

## On the prospects for increasing the flow rate of pulverized coal in iron production within the operating conditions of Blast Furnace Shop of PJSC “Ilyich Iron and Steel Works”

**Zinchenko Y.A.**

*Director General of PJSC «Ilyich Iron and Steel Works of Mariupol»  
Ukraine.*

*E-mail: referentGDMMK@ilyichsteel.com.*

**Kosolap N.V.**

*Head of the Blast Furnace Shop of PJSC «Ilyich Iron and Steel Works of Mariupol» Ukraine.*

*E-mail: nikolay.kosolap@ilyichsteel.com.*

### Abstract

The experience on solving the problem of blast furnace smelting efficiency increase through the introduction of blast furnace iron making technology that implies to replace part of the coke with pulverized coal (PCI) is generalized.

An analysis of changes in the technological parameters and the thermal conditions of the furnace with pulverized coal injection is made. Technological and technical ways of increase of pulverized coal injection to Blast furnaces are defined.

Key words: BLAST FURNACE SMELTING, PULVERIZED COAL, COKE, TECHNOLOGICAL PARAMETERS, CRITERION OF GAS-DYNAMIC STABILITY, COHESIVE ZONE

### Problem statement

Iron industry of Ukraine is characterized by high energy consumption in blast furnace production, which was mainly provided by such deficient and expensive energy resources as coke, black fuel oil and natural gas. Up to 70% of all energy consumption in the iron industry is used for iron smelting which makes 35-45% of the iron prime cost (Fig. 1).

The main sources of heat in the iron production at the Blast Furnace Shop of PJSC «Ilyich Iron and Steel Works of Mariupol» before PCI implementation were

coke and natural gas (Fig.2).

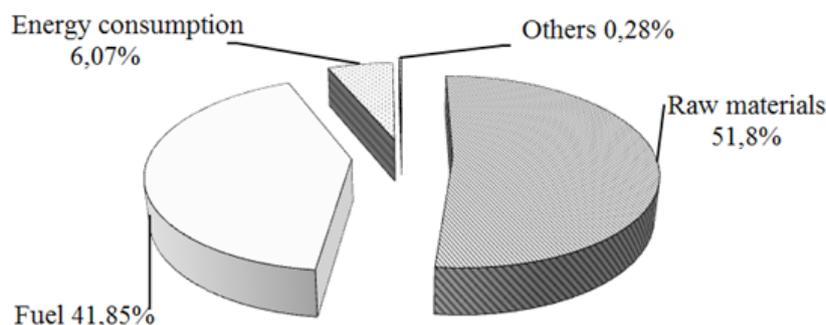
As can be seen from the above data, the level of coke flow rate per one ton of iron is an indicator of the efficiency and competitiveness of the steel industry as a whole.

The analysis of the Iron and Steel sciences, correlation of operation results of some Blast Furnace Shops in the number of countries, the analysis of dynamics of changes in coke rate for iron smelting, give grounds to assume that on the basis of the current level of technology of blast furnace smelting and use

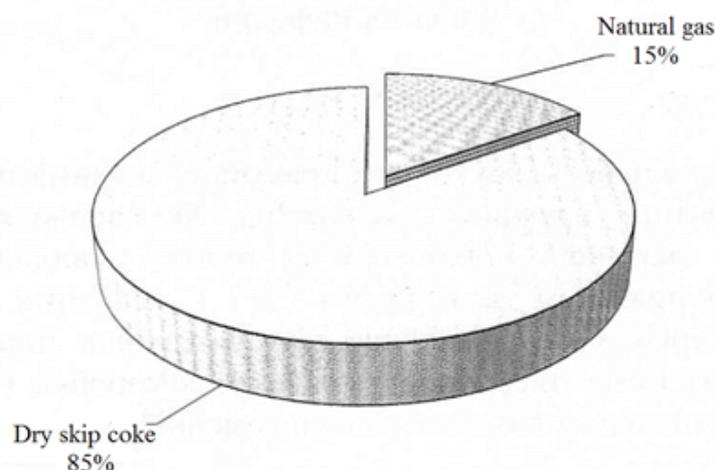
## Blast-furnace process

of pulverized coal injection, consumption of coke per one ton of iron can be reduced to 200 kg maintaining

high levels of blast furnaces performance and iron quality.



