Metallurgy and materials
*Metalurgia e materiais*

# Influence of moisture and particle size on coal blend bulk density

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## Abstract

Coal blend bulk density is an important property in the coking process. Some variables, such as moisture and particle size, which are controlled or measured in the coal beneficiation process in steel mills, exert a strong influence on this feature. This study aims to understand the density variation of coal blends by the influence of moisture and particle size when using dry and wet bases. The investigations showed that higher density can be reached when drying the coal blend or even with excess of moisture by an agglomeration process. However, for a coal blend of lower moisture content, such as 4%, the better effects on the coking process are evident. Changes on the density from particle size require care, since they can fall in a region of high density achieved by larger particles or in a region with excess coal fines, where either or both can compromise the coke quality.

**Keywords:** coal, bulk density, moisture, particle size.

## 1. Introduction

Coke is the main fuel used in the blast furnace for hot metal production. An efficient operation of the blast furnace is mainly linked to the coke quality that depends on the coal blending used and the coking process.

Among the coal characterization parameters, the coal charge bulk density is one of the most important properties, which in the case of coke ovens, helps to determine the coal charge to be put into the oven with a specific volume. The increase in its value leads to a greater amount of charging, increasing coke production and contributing to an improvement in its quality (Sabadini *et al.*, 2013), mainly in terms of its strength (Drum Index and Coke Strength after Reaction) that will allow a steady operation of the blast furnace and coke rate reduction. However, it is significant to consider the impact of high density on the coking pressure of coal on the coke chamber walls and the ability of the coke oven to support it.

Coal pre-treatment processes, such as preheating (Standish *et al.*, 2011), stamping (Standish *et al.*, 2011), dry charging (Masahiko *et al.*, 2016), briquetting (Masahiko *et al.*, 2016), and even, oil addition (Sabadini *et al.*, 2013) and mechanical vibration (Nascimento, 2016) are commonly employed to increase the density. However, variables such as moisture and coal particle size can also have a strong influence on these operations.

Sabadini *et al.* (2013) and Leeder *et al.* (2014) reported that the gain of oil addition on coal charge bulk density depends on the moisture content of the coal blend. When the moisture content becomes excessively high (> 11%), the effect of oil has no influence on the bulk density increase.

It is important to note that when a coal blend of high moisture content is charged into the coke oven which has a certain volume, this implies that for the same density, there will be less coal than expected, reducing productivity. In addition, variations in the moisture content of coal cause adverse effects on the stable operation of coke ovens, leading to an increase in heat consumption and variations on coke quality. Whereas, when the moisture overly declines, the amount of dust during the transportation increases and also the pulverized coal into the ascension pipes (Wakuri *et al.*, 1985).

When combining the influence of moisture and particle size on bulk density, Elliott (1981) demonstrated in their work, which for the same moisture, bigger particles also have higher density. However, the coal particle size and the greater constancy in its distribution become quite critical for the coking process and the final mechanical strength of the coke (Ulhôa, 1988).

Silva *et al.* (2011) justifies the importance of particle size distribution linked to the petrographic characterization. As inert materials present in coals have higher hardness and resistance to crushing, they are concentrated within a higher size range, while the reactive macerals, the softer portion, present an antagonistic behavior. Due to its infusibility and characteristics mentioned previously, the excessive presence of inerts become responsible for fracture and cracking areas in coke and, therefore, coal crushing becomes a fundamental operation to eliminate these points (Silva *et al*, 2011).

On the other hand, reactive particles of inferior size (< 0.15mm) lose their swelling and fluidity, and their excessive generation leads to a decrease in coal charge bulk density. Consequently, the contact effectiveness between the coal particles decreases, by effect, the mechanical resistance of coke also decreases (Silva *et al*, 2011).

In view of this situation, the present article intends to present and understand the effect of moisture content and the particle size variation of coal charge on bulk density, showing the results for wet and dry bases.

