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MAXIMIZING THE USE OF PULVERIZED-COAL FUEL IN THE BLAST-FURNACE SHOP AT THE MARIUPOL METALLURGICAL COMBINE

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The prerequisites for maximizing the use of pulverized-coal fuel (PCF) injected into the hearth of blast furnaces are examined for the operating conditions in the blast-furnace shop at the Mariupol Metallurgical Combine. The maximum possible amount of PCF that can be used is determined based on the thermal state of the furnace, its gasdynamic regime, and the durability of the lining and the coolers in the bosh. Calculations are performed using both shop performance data and results obtained by mathematical modeling.
Keywords: *pulverized-coal fuel, thermal state, gas permeability, cohesion zone, combustion focal point, blast furnace, coke, pig iron, slag, gasdynamic stability.*

Pig iron is the main raw material used to make steel. Given the current market conditions, metallurgical companies need to use innovative technologies in order to make competitive products and expand their markets. Such technologies allow a company to not only improve its financial standing but also elevate the quality of its products.

The most promising approach to making competitive metal products is to reduce the cost of pig iron by reducing the consumption of the main type of fuel employed in blast-furnace smelting – coke (Fig. 1).

Expenditures on the purchase of coke account for about 40–50% of the cost of making pig iron (Fig. 2). The cost of coke is nearly twice as great as the cost of pulverized-coal fuel (PCF). Replacing coke by PCF is economically expedient, especially given the rising price of natural gas for metallurgical plants in Ukraine.

The blast-furnace shop at the Ilyich Mariupol Metallurgical Combine (MMK im. Ilyicha) introduced a PCF injection technology in 2012 to reduce the amount of coke used to make pig iron. The shop currently injects the hearths of its blast furnaces with more than 100 kg of pulverized coal per ton of pig iron (Fig. 3). The value of the coefficient that characterizes the replacement of coke by pulverized coal is now 0.8, which makes it possible to save up to 120 kg of coke for each ton of pig iron that is made. The amount of coke consumed per ton of pig iron has decreased from 470–520 kg to 350–400 kg (Fig. 3). A further decrease in coke use as a result of an increase in PCF injection might be possible if the counter-flow of the charge materials and the gas is properly organized, since an increase in the amount of PCF injected into the furnace also increases the gas-pressure gradient over the height of the furnace (Fig. 3).

The maximum amount of PCF that can be injected is limited by the thermal state of the blast furnace during smelting. That state can be evaluated based on the composition of the pig iron and the slag and the furnace's gasdynamic regime. The gas-

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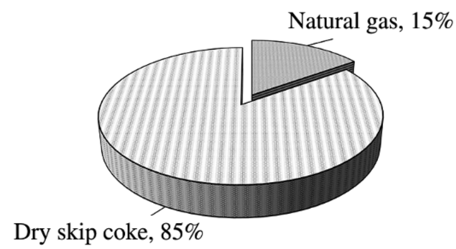

Fig. 1. Structure of the process fuel for making pig iron at the MMK im. Ilyicha during 2012.

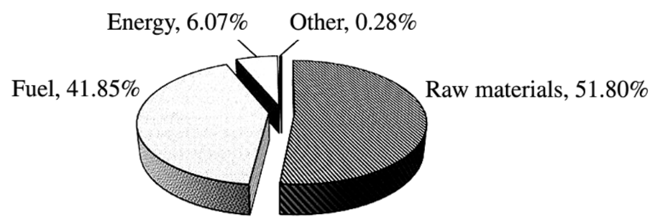

Fig. 2. Structure of the expenditures on the production of conversion pig iron at the MMK im. Ilyicha during 2012.

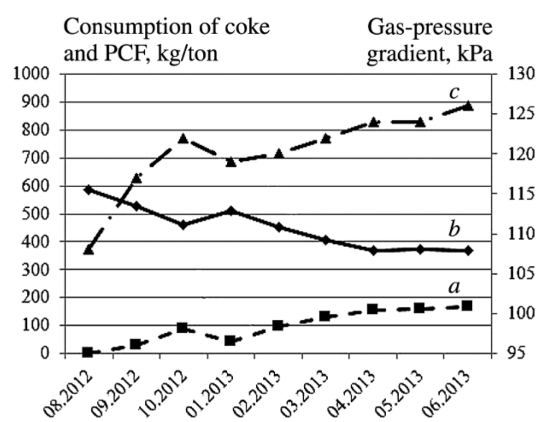

Fig. 3. Dynamics of the change in coke rate (*b*) and the gas-pressure gradient (*c*) in BF-3 at the MMK im. Ilyicha with an increase in the consumption of PCF (*a*) for making pig iron.

