Journal of Chemical Technology and Metallurgy, 50, 6, 2015, 569-573

GAS-BLAST REGIME OF BLAST-FURNACE SMELTING AT THE BEGINNING OF THE FURNACE BLOWING-IN PERIOD AFTER THOROUGH REPAIRS

Lubov S. Ivleva[1], Vladimir N. Titov[1], Daniela Choshnova[3], Nikolay S. Inozemtsev[2]

[1] *Novolipetsk Steel, 2, Metallurgov sq., 398040, Lipetsk, Russia, E-mail: vladimir_titov76@mail.ru*
[2] *Lipetsk State Technical University, Department of Metallurgy, 30Moskovskaya Street, 398600 Lipetsk, Russia*
[3] *University of Chemical Technology and Metallurgy, 8 Kl. Ohridski, 1756 Sofia, Bulgaria*

Received 19 February 2015
Accepted 03 September 2015

ABSTRACT

Thermal and gas-dynamic phenomena on the top throat of the blast furnace in the blowing-in period regarding the oxidation and heat transfer processes in the hearth of the blast furnace are considered. The first blast should be produced in the forced mode to prevent the emergence of anomalous thermal and gas-dynamic phenomena at the throat that are dangerous to the blast furnace construction and to speed up the normal operating mode parameters of the furnace.
Keywords: blast furnace, gas-dynamic, blast, blowing-in.

INTRODUCTION

Unsteadiness of all phenomena of the blast furnace process is the main feature of the heat and mass transfer processes for the first blowing of the blast furnace and perhaps the main reason for its run instability in this period. With beginning of coke combustion some processes start immediately and they develop with some positive or negative acceleration while others start with a time delay. There are often deviations from the normal regime of the furnace blowing. For example, there is a sharp and stepwise temperature rise of blast furnace gas in the initial period of first blast after coke combustion to the level (> 800°C) that poses a serious threat to the metallic constructions of the blast furnace mouth especially that the circumferential temperature distribution can be very irregular. At the same time the pressure of blowing gas also increases abruptly although the absolute values at opened air valves and iron notch pose no risk to the furnace construction.

Operating experience of blast furnaces has not allowed creating the rules to prevent such abnormal phenomena. Technologists use such practical techniques of the throat protection as passing one or two (working) feeds before every blast, therefore the load of blowing charge is stopped at the furnace incompleteness of about 3 - 4 m.

FEATURES THERMAL PERFOMANCE AT THE INITIAL MOMENT OF BLOWING BLAST FURNACE

Fig. 1 shows the temperature and blast furnace gas pressure changes in the initial period of first blowing after thorough repair of the 2 category blast furnaces whose volume is (m^3): 4300 (A, 2011, a new furnace), 3200 (B, 2005), the same furnace 3200 (C, 2011) and 2000 (D, 2007).

In blowing options of technologies A and B blast furnace gas temperature remained stable at 3540°C during the first 6 - 8 hours (hot coke of dry quenching was used in the charge composition). The gas pressure changed insignificantly. Subsequently values of these parameters