**Figure 1.** The structure of pig iron cost of production in the Blast Furnace Shop of PJSC «Ilyich Iron and Steel Works of Mariupol» for 2012



**Figure 2.** The structure of process fuel for the production of iron at PJSC «Ilyich Iron and Steel Works of Mariupol» for 2012

### Analysis of recent achievements

The development and testing in the operating conditions of the theory of full and complex compensation of technological mode disturbance caused by the combustion of pulverized coal and by decrease of the coke percent in the blast charge became an important stage in the development of blast furnace technology with the use of PCI.

«Trial and error method», which was often prevalent during the development of new technological modes, is replaced by rigorous and justified calculation that determines the ability to reduce substantially the lead time of the most efficient modes with pulverized coal flow rate of 150-250 kg /m t of iron [1]. The main compensating effects are: improved quality of iron ore materials and coke, growth of blast temperature and oxygen concentration therein, entry into the furnace of the iron ore charge in mixture with the coke nuts. This complex of compensating measures, according to international practice, is

obligatory, and can be realized at the metallurgical enterprises of Ukraine with minimum costs.

By national Program of Mining and Metallurgical Complex Development in Ukraine it was recommended to transfer all blast furnace production (26-32 million tons of iron per year during the development of the Program) to the technology of pulverized coal injection in the amount of 150-200 kg per ton of iron. [2]

The shortage of metallurgical coal is now felt throughout the world, including Ukraine. The demand for power generating coal, which is used in PCI, can be covered by existing reserves of such coal in Ukraine. Over 2 million tons of coke will be replaced with the withdrawal from the coking charge of the appropriate amount of low coking coal, which can be used in PCI production, while the quality of the coke produced will be significantly improved, along with the withdrawal of more than 2 mln. m<sup>3</sup> of the imported natural gas [2]. The quantity of detrimen-

tal emissions during coke and by-product production will be significantly decreased.

An important factor that must be considered while using pulverized coal in blast furnaces, is the necessity to create such thermal and gas-dynamic conditions in the lower part of the furnace, which would ensure its operation at high consumption rates of pulverized coal. The determining factors in this case [3,4] are :

- blast temperature and content of oxygen in the blast (not lower than 1100° C and 25%, respectively), to compensate the theoretical combustion temperature reduction at the tuyeres, to provide the necessary thermal state of the hearth and pulverized coal combustion rate;
- («hot») coke strength after reaction (CSR, not less than 60%), and therefore its reactivity (CRI no more than 25-30%), which directly affect coke packing permeability for gases and liquid smelting products;
- increase in the strength of iron ore components in charge and the reduction of the fines content in it (no more than 5% of the fractions less than 5 mm in size). These factors are to some extent carried out in the Blast Furnace Shop of Ilyich Iron and Steel Works.

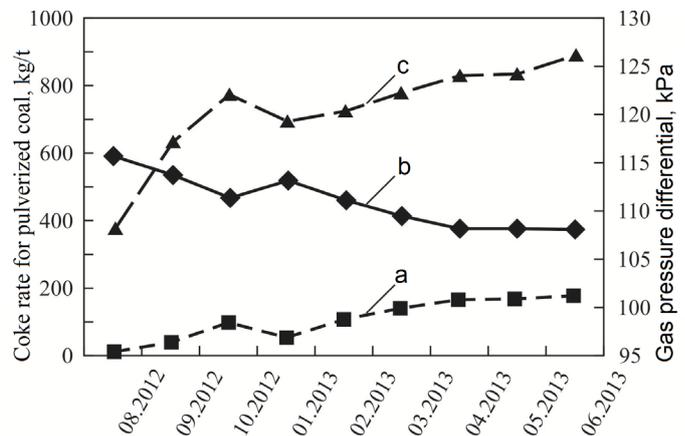
Equally important is the efficiency of coal particles combustion in the hearth of the blast furnace. However, the conventional oxygen enrichment of the blast does not give the desired effect, therefore methods are developed for its local supply directly to the jet of pulverized coal. As the result, different options were proposed for joint injection of pulverized coal and oxygen, the most common of which is coaxial burner, successfully tested abroad.

