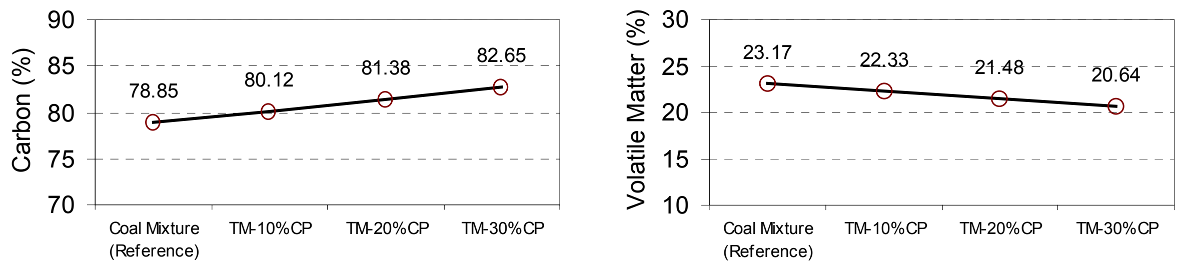



**Figure 3** – Main parameters of characterization for ternary mixtures made by coals and anthracite.

## 4.3 Characterization of the Ternary Mixtures Made by Coals and Petroleum Coke

The results of characterization for the mixtures of coals with the petroleum coke addition are shown in Figure 4.



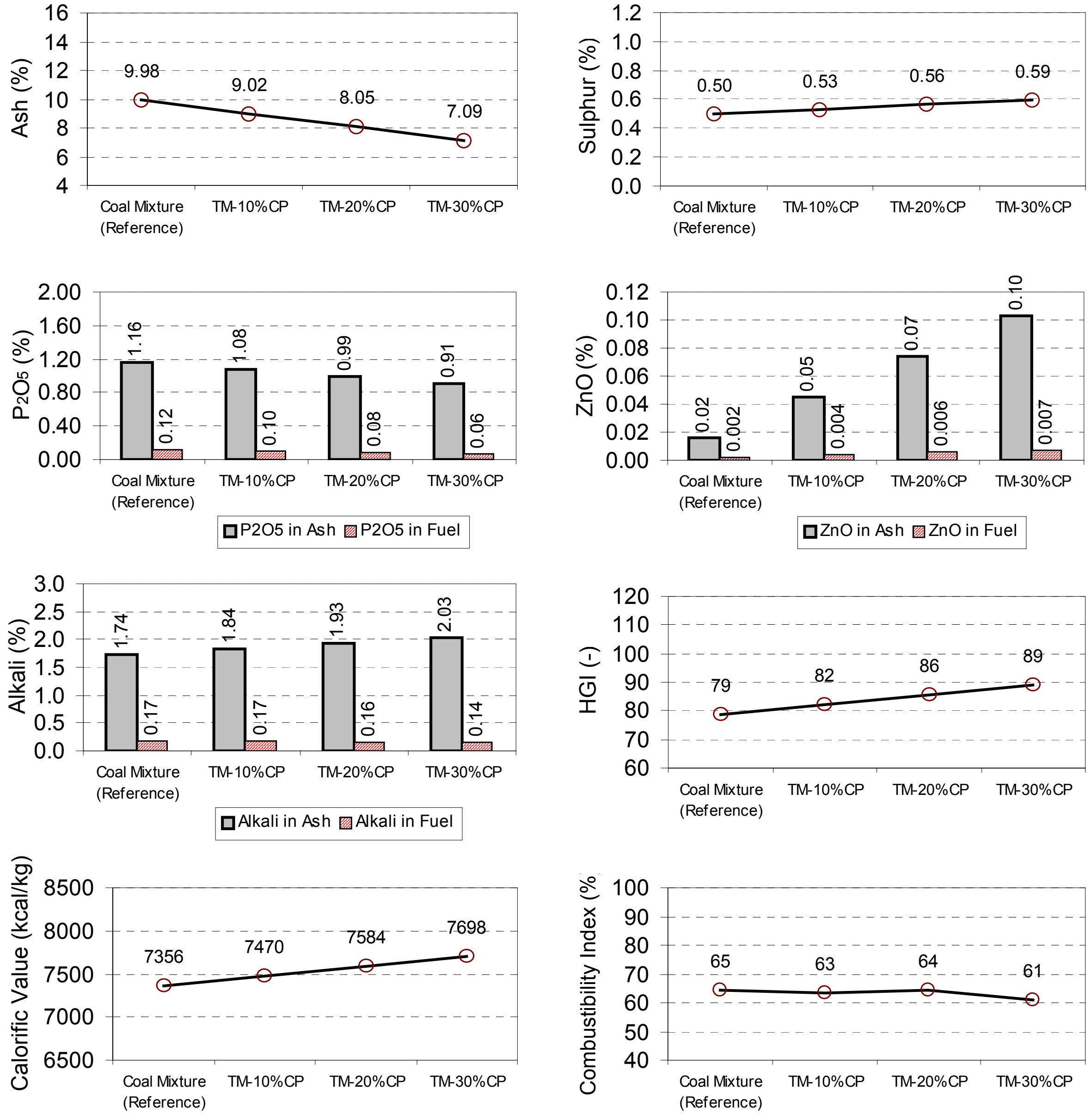
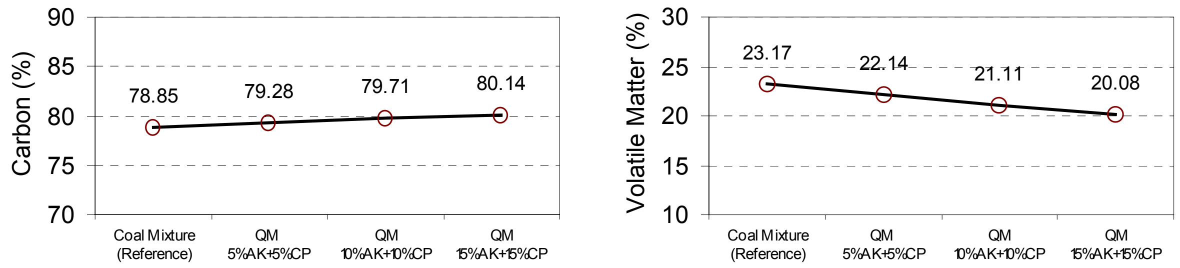