## 2. Materials and methods

### 2.1 Density determination by varying the moisture and grain size of the coal blend

A characteristic coal blend as shown in Table 1 was prepared, dried at 105 °C for 2 hours and divided into two grain size fractions by ASTM 7Mesh sieve. Thus, two base blends were made: one with particle size below 2.83 mm and another with particle size above this range (Figure 1).

| Coal type and pet coke in the blend (weight %) | | Proximate Analysis (weight%) | | Petrographic (%) | |
|---|---|---|---|---|---|
| High Volatile | 22 | Moisture | 6.98 | Reactives | 69.29 |
| Medium Volatile | 54 | Volatile Matter | 25.72 | | |
| Low Volatile | 18 | Ash | 8.07 | Reflectance | 1.13 |
| Pet coke | 6 | Other – Sulfur | 0.84 | | |
| Rheology | | | | | |
| Maximum Fluidity (Log MF/ddpm) | Softening Temperature (°C) | Maximum Temperature of Fluidity (°C) | Solidification Temperature (°C) | Contraction (vol %) | |
| 2.71 | 403 | 455 | 487 | -11.54 | |
| Ash Mineral Analysis (weight %) | | | | | |
| $Na_2O$ | $K_2O$ | $Al_2O_3$ | CaO | MgO | $Fe_2O_3$ |
| 0.58 | 1.69 | 26.90 | 1.95 | 0.84 | 7.29 |
| MnO | $SiO_2$ | $TiO_2$ | $P_2O_5$ | ZnO | |
| 0.04 | 54.81 | 1.42 | 0.62 | 0.02 | |

Table 1
Analysis of the coal blend used.

Coal blends were used to compose new blends with particle sizes 77, 79, 81, 83 and 85% below 2.83mm, typical ranges for use in top-filling coking plants. From a known fixed volume container and the weight of the blend which fills the entire container, the density of each blend was determined (see Figure 1).

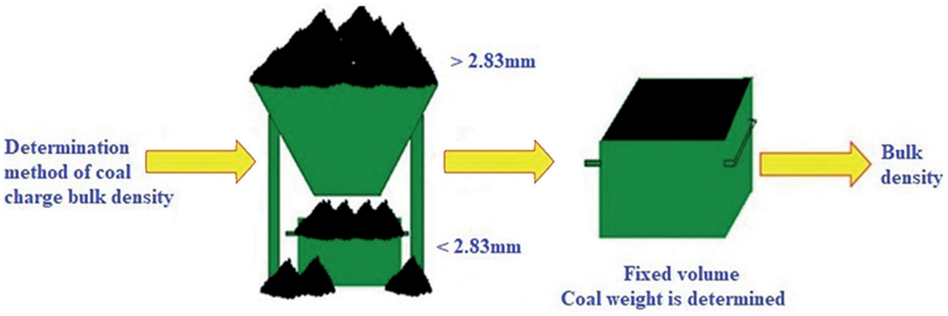

Figure 1
Determination method of coal charge bulk density.

The samples were then homogenized in a rifle splitter adding water to achieve a moisture content of 4%. Thus, new densities were measured. The procedure was repeated, homogenizing and adding water, for the following moisture levels: 5, 6, 7, 8, 9, 10, 12, 14 and 16%.

## 3. Results

The density results for measurements at all moisture levels and grain size variation on a wet basis are presented in Table 2 and on a dry basis by discounting of moisture content in Table 3.

Bulk density (kg/m$^3$)

| Particle size < 2.83mm | Moisture | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 4% | 5% | 6% | 7% | 8% | 9% | 10% | 12% | 14% | 16% |
| 85% | 791 | 734 | 695 | 682 | 657 | 641 | 635 | 652 | 707 | 726 |
| 83% | 828 | 765 | 725 | 698 | 669 | 662 | 665 | 684 | 739 | 771 |
| 81% | 784 | 748 | 705 | 672 | 662 | 661 | 673 | 697 | 756 | 799 |
| 79% | 812 | 760 | 691 | 678 | 670 | 680 | 672 | 709 | 775 | 848 |
| 77% | 820 | 769 | 714 | 693 | 677 | 677 | 680 | 713 | 774 | 840 |

Table 2
Coal blend bulk density for different moisture levels and particle size on wet basis.

Bulk density (kg/m$^3$)

| Particle size < 2.83mm | Moisture | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 4% | 5% | 6% | 7% | 8% | 9% | 10% | 12% | 14% | 16% |
| 85% | 759 | 698 | 653 | 634 | 605 | 583 | 571 | 574 | 608 | 610 |
| 83% | 795 | 727 | 681 | 649 | 616 | 602 | 599 | 602 | 636 | 648 |
| 81% | 753 | 711 | 663 | 625 | 609 | 602 | 605 | 613 | 650 | 671 |
| 79% | 780 | 722 | 649 | 631 | 617 | 619 | 605 | 624 | 667 | 712 |
| 77% | 788 | 730 | 672 | 644 | 623 | 616 | 612 | 627 | 666 | 705 |

Table 3
Coal blend bulk density for different moisture levels and particle size on dry basis.