There is an opinion [5], based on the well-known studies [6] that this method of mixing pulverized coal with oxygen is not efficient enough, as at the early stages of coal particles combustion (heating, emission of volatiles) oxygen is almost never used. Only after the release of volatile and warming up of coke residue, starts the active interaction of oxygen with carbon of pulverized coal particles. Taking this into account, a method of individual supply of oxygen to the flow of pulverized coal after its release into the flow of the blast was developed with the appropriate design of the oxygen tuyere [5].

*Objective* – summarizing the experience of implementation of the blast furnace technology with the injection of pulverized coal into the furnace at the Blast Shop of Ilyich Iron and Steel Works and the analysis of its impact on the process parameters and the thermal state of the blast furnace, to develop technical proposals, the use of which will increase the pulverized coal flow rate up to 200 kg per ton of iron.

### Statement of the basic material

In order to reduce coke flow rate in the process of iron production in the blast furnace shop of PJSC «Ilyich Iron and Steel Works of Mariupol» the technology of pulverized coal injection was implemented in 2012 [7]. Currently, the amount of coal dust blown into the furnace blast furnaces exceeds 100 kg / m t of iron (Fig. 3a), thus, with the rate of replacement from coke to coal dust 0.8 the coke saving amounts up to 120 kg per 1 t of iron produced. The flow rate of coke per ton of iron is reduced from 470 - 520 to 350-400 kg / t (Fig. 3b). Further reduction in coke flow rate by increasing the rate of pulverized coal injection is possible providing that rational management of the counter-flow of charge mixture and gas is ensured, since the increased injection of pulverized coal will result in an increased gas pressure differential along the furnace height (Fig. 3c).



**Figure 3.** Dynamics of changes in the coke rate and gas pressure differential in the blast furnace No 3 at PJSC «Ilyich» in case of increased injection of pulverized coal during the process of iron production : a – the rate of pulverized coal injection, kg per 1 t of iron; b - coke rate, kg/t of iron; c - the gas pressure differential along the height of the blast furnace, kPa

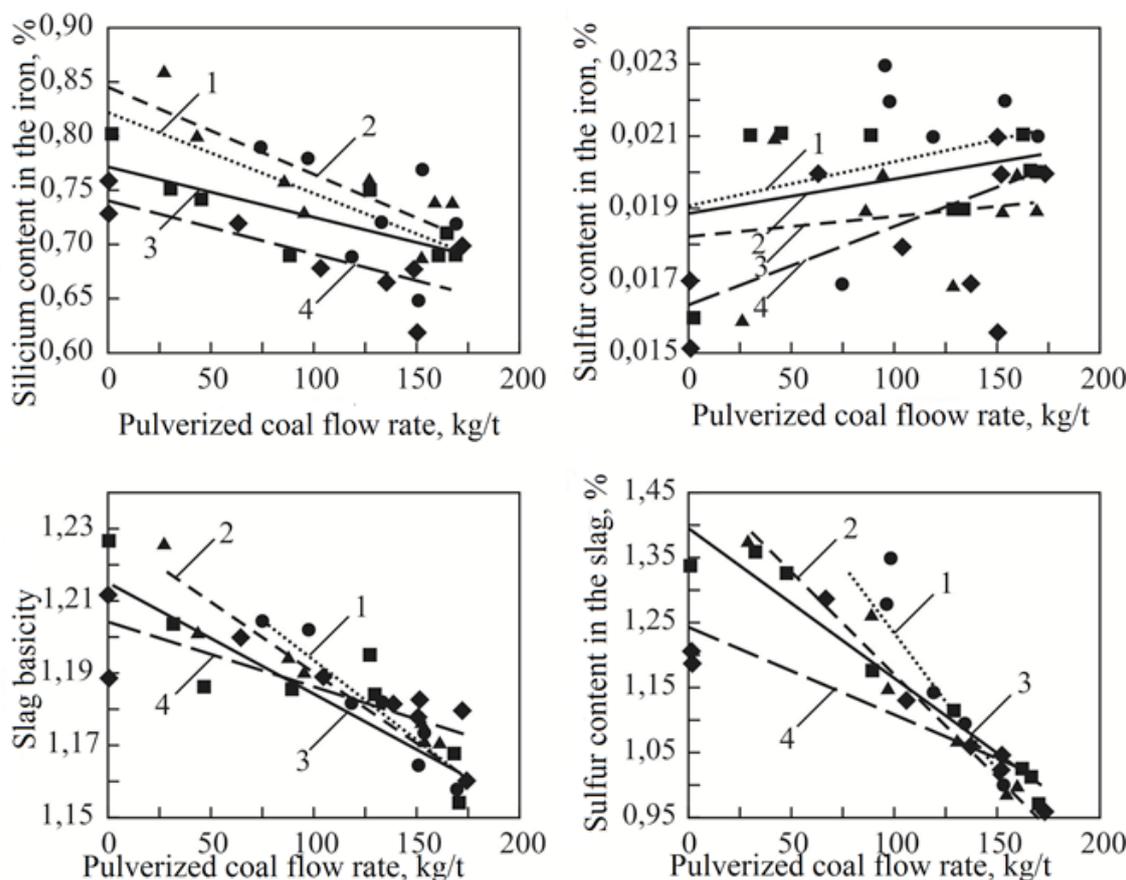
The maximum possible amount of injected pulverized coal is limited by the thermal state of blast furnace melt, which can be estimated according to the composition of iron, slag and the gas-dynamic mode determined by the gas pressure differential along the height of the furnace and the criterion of gas-dynamic stability of the charge column.