**Figure 4** – Main parameters of characterization for ternary mixtures made by coals and petroleum coke.

## 4.4 Characterization of the Quaternary Mixtures Made by Coals and Simultaneous Additions of Anthracite and Petroleum Coke

The results of characterization of the mixtures of coals with additions of anthracite and petroleum coke are shown in Figure 5.



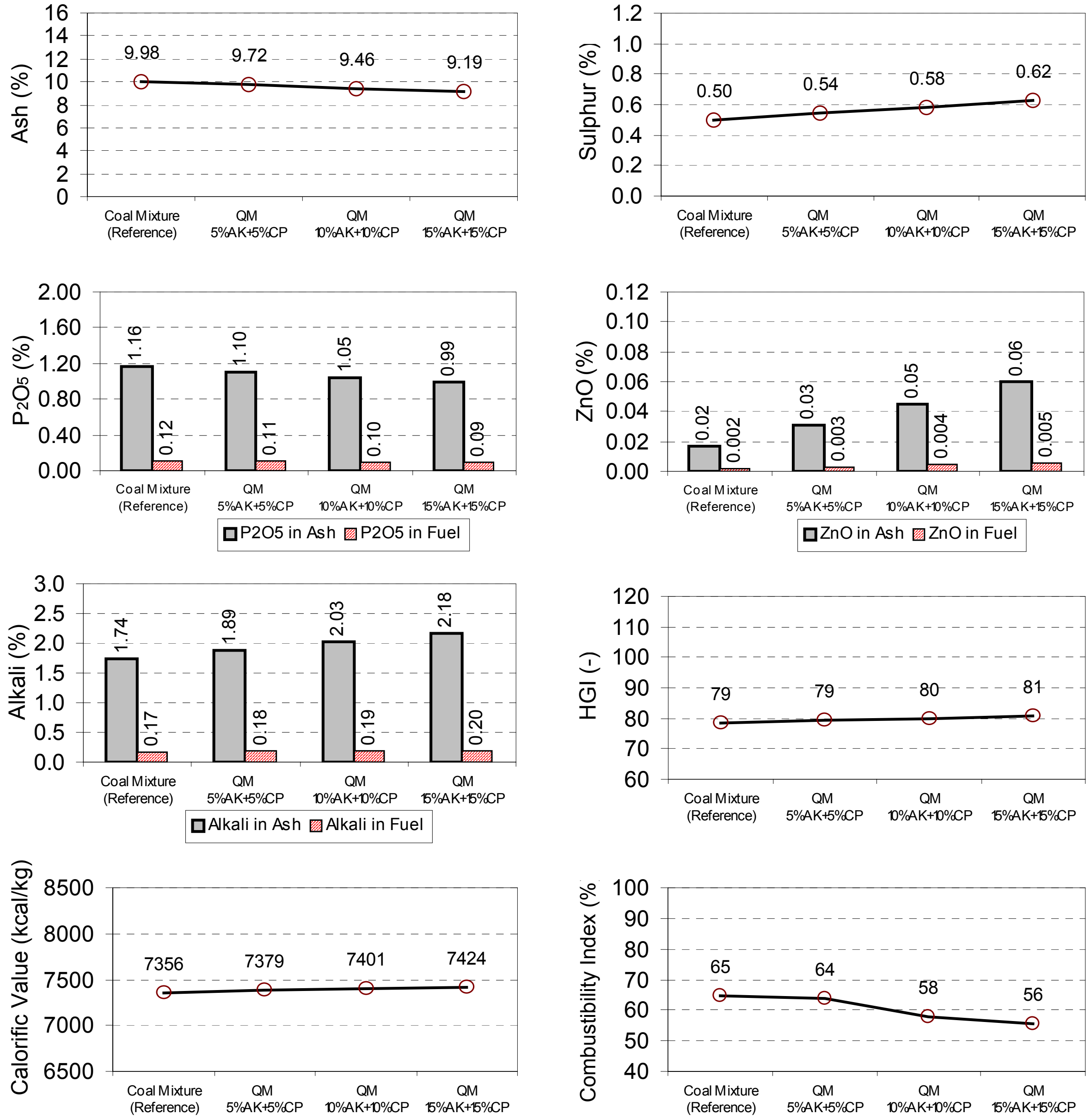



**Figure 5** – Main parameters of characterization for ternary mixtures made by coals with the simultaneous use of anthracite and petroleum coke.

## 5 DISCUSSION OF RESULTS

### 5.1 Evaluation of the Use of Anthracite in Ternary Mixtures

- *System of fuel preparation for PCI.* Although the anthracite possess a low HGI value (57), which makes it to be classified as a hard material, its effect on the mixtures is minimized by the presence of the coal, provided that its content ranges from 10%, 20% to 30%. Consequently, productivity loss of the mills is not expected, that is, no impairment of the charging of the blast furnaces will occur.

- *Region of the blast furnace tuyeres.* The binary mixture of coals presented 65% combustibility index. However the presence of anthracite leads to reduction in such index. By using this fuel up to 20% the permeability in the dead-man (formation of bird nest) will certainly not be impaired. It should be pointed out that the mixtures with mean content of volatile matter generate a volume of gas in raceway that does not contribute to a higher degradation of the coke in this region. The use of anthracite promotes, however, a gradual reduction in the calorific value of the ternary mixture.
- *Blast furnace process.* The anthracite tends to deteriorate the chemical quality of the mixture. A gradual increase in the ash content with the presence of the anthracite was observed. A slight increase in the contaminant sulphur is expected while the other contaminant phosphorus shall not be altered. Regarding the pace of the blast furnace and its disturbers (alkalis and zinc), the main problem is the high content of alkalis found in the anthracite.