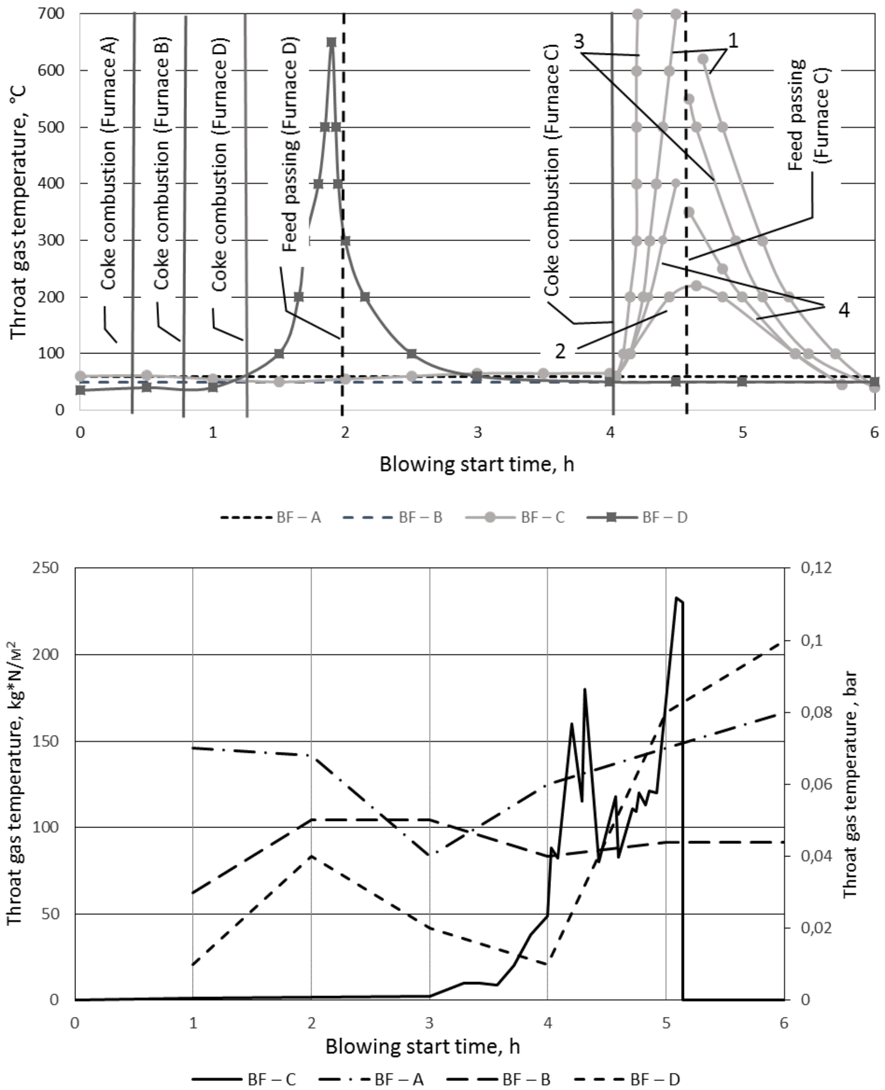

Fig. 1. Throat gas temperature and pressure change at the initial period of blowing. The left scale is instantaneous pressure measurements on the furnace C; right - hourly values for furnaces A, B and D. The numbers on the curves - numbers of gas outlets.

increased while the charge materials were heated, the blast flow increased and gradual increase of the blast gas pressure at the throat took place. Coke combustion in these furnaces started 20 - 40 minutes later, respectively, after the hot air blast feeding to the furnace.

In blowing options C and D blast furnace gas temperature abruptly increased to 660°C in furnace C 6 - 10 minutes later after the coke combustion and from 250°C to 860°C for different gas vents in furnace D. In both cases the temperature reduction of the throat was achieved by missing two working feeds.

The throat thermal performance is largely determined by the behavior of unsteady transient of heat transfer in the hearth and coke combustion in the tuyeres. As coke is heated by hot blowing its combustion is preceded by layers formation process with high coke reactivity: gasification phenomena are entirely over, intermediate products are formed (radicals, oxides, peroxides and others). They have an increased energy level and are in an unstable state [1]. The flame front is formed around sources of ignition whose speed and direction depend on the ratio of the amount of heat generated and thermal costs inside and outside the source of ignition as well as on the interrelated aero dynamic and heat processes.

Operating experience of heat installations (indeed it is the blast zone of the hearth) shows that in such circumstances the amount of oxidant and consequently combustion products is significantly higher than the stoichiometric amount of carbon oxidized by the reaction of complete combustion [2]. The only product of coke combustion heterogeneous reaction in the first step is carbon dioxide:

$$n\cdot C + m\cdot(O_2+3,76\cdot N_2) = n\cdot CO_2 + (m-n)\cdot O_2 + m\cdot 3,76\cdot N_2.$$

In the blast furnace working in the normal operating regime parameters the rate of regeneration of carbon monoxide by the reaction $CO_2 + C = 2CO$ is not essential for the known reasons affecting only the length of the combustion zone and some oxidation and reduction processes in cast iron elements. In the initial period of blowing process the conditions of this reaction are radically different: the heat source is surrounded by a large mass of cold coke which does not have sufficient reactivity.

THE ALGORITHM OF CALCULATION OF HEAT TRANSFER BETWEEN THE HOT BLAST AND WELL ORGANIZED DYNAMICALLY LAYER OF LUMPY COKE

In specific thermal conditions, completely depending on the heat transfer in the furnace hearth, the coke carbon combustion can be completed with formation of carbon monoxide and therefore reducing gas goes into the furnace throat space filled with an atmospheric air. Oxidative gas passes into the throat space at low speed of the reduction reaction or with its full absence. The calculation of heat transfer between the hot blast and well organized dynamically layer of lumpy coke makes some uncertainly in the consideration of this issue clear. The intensity and length of the coke heating zone are determined considering the blowing options, coke layer and time factors.