$$GDS = \frac{\Delta P / H}{\rho g} \quad (1)$$

where  $\rho$  is the bulk density of the charge column, kg / m<sup>3</sup>; g - is the gravitational acceleration, m/s<sup>2</sup>;  $\Delta P / H$  - is the gradient of the gas pressure drop along the height of the charge column, kg / (s<sup>2</sup> m<sup>2</sup>).

Additionally, another important criterion, which restricts the rate of injection of pulverized coal, is the theoretical temperature of combustion and the characteristics of the oxidizing zone (its size). The ana-

lysis was made of changes in the thermal state of blast furnaces of PJSC «Ilyich» due to changes in the rate of the pulverized coal. (Fig.4)



**Figure 4.** Changes in the parameters of the blast furnace melt with different rate of injection of pulverized coal in the blast furnace shop of PJSC «Ilyich»: 1 - blast furnace №1; 2 - blast furnace №3; 3 - blast furnace №4; 4 -blast furnace №5

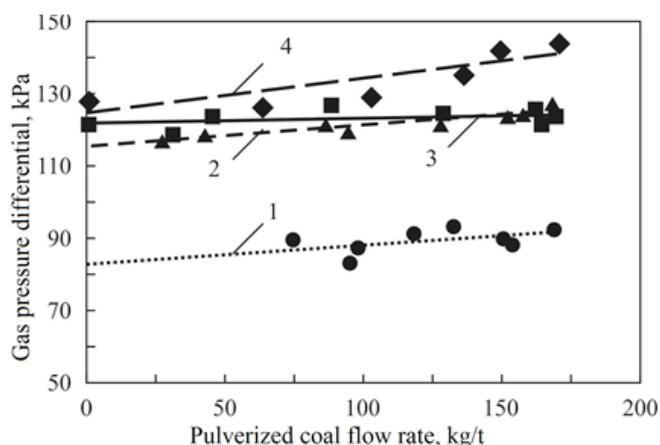
The increased flow rate of pulverized coal has resulted in decreased heating of the blast furnaces, as proved by decreased chemical heating of the iron ( $[Si]$ ,  $\downarrow [S]$   $\uparrow$ ) and slag ( $(S) \downarrow$ ,  $(CaO) / (SiO_2) \downarrow$ ). In case the rate of pulverized coal is increased up to 200 kg per 1 t of iron then the content of silicon in the iron and sulfur will approach their boundary conditions. Thus, according to technical requirements, the content of silicon and sulfur in iron should be within the range 0.6 - 0.9%, and 0.025% respectively. According to the thermal condition of the furnaces (Fig. 4) the critical flow rate of pulverized coal for blast furnaces, according to the optimal value of the gas-dynamic stability layer criterion, may be estimated as 200 kg per 1 m t of iron.

The content of silicon in the cast iron decreases due to slowing down of the endothermic reaction of its reduction at low temperatures. The content of the sulfur in the iron increases due to reduction in the slag

basicity and its increased viscosity caused by the lowering temperature. Under these conditions, the transfer of sulfur in slag goes down. The slag basicity is reduced due to lower reduction of silicon, i.e. large amount of silica remains in the slag.