dynamic regime is in turn determined by the gas-pressure gradient in the furnace and the criterion of gasdynamic stability (GDS) in accordance with the equation [1]

$$\mathrm{GDS} = (\Delta p/H)/(\rho g),$$

where $\Delta p/H$ is the gas-pressure gradient over the height of the stock, kg/(sec^2·m^2); ρ is the bulk density of the stock, kg/m^3; and g is acceleration due to gravity, m/sec^2.

The theoretical combustion temperature and the characteristics of the oxidative zone (its dimensions) are equally important as criteria that restrict the amount of PCF which can be used.

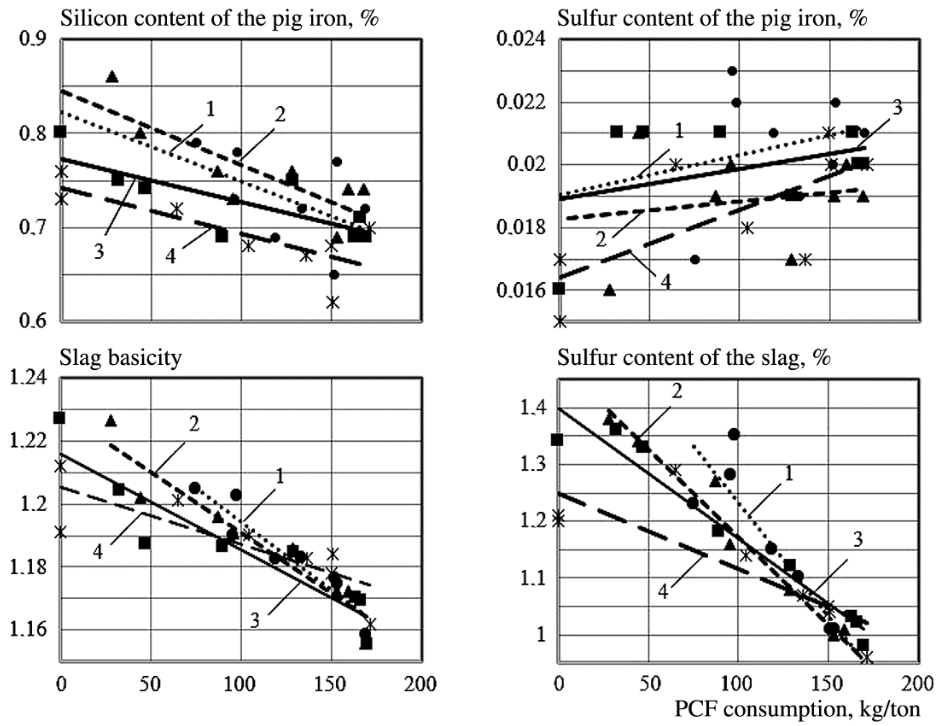

Fig. 4. Change in blast-furnace smelting parameters with a change in PCF consumption in the blast-furnace shop at the MMK im. Ilyicha: *1*) BF-1; *2*) BF-3; *3*) BF-4; *4*) BF-5.

An analysis was made of the thermal state of blast furnaces at the MMK im. Ilyicha (Fig. 4) in relation to changes in the consumption of PCF. It was determined that an increase in PCF use is accompanied by a decrease in the heating of the furnaces. This was confirmed by the reductions that were seen in the chemical heating of the pig iron ([Si]↓, [S]↑) and the slag [(S)↓, (CaO/(SiO_2)↓]. The silicon content of the pig iron and the sulfur content approach the boundary conditions with an increase in the composition of PCF to 200 kg/ton pig iron. Thus, in accordance with the specifications, conversion pig iron should have a silicon content within the range 0.6–0.9% and can have a sulfur content of up to 0.025%. The thermal state of the furnaces (Fig. 4) shows that 200 kg/ton pig iron can be considered the critical PCF consumption for blast furnaces.