The low chemical quality of the anthracite implies a major restriction to the use of the mixtures of coals, due to mainly the high alkalis content. It is worth to stress that the alkalis content in the ternary mixture with coals MH AUS and ML AUS is quite high, as these coals have high alkalis content. Based on the combustibility results it is recommended to use this fuel up to 20% weight in the analysed mixtures of coals. The use of higher ratios of anthracite in the industrial process would be limited because of the elevated alkalis content, besides the deterioration in the combustibility.

### 5.2 Evaluation of the Use of Petroleum Coke in Ternary Mixtures

- *System of fuel preparation for PCI.* Because of the high HGI value (113), the petroleum coke is classified as a very soft material. Therefore, it can be added to the coals mixtures in varied contents of 10%, 20% and 30% giving favourable results, and reductions in the productivity of the mills will not be expected.
- *Region of the blast furnace tuyeres.* The use of petroleum coke tends to decrease the combustibility, although when its content is less than 20% such effect is little. Due to low content of volatile matters, coke degradation in the raceway is not expected as a function of the volume of gaseous species generated in this region.
- *Blast furnace process.* Generally speaking the petroleum coke has the effect of improving the final quality of the mixtures, bringing about significant decrease in the ash content. In terms of contaminants, on one hand the phosphorus is slightly reduced by the addition of the petroleum coke. On the other hand, the sulphur content tends to rise in the mixtures with the petroleum coke yet still lying below the target value in Usiminas. The effect of petroleum coke on blast furnace pace disturbers is beneficial, because alkalis and zinc contents are a little reduced.