Also, the analysis of the gas-dynamic state of furnaces with increase of pulverized coal flow rate was carried out (Fig. 5). It was found out that the gas pressure differential in the furnaces increased despite the fact that the volume of the furnace gases decreased in case of increasing the flow rate of pulverized coal. This fact is explained by reduced gas permeability of the dry zone of blast furnace due to lower coke percent in the charge and, as a result, by reduction of coke windows height in the cohesion zone. The gas permeability in the bottom area of blast furnace may be reduced because the pulverized coal may not be burnt fully in the oxidation zone and thus settles in the cavities between particles of coke in the bottom

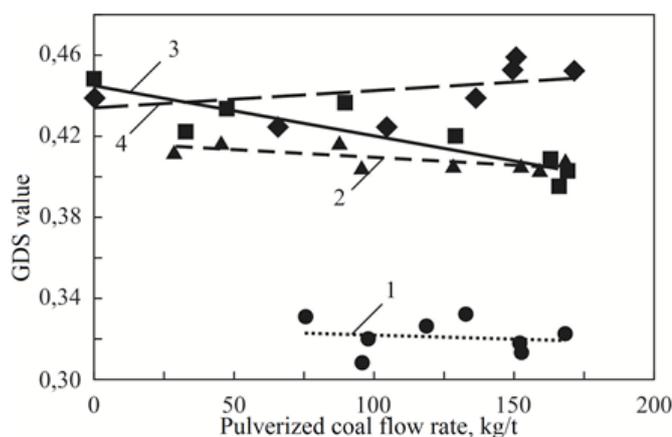
of the furnace and in the cohesion zone [8]. In addition, the unburnt particles of the coal dust connecting with the slag enhance its viscosity thereby reducing the gas permeability in the bottom of the furnace.



**Figure 5.** Variation in the gas pressure differential in the blast furnaces of PJSC «Ilyich»: 1 – blast furnace №1; 2 - blast furnace №3; 3 - blast furnace №4; 4 -blast furnace №5

The most feasible gas pressure differential in the blast furnace, which will not adversely affect the furnace's operation can be determined according to the GDS criterion, the value of which should not exceed 0.5 - 0.6.

The injection of pulverized coal influences not only the gas pressure differential, but also the bulk density of the materials present in blast furnace. This is because the coke is now excluded from the charge mix and replaced by iron ore materials. The criterion of gas-dynamic stability of the layer, determined for the furnaces of PJSC «Ilyich» is shown in Fig. 6.



**Figure 6.** Change of the gas-dynamic stability criterion when applying different flow rates of pulverized coal: 1 - blast furnace №1; 2 - blast furnace №3; 3 - blast furnace №4; 4 -blast furnace №5

Figure 6 shows that under conditions of increased flow rate of pulverized coal and gas pressure differential a decreased GDS value has been detected on all furnaces, with exception of the blast furnace №5, as a result of reduced output of furnace gases. Meanwhile, the productivity of the furnaces has not declined. It is possible further to increase the flow rate of pulverized coal while reducing blast consumption by implementing the oxygen enrichment, however this will have a negative impact on gas distribution radially within the furnace. When the blast volume is reduced, the extent of the coke circulation area reduces and the intensity of the peripheral gas flow increases. This will have negative impact on utilization of thermal and chemical energy of gases as well as on the lining life of the furnace and its cooling system. Under existing conditions, the optimum flow rate of pulverized coal for Ilyich's blast furnaces is considered to be 145-160 kg per 1 t of iron. In order to further increase the flow rate of pulverized coal it is necessary the blast volume to be increased as well to prevent burning of bosh coolers and slumping of slag lining, however, it is also necessary to increase permeability of the gas in the charge column.

The calculations showed that, for blast furnaces №4 and 5, an increased flow rate will make the combustion focus in the oxidizing zone move to the periphery. If the injection of pulverized coal is not applied the combustion focus is located at a distance approximately 0.5 m from the end of the tuyere, while an increase in the flow rate up to 170 kg / t will relocate the combustion focus at a distance of 0,38-0,4 m, providing that both the blast temperature and the content of oxygen in the blast have been increased. In case the flow rate is 145 kg per 1 t of iron, the location of the focus of combustion will be at a distance of 0,42-0,45 m from the tuyere's end.