From these data, graphs were plotted that elucidate the bulk density behavior by grain size and moisture on a wet basis and on a dry basis (Figure 2).

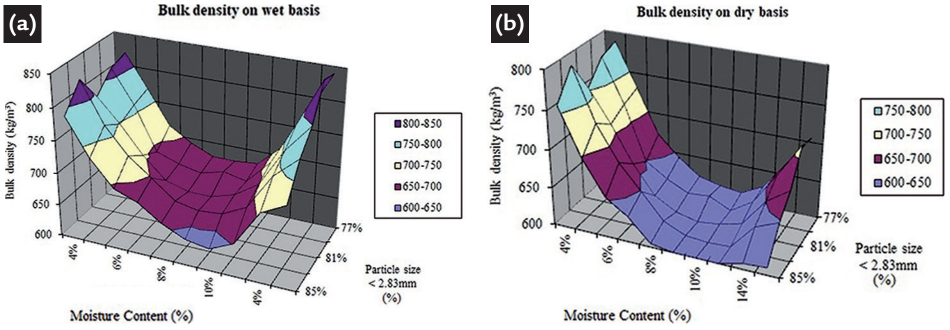

Figure 2
Coal blend bulk density for different moisture levels and particle size on (a) wet basis and (b) dry basis.

## 4. Discussion

### 4.1 Behavior of results

The coal charge bulk density (BD) under study can be expressed by Equation 1, obtained from a multivariable linear regression of blend bulk density (Aiken, 1991; Tabachnick *et al.*, 2011; Cohen *et al.*, 2013) with a determination coefficient ($R^2$) equal to 92.1% (Cohen *et al.*, 2013), where M = moisture and PS = particle size.

$$BD = 731 + 39146 * M^2 + 380 * PS - 9472 * PS * M \qquad (1)$$

Using interacting plots, we come to the results of the Figure 3 and Figure 4, where they can separately realize the moisture and particle size impact on coal blend bulk density for wet basis and even with an overlapping dry basis.

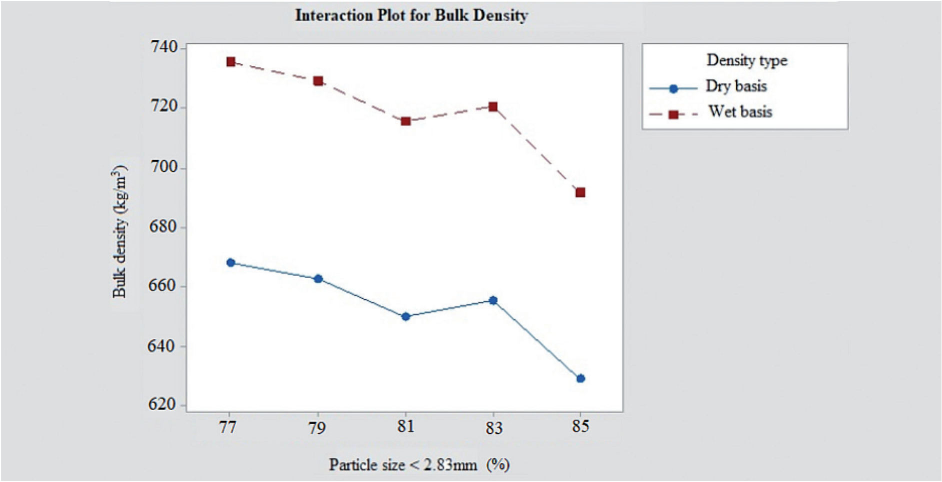

Figure 3
Interaction plot
(bulk density/particle size).