The major constraint to the use of petroleum coke in the mixture of coals is due to its low combustibility. However, the addition of this fuel to the analysed mixtures (MH AUS and ML AUS) is still advisable in contents up to 20%, because of its very low ash content associated to its softness.

### 5.3 Evaluation of the Simultaneous Use of Anthracite and Petroleum Coke in Quaternary Mixtures

- *System of fuel preparation for PCI.* Although the anthracite is a very hard material (low HGI), good results of HGI were achieved for the three tested levels when it was used together with mixtures of petroleum coke and mineral coal.

- *Region of the blast furnace tuyeres.* The results have shown that the combustibility of the quaternary mixtures decreased with the increase in the amount of coke. However, this decrease was not significant for 5% addition of either anthracite or petroleum coke in comparison with the combustibility of the binary mixture of the coals. Besides, problems of coke degradation in the raceway are not expected, as these fuels have low volatile matters. It shall be stressed that a slight increase in the calorific value of the quaternary mixture with the increase of the anthracite/petroleum coke will occur.
- *Blast furnace process.* As the amount of these fuels in the quaternary mixture increased the ash content decreased slightly. Moreover, there were also little variations in phosphorus and sulphur content, the former diminishing and the latter augmenting. Yet those contents lied below the standard value of Usiminas. Alkalis and zinc contents gradually increased with the fuels additions, the major contribution coming from the anthracite.

The major constraint to the use of quaternary mixtures with anthracite and petroleum coke additions is the low combustibility. However, the use of coal mixtures (MH AUS and ML AUS) with additions of up to 5% anthracite and up to 5% petroleum coke is still suggested, as good chemical and physical qualities were obtained, that is, low ash content and softness, respectively.

## 6 CONCLUSIONS

By using the anthracite in ternary mixtures with Australian coals, both the chemical quality and the combustibility worsen. In terms of chemical quality the use of anthracite causes a significant increase in the ash and alkalis contents, and decreases the volatile matter. In spite of the combustibility deterioration the experimental results have shown that the anthracite can be used up to 20%. In this case coke rate will increase as the calorific value decreases. Regarding the physical quality the use of anthracite will not impair the mill productivity, even though it is a hard material (HGI of 57). In this way, as high as 30% in weight of anthracite can be used.

The petroleum coke in ternary mixtures with the Australian coals functions as a corrective of the chemical quality, and gives rise to a significant reduction in ash content, and that leads to mixtures with minor phosphorus, zinc and alkalis contents. Another benefit of the use of petroleum coke is the easiness of milling (HGI index 89 with 30% addition), which favours the productivity in the preparation plant. Although this fuel presents a high calorific value, its use is limited by the effect in lowering the combustibility (such index can reach 61% in the ternary mixture), besides its low content of volatile matter. In spite of this constraint, the use of petroleum coke is recommended by up to 20% addition in the analysed colas (MH AUS and ML AUS), because of the good chemical and physical qualities.

With regard to the quaternary mixture, it was verified that the petroleum coke offsets most of the deleterious effect of the anthracite. It is worth noticing a remarkable reduction in the combustibility of the mixture (the index can reach 56% in the quaternary mixtures) when these fuels are simultaneously used, and that this is caused by the low content of volatile matter. Taking all these considerations into account the combined use of anthracite and petroleum coke, setting a 5% limit for both is yet recommended.

The results have shown that the use of ternary mixtures with up to 20% anthracite or petroleum coke is more attractive than the quaternary mixtures with 5%

anthracite and 5% petroleum coke. The ternary mixtures obtained with petroleum coke have shown better results than those with anthracite.

The introduction of 15% of anthracite in ternary mixtures with MH AUS and ML AUS coals was tested in the Blast Furnace #3 of Usiminas. Alterations in fuel rate were not observed, whereas oscillations in the furnace output mainly due to instabilities in the furnace pace were noticed. This instability meant deterioration of permeability in the bed, and could not be attributed to the introduction of the anthracite, once this behaviour had been observed before the experiment. No problem was detected regarding the productivity in the mills during the preparation stage.

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