For the blast furnace №4, in order to maintain such distance under condition when the flow rate increases up to 170 kg/t, it is necessary to ensure that the blast consumption is to be within 68-70 m<sup>3</sup>/s. In this case the gas pressure differential increases from 123 kPa to 151 kPa. With such pressure drop of gas in the furnace will cause a tight descend of the charge material since the GDS index is close to 0.5. Therefore, assuming the gas-dynamic circumstances, the maximum flow rate of pulverized coal is 170 kg per 1 t of iron, with increased blast consumption, in order to remove the focus of combustion in the coke circulation area at a distance of 0,42-0,45 m. In case when the increasing of the blast consumption for removal of the focus of combustion from the furnace's walls, the diameter of the tuyeres should be reduced or their

retraction should be extended.

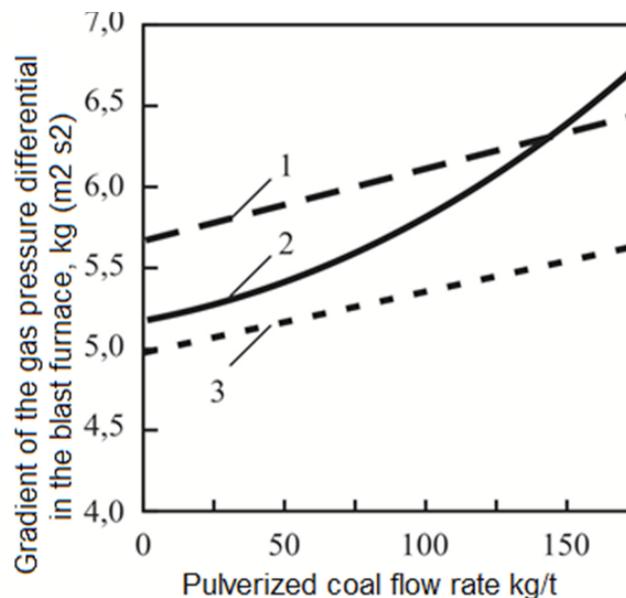
For further increase of the coal dust flow it is necessary to solve the problem on improvement of the gas permeability to the charge column. The largest reserve for reducing gas pressure differential in the charge column of the blast furnace is in the cohesive zone.

For the operating conditions of the blast furnace No.3 with working volume of 2002 m<sup>3</sup> at PJSC "ILYICH IRON AND STEEL WORKS OF MARIUPOL" the calculations were made to determine the flow rate of pulverized coal that does not result in disturbance of smooth operation of the furnace without the use of measures to improve the gas permeability of the cohesive zone. The calculation was made assuming that the mass of the charged iron ore material is 50 t, the mass of coke – 15 t without pulverized coal and 12 t with pulverized coal in the amount of 100 kg per ton of iron. Reduction of the coke mass in the feed by 3 t results in the reduction of coke window height by 0.1 m. The coke window height is 0.46 m, when feeding 15 tons of coke, and 0.36 m – when feeding 12 t of coke. Burden-weight ratio on coke in the furnace while reducing the mass of coke in the specified range is increased from 3.3 to 4.2 t/t. Fig. 7, curve 2, shows the change in the gradient of the gas pressure differential when changing the pulverized coal flow rate. The gradient of the gas pressure differential in the blast furnace is calculated based on the pressure distribution heightwise the furnace. In its turn the distribution of gas pressure heightwise the furnace is calculated by solving the differential equation of motion implicitly.

As can be seen from Fig. 7 with increase in the pulverized coal flow, the gas pressure differential and the upper bound (line 1), which limits the area of the blast furnace optimal performance, also increase. The gas pressure differential in the furnace rises more sharply than the pressure of materials as a result of increasing the percent of heavier iron materials as compared with coke. As a result, with increase of the pulverized coal flow rate above certain quantity it will be a point (intersection of lines 1 and 2, Fig. 7), when a further increase in its consumption will be only possible in applying of compensatory measures. As stated previously the increase in the pulverized coal flow rate may decrease the blast volume. This factor may be a compensatory one. As the calculation has shown for the operating condition of the blast furnace No.3 at the Blast-Furnace Shop of PJSC «Ilyich Iron and Steel Works of Mariupol» the critical pulverized coal flow rate is 150 kg/t. With decrease of the blast volume to a level which provides the location of the

combustion focus point at a distance of 0,42-0,45 m from the tuyeres it is possible to increase the pulverized coal flow rate up to 170 kg/t of iron.