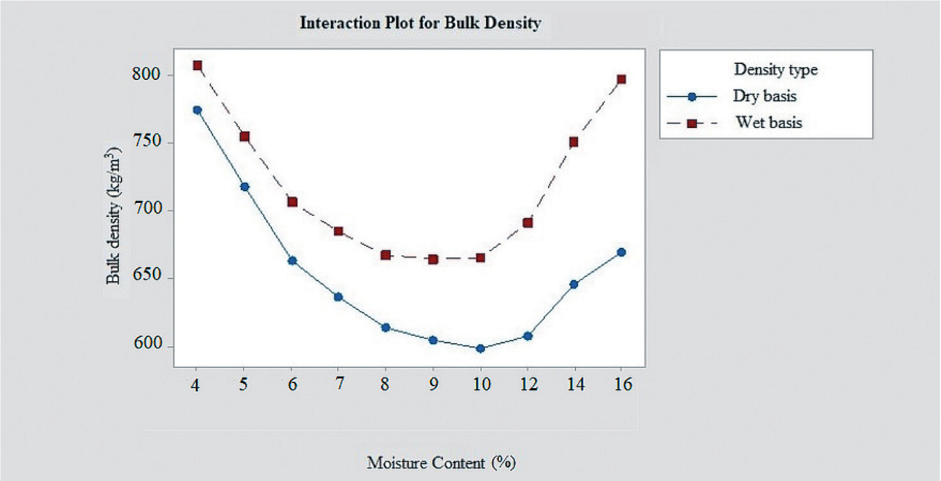

Figure 4
Interaction plot
(bulk density/moisture content).

Figure 4 shows the influence of charge moisture on bulk density, which has a direct impact on the weight of the coal charged in a coke oven. Although the density increases beyond 10%, the difference in the charge bulk density between wet and dry bases is higher, thus influencing the expected productivity that would be reduced.

## 4.2 Theories for obtained results

### 4.2.1 Effect of particle size on charge bulk density

When particles are divided, the total surface area and the number of voids between the particles are increased (Figure 5), reducing the density because the coal volume increases, justifying the results for an excessive crushing at 85% < 2.83mm. The reason for misunderstanding: the resolution limit of the human eye at a distance of 25 cm is 0.2 mm, which means that we do not realize that the empty space increases when the particle size of the coal decreases.

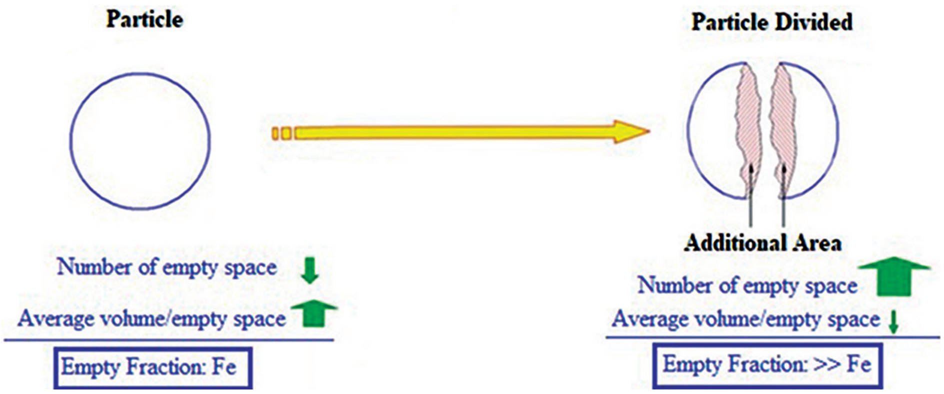

Figure 5
Division effect of a particle
on its surface area and void formation.

Thus, the modification of density due to particle size changes must be careful since the reducing of particle size for finer fractions up to 83%, there may be a loss of fluidity, compromising the coke quality. While for a coarser grain size, such as 77% < 2,83mm, it falls into a region where the inert particles will not be fully enveloped by reactive particles and depending on their size, they will serve as cracking points reducing the coke quality too.

### 4.2.2 Effect of moisture on coal charge bulk density

The effect of the moisture on coal charge bulk density following a U-shaped curve suffers the action of two effects, substitution and compaction, that has a valley where the lowest bulk density occurs, which goes up both for high and low moisture levels (Figure 6).

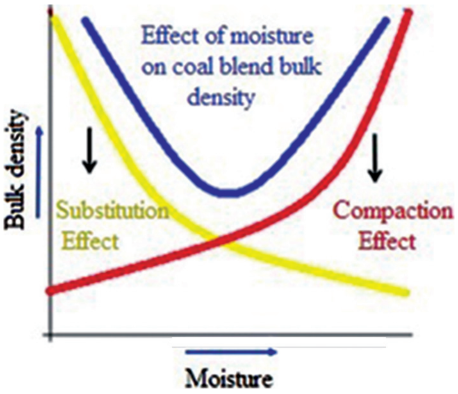

Figure 6
Effect of moisture on coal charge bulk density.

The bulk density initially decreases, since coal density is 1.4 g/cm$^3$ and the water density is 1g/cm$^3$. Thereby, the substitution of coal by water justifies the result found. This can also be explained by the fact that the water enables hydrophobic coal particles to repulse each other, increasing the free space and, consequently, decreasing the density.