Physical formulation of the problem is the following:

- Distribution of the hot blast blow occurs only along the axis of the air tuyere in the direction of the hearth;
- Central opening angle of the air stream is about 22 - 24° [1];
- To calculate the temperature distribution in the layer of coke in various consecutive intervals the airstream is split into equally long portions and for each of them the air speed referred to the free cross-section area of the hearth is calculated;
- Thermal properties of coke and air are taken as independent of temperature.

Mathematical formulation of the problem is the following [3, 5]:

1. Calculation of two dimensionless criteria x and y respectively proportional to the heated layer height (h, m) and the heating time (t, hour) which are basic parameters, included in the coke heating equation in a fixed layer.

$$\frac{t_M}{t_0} = e^{-(y+z)} \cdot \sum z^n \cdot M_n(a)$$
$$y = \frac{\alpha_v \cdot h}{W \cdot C_h}; z = \frac{\alpha_v \cdot \tau}{C_c \cdot (1-\varepsilon)} \quad (1)$$

where:
α_v - volumetic heat transfer coefficient;
W - speed of the air flow referred to the free area of

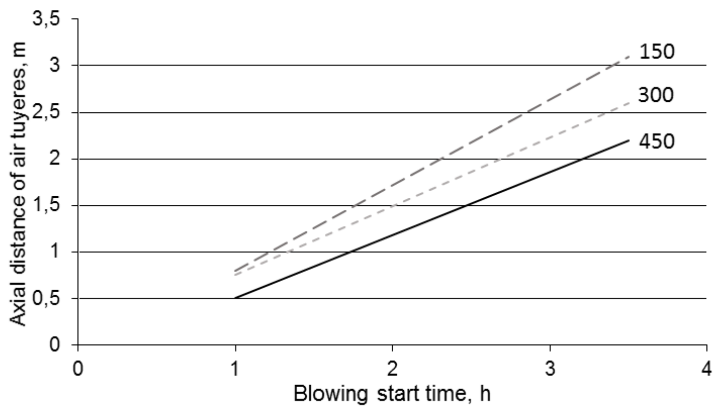

Fig. 2. Temperature zones activation dynamics in the hearth tuyere zone of the furnace C. The numbers on the isotherms is the temperature of coke, ^{o}C.

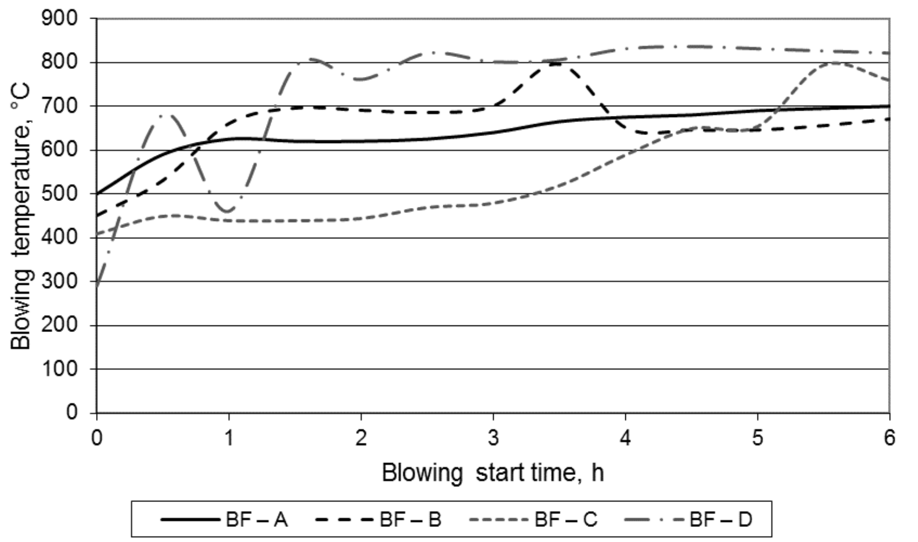

Fig. 3. Blowing temperature change at the initial period of blowing.

tuyere volume of hearth in the borders of the cone and the air stream;
C_h, C_c - the heat capacity of the hot air and the coke;
ε - coke layer porosity;
M_n - endless convergent series presented in the form of graphs for different values.