An analysis was also made of the gasdynamic state of the blast furnaces (Fig. 5). An increase in PCF consumption is accompanied by an increase in the gas-pressure gradient inside the furnaces, this despite the fact that the volume of the furnace gases which are formed decreases when PCF use is increased. This result can be attributed to a decrease in the gas permeability of the dry portion of the furnace charge as a result of a decrease in the furnace's content of high-permeability coke and a reduction in the size of the cohesion zone due to the reduced height of the coke windows. There may also be a decrease in gas permeability in the lower part of the furnace because the PCF may not undergo complete combustion in the oxidative zone and may instead settle into cavities between the coke particles in the lower part of the furnace and the cohesion zone [2–5]. In addition, unburned PCF particles, combining with the slag, make the slag more viscous and thus reduce gas permeability in the furnace's bottom part.

The maximum gas-pressure gradient that will not adversely affect the furnace's performance can be determined based on the GDS criterion, which ranges from 0.5 to 0.6 [6]. The injection of coal dust changes not only the gas-pressure gradient but also the bulk density of the materials inside the furnace. This takes place because part of the charge's content of coke, which is relatively light, is replaced by iron-ore-bearing materials, which are heavier.

The GDS criterion for the furnaces at the combine (Fig. 6) was calculated with the assumption that the bulk densities of the iron-ore materials and the coke do not change over the height of the furnace and are respectively equal to 1.7 and

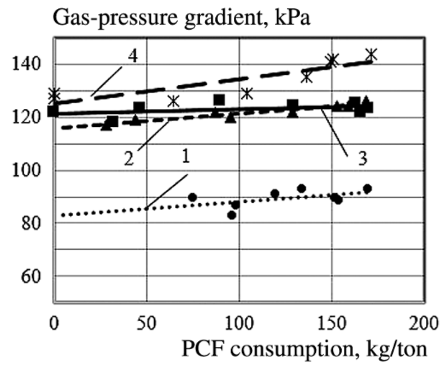

Fig. 5. Change in the gas-pressure gradient in blast furnaces at the MMK im. Ilyicha with a change in PCF consumption: *1*) BF-1; *2*) BF-3; *3*) BF-4; *4*) BF-5.

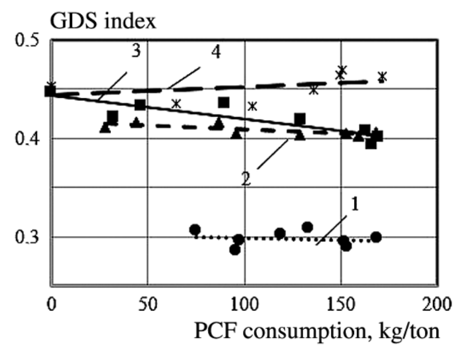

Fig. 6. Change in the gasdynamic stability index with a change in PCF consumption: *1*) BF-1; *2*) BF-3; *3*) BF-4; *4*) BF-5.

0.5 tons/m^3. It is evident from Fig. 6 that for all the furnaces except No. 5 the value of the GDS criterion decreased with an increase in PCF consumption and the gas-pressure gradient. This linkage has to do with a reduction in the volume of the furnace gases that are created; furnace productivity does not decrease in this case. An even larger increase in PCF consumption might be possible with a decrease in wind rate if the blast air is enriched with oxygen, although oxygen enrichment of the blast would adversely affect the gas distribution over the radius of the furnace. A decrease in wind rate would decrease the size of the coke circulation zone and the velocity of the peripheral gas flow. Those two developments would in turn adversely affect the use of the gases' thermal and chemical energy, the durability of the lining, and the condition of the furnace's cooling system. At present, a PCF injection rate of 145 kg/ton pig iron is considered normal for the furnaces at the combine. To further increase PCF use, it would be necessary to increase the wind rate in order to prevent burning of the cooling devices in the bosh and slippage of the slag crust. However, in the case being discussed, it would also be necessary to increase the gas permeability of the stock.

Calculations showed that on furnaces Nos. 4 and 5 an increase in PCF consumption caused the focal point of the combustion process to move closer to the furnace's periphery. Without the injection of PCF, the focal point is located roughly 0.5 m from the end of the tuyeres. When PCF consumption is increased to 170 kg/ton pig iron, the focal point moves to a location 0.38–0.4 m from the end of the tuyeres if the temperature and oxygen content of the blast are both increased as well. The distance between the combustion focal point and the end of the tuyeres is 0.42–0.45 m at a PCF consumption of 145 kg/ton pig iron. To keep this distance from changing on furnace No. 4 when PCF consumption is raised to 170 kg/ton pig iron, the wind rate needs to be held within the range 68–70 m^3/sec. The pressure gradient increases from 123 to 151 kPa in this case.