Quantity of the pulverized coal, which will not adversely affect the operation of the blast furnace, can be calculated for the specific conditions.



**Figure 7.** Gradient of the gas pressure differential in the blast furnace when changing the coke flow rate: 1,3 – lines limiting the area of the blast furnace optimal performance by GDS criterion; 2 – gas pressure differential in the blast furnace

### Prospects for further researches

For effective resolution of the main task – the reduction of the coke rate for iron smelting ensuring stable and high-performance operation of blast furnaces – it is necessary to continue researches focused on optimization of systems for charge loading into blast furnaces in order to obtain rational arrangement of softening zone, and investigate the effect of coke nut entry into the charge mixture on the gas-dynamic conditions of blast furnaces at various ways of its loading into blast furnaces. To investigate the possibilities of more complete use of the theory of full and comprehensive compensation of technological mode disturbances caused by combustion of the pulverized coal and by decrease of coke percent in the blast charge.

### Conclusions

1. Analysis and calculation has shown that the maximum pulverized coal flow rate for operating conditions of the Blast-Furnace Shop of PJSC «Ilyich Iron and Steel Works of Mariupol» is 150-170 kg per iron ton;

2. For increase of the pulverized coal flow rate up to 200 kg per iron ton it is necessary to make better

use of compensatory measures, such as decrease of fine fractions in the charge, increase of oxygen concentration in the blast, decrease of slag ratio.

3. For evaluation of gas-dynamic conditions of blast furnace operation it is reasonable to use the criterion of the layer's gas-dynamic stability;

4. When increasing the pulverized coal flow rate, in order to maintain the combustion focus point at a distance of 0,42-0,45 m from face ends of tuyeres it is necessary to increase the blast volume or to decrease diameter of tuyeres and increase their projection in case of blast volume decrease;

5. In the course of pulverized coal injection and keeping the smelting rate in terms of the blast it is necessary to make rational arrangement of cohesive zone in order to decrease in it gas pressure losses.

### References

1. Yaroshevskiy S.L., Kuznetsov A.M., Afanasev Z.K. Reserves for efficiency of the fuel-enriched blast in blast-furnace shops in Ukraine. Donetsk, Nord Computer, 2006, 31 p.
2. Pliskanovskiy S.T., Bochka V.V., Stupak Y.A. Focal points of improvement in techniques of preparation and injection of pulverized coal. Proceedings of the International science-and-technical conference "Pulverized coal is an alternative to the natural gas for iron smelting. Donetsk, UNITEH. 2006, 398 p.
3. Yaroshevskiy S.L. Pulverized coal is a realizable and effective alternative to the natural gas in iron and steel industry. Donetsk, Nord Computer. 2006, 16 p.
4. Amosha A.I., Bolshakov V.I., Minaev A.A. Iron and steel industry in Ukraine: present challenges and development prospects. NAS of Ukraine, Institute of Economics and Industry. 2013, 114 p.
5. Kochura V.V., Yaroshevskiy S.L., Babich A.I. Pulverized coal combustion augmentation in the blast-furnace smelting. International conference «Quality policy in industry and education», 3-10 June 2005, Varna-Dnepropetrovsk, Porogi, 2005, p.53-56.
6. Kalinchak V.V., Zinchenko Y.A., Chernenko A.S. (2013). High temperature mass exchange and kinetics of chemical reactions between carbon particles and gases. *Metal and casting in Ukraine*. No 11, p.p. 14-25.
7. Zinchenko Y.A. Pulverized coal injection development in iron smelting at PJSC «Ilyich Iron and Steel Works of Mariupol» /Y.A.Zinchenko, V.A.Strutinskiy// *Metal and casting in Ukraine*. - 2013. - № 10 – p.11-14.
8. Kalinchak V.V. Evaluation of burn-up fraction of pulverized coal in tuyere zone / V.V.Kalinchak, Y.A.Zinchenko, A.S.Chernenko, [and others] // *Metal and casting in Ukraine*. – 2013. - №12 – p.9–15.