In the second part of the graph, the excess moisture causes coal particle agglomeration forming pseudo-particles (Kato *et al.,* 2006). Therefore, there is a compaction effect that leads the space between the particles to decrease and the density to increase.

In respect to the bulk density earning due to changes in moisture, drying of coals up to 4% is more interesting because the density difference between its wet and dry bases is lower; thus, the productivity of the coke oven is greatly increased, and the energy consumption is reduced, since there is lower excess moisture to be removed. However, it is necessary to consider the effect of lower moisture on the increasing of carbon deposition into the coke oven chamber.

## 5. Conclusions

The coal blend bulk density for coking processes can be adjusted by changes on particle size, i.e., the coal crushing level, or even drying or humidifying the coal, that are easily manipulated in the coal beneficiation.

The modification of density in relation to the particle size requires care, since it can fall in a region of high density achieved by larger particles or even in a region with excess of coal fines, where both can compromise the coke quality.

The drying of coal or even the excess of moisture by an agglomeration process can increase the bulk density. Nevertheless, coal blend with a moisture content as low as 4% can present better benefits on the productivity and during the coking process; however, it needs attention with carbon deposition into the coke oven.

Due to coal blend burdening grain size and moisture control, under the economic and environmental point of view, there is a rise of the bulk density in cokemaking that is extremely important, since it permits increase the coke yield, reduces the heat consumption and produces a high-strength coke, thereby enabling an increase in the soft coal ratio of the blend.

## References

AIKEN, L. S. et alii. ***Multiple regression: testing and interpreting interactions.*** Sage, 1991. 224p.

COHEN, J. et. alii. ***Applied multiple regression/correlation analysis for the behavioral sciences.*** 2003. 736p.

ELLIOTT, M. A. ***Chemistry of coal utilization,*** 1981. (Second supplementary volume).

KATO, K., YAMAMURA, Y., NAKASHIMA, Y. Development of dry-cleaned and agglomerated pre-compaction system (daps) for metallurgical cokemaking. Shinnittetsu Giho, v. 384, p. 38, 2006.

LEEDER, R., HOWEY, C., TODOSCHUK, T., GRANSDEN, J., GIROUX, L., Ng, K. W. Coal stockpile moisture and cokemaking. In: AISTECH, 2014. ***Anais...*** Indianápolis: 2014. p. 357-365.

MASAHIKO, W., KUBOTA, Y., UEBO, K., NOMURA, S. Effects of briquette blend on packing structure of fine coal part. In: EUROPEAN COKE AND IRONMAKING CONGRESS – ECIC, 7. ***Anais...*** Linz: 2016. p. 539-546.

NASCIMENTO, L. M. ***Simulação física a frio da densificação da mistura de carvões em coqueria via vibração mecânica.*** Ouro Preto: Universidade Federal de Ouro Preto, 2016. 83 p. (Dissertação de Mestrado em Engenharia de Materiais).

SABADINI, M. B., FERNANDES, D. C., REIS, H. M. B. Adição de óleo na mistura de carvões para fabricação de coque na Usiminas Ipatinga. In: SEMINÁRIO DE REDUÇÃO DE MINÉRIO DE FERRO E MATÉRIAS-PRIMAS, 43. Belo Horizonte: ABM, 2013. (Contribuição Técnica).

SILVA, G. L. R., DESTRO, E., MARINHO, G. M., ASSIS, P. S. Caracterização química, física e metalúrgica das frações granulométricas da mistura de carvão da Gerdau Açominas. In: SEMINÁRIO DE CARVÃO, 1. Gramado, 2011. (Contribuição Técnica).

STANDISH, N., YU, A. B., ZOU, R. P. Optimization of coal grind for maximum bulk density. ***Powder technology,*** v. 68, n. 2, p. 175-186, 1991.

TABACHNICK, B. G. et alii. ***Using multivariable statistics.*** Boston: Allyn and Bacon, 2001.

ULHÔA, M.B. Britabilidade de carvões. In: SEMINÁRIO ABM, Rio de Janeiro: 1988.

WAKURI, S., OHNO, M., HOSOKAWA, K., NAKAGAWA, K., TAKANOHASHI, Y., OHNISHI, T., KUSHIOKA, K., KONNO, Y. New Moisture Control system for coal for coking. ***Transactions ISIJ,*** v. 25, p. 1111-1115, 1985.

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