2. Calculation of the heated coke layer temperature according to the theoretical graphs [3].

Calculations are made for working conditions in the blowing period of B and C furnaces. Significant fluctuations in blowing temperature of furnace D did not allow making a similar calculation. Fig. 2 shows the dynamics of the temperature zone spreading in the layer of coke in furnace C.

EXPERIMENTAL

This furnace was blown with a total gas pressure drop about 0.2 - 0.3 bar, blowing flow rate to each tuyere about 20 - 30 $m^3 min^{-1}$ and a temperature of 450°C for 3.5 hours without coke combustion (the aim was to dry the cast lining of the mine bottom). Coke ignition occurred at the blowing temperature about 600˚C after 4 hours of the furnace work (Fig. 3). The calculated length of the temperature field was about 2 meters. During this time the arrival of the heat from blowing was 70 kJ (min·kg $C_к)^{-1}$, where $C_к$ is the amount of coke carbon which is located in the air tuyere area.

RESULTS AND DISCUSSION

Long coke heating at a temperature close to the ignition temperature promoted the formation of a coke layer with high reactivity. Assuming that under these conditions the volume, composition and temperature of the hearth gas are mainly calculated using stoichiometric ratios of the thermochemical equations. They were“canonized” by the nature of the blast furnace process itself [4]. Reducing gas reacts with the air contained between the pieces of the charge materials but perhaps most of it goes into the throat space where its combustion occurs. Relaxation phenomena, characterizing the rate and completeness of the carbon monoxide oxidation into carbon dioxide with releasing up to 70 % of carbon energy, are accompanied by a sharp temperature and pressure increase at the throat (Fig. 1). The right side of the temperature curves is a graphic interpretation of the cooling process of the gas outlet refractory lining (after gas burning) with a description of the process by this equation:

$$y = K_0 + K_1 \cdot \exp(-K_2), \quad (2)$$

where K_1, K_2 are coefficients, characterizing the heat transfer process.

It is known from the theory of combustion [1], that the temperature field is extremely inhomogeneous in the reaction space at a high level of combustion instability. In this case combustion regulators are not only the chemical order factors but the physical phenomena, for example, hearth gas and air mixing factors over the throat square of 65 m^2. It is extremely difficult to establish the exact proportions of these factors but their very existence can explain such a significant temperature difference at the gas outlet.

With forced blowing of furnace B with the blowing flow rate of 50 - 60 $m^3 min^{-1}$ for each tuyere and the initial temperature of 450˚C coke combustion occurred after 35 - 40 minutes and the blowing temperature about 670˚C. By that time the estimated length of the temperature field in the tuyere space was 850 - 1000 mm; and the heat of 420 kJ ((min·kg $C_c)^{-1}$ was received with blowing. Actually the coke heat source was localized to even a smaller volume because the high temperature zone is located at some distance from the air tuyere moving in the direction of decrease of combustion products and the temperature increase. Assuming that the process of carbon monoxide regeneration was not significantly developed and the tuyere oxidizing gas constantly changing its composition remained in this state as long as that was enough to "wash out" the blowing charge column. The air was displaced and no conditions for the anomalous thermal and gas-dynamic phenomena emergence at the throat were created.

The blowing-in of the new furnace blast (A) was made on the "woods":the hearth was filled with oversized wood burning fragments (pieces of logs, sleepers) stacked in the stand. Wood ignition occurred immediately after the blast at temperature of 500˚C. There were the pieces of burning coke in some tuyeres along with wood fragments a few minutes later. The wood played the role of an ignition torch. In such forced ignition the coke heat source is localized in a very small volume while a large mass of coke remains unheated and the probability of the coke carbon oxidation in the initial period of blowing by the complete combustion reaction is the highest. From this point of view it would probably be advisable to introduce flammable briquettes into the blowing charge just loading them into the tuyere zone of the hearth.

CONCLUSIONS

The first blast should be produced in the forced mode to prevent the emergence of anomalous thermal and gas-dynamic phenomena at the throat that are dangerous to the blast furnace construction and to speed up the normal operating mode parameters of the furnace:

- the flow rate is more than 50$m^3 min^{-1}$ for each open air tuyere;
- total gas pressure drop should be maximized with the blowing charge of ore loading and technological requirements for fast and unobstructed charge descent (it is about half of the total difference from the furnace operation);
- the blast temperature should be maximal (700 - 800˚C), to achieve it the hot blowing tract is advised to be preheated.

It is necessary to preheat the filling charge and the furnace lining with a liquid nitrogen to avoid very heavy disorders of technological furnaces progress (especially those of large volume).

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