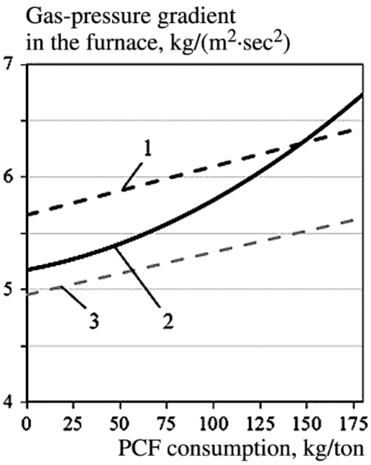

Fig. 7. Gas-pressure gradient in a blast furnace in relation to changes in PCF consumption: *1*, *3*) straight lines corresponding to the region in which furnace operation is optimal based on the GDS criterion; *2*) gas-pressure gradient.

The descent of the stock will be slowed by this increase, since the GDS will approach 0.5. Thus, from a gasdynamic standpoint, with the use of a high wind rate the maximum possible PCF consumption must be kept to 170 kg/ton pig iron if the combustion focal point is to be located at a distance of 0.42–0.45 m inside the coke-circulation zone. If the wind rate cannot be increased for some reason, the focal point of the combustion zone can be moved away from the furnace wall by reducing the diameter of the tuyeres or increasing the amount by which they project into the furnace.

In order to increase PCF use further, it is necessary to improve the gas permeability of the stock. The best opportunity for decreasing the gas-pressure gradient in the stock lies in the cohesion zone [7].

Calculations were performed for 2002-m^3 blast furnace No. 3 to find a value of PCF consumption that will not disrupt the furnace's smooth operation if no special measures are used to improve gas permeability in the cohesion zone. For the purposes of the calculations, the weight of the iron-ore materials in each round was 50 tons and coke weight was 15 tons when no PCF was injected. Coke weight was 12 tons when PCF was injected at a rate of 100 kg/ton pig iron. The 3-ton reduction in the weight of the coke in the charge led to a decrease in the height of the coke windows by 0.1 m; coke-window height was 0.46 m when 15 tons of coke were charged and was 0.36 m when 12 tons of coke were used. The ore burden increased from 3.3 to 4.2 tons/ton pig iron when coke consumption was changed within the range just indicated. Figure 7 shows the change in the gas-pressure gradient as PCF consumption was changed. The gradient was calculated based on the pressure distribution over the height of the furnace, which in turn was calculated by using the finite difference method with grids to solve the Navier–Stokes differential equation in implicit form [8].

It can be seen from Fig. 7 that an increase in PCF consumption is accompanied by an increase in the gas-pressure gradient and upward movement of the top boundary (straight line *1*) of the region in which furnace performance is optimal. The increase in the gas-pressure gradient is more rapid than the increase in the pressure exerted by the stock due to its higher content of heavy (compared to coke) iron-ore materials. After PCF consumption is raised above a certain value, the moment (corresponding to the intersection of lines *1* and *2*) arrives when PCF use can be increased further only if compensating measures are used (see Fig. 7). As was noted earlier, the wind rate can be decreased if PCF consumption is increased, and such a decrease can act as a compensating factor. Calculations performed for furnace No. 3 showed that the critical value of PCF consumption is 150 kg/ton pig iron. This parameter can be increased to 170 kg/ton pig iron if the wind rate is decreased to a level which ensures that the combustion focal point will be located 0.42–0.45 m from the tuyeres.

The amount of PCF that will not adversely affect blast-furnace performance can be determined by calculation for specific operating conditions.

Conclusions

1. It is best to use an index which characterizes gasdynamic stability in order to assess the stability of the operation of a blast furnace.

2. Analysis and calculation showed that the maximum possible PCF consumption for the operating conditions in the blast-furnace shop of the MMK im. Ilyicha is within the range 150–170 kg/ton pig iron.

3. When PCF consumption is increased, in order to keep the combustion focal point located 0.42–0.45 m from the end of the tuyeres it is necessary to either increase the wind rate or to decrease the volume of the blast and the diameter of the tuyeres while also increasing the amount by which they project into the furnace.

4. If PCF is injected into a blast furnace and the same blast-based smelting rate is maintained, then the cohesion zone needs to be configured in such a way as to reduce the loss of gas pressure inside it.

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