ISSN 0967-0912, Steel in Translation, 2017, Vol. 47, No. 6, pp. 389–393.

Using Thermal Probes to Regulate the Batch Distribution in a Blast Furnace with Pulverized-Coal Injection

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Received June 14, 2017

Abstract—Experience with stationary thermal probes above the batch in blast furnaces is discussed. The influence of the incoming batch on the readings of the thermal probes is investigated. On the basis of the thermal-probe data, requirements on the batch distribution are formulated for blast furnaces with pulverized-coal injection.

Keywords: blast furnace, charging program, thermal probes, batch temperature, gas temperature, pulverized coal

DOI: 10.3103/S0967091217060092

In recent years, thermal probes have been widely used to assess the gas-flux distribution in blast furnaces. The probes are positioned above the batch surface in the furnace on one or more charge-hole radii. The thermal probes permit continuous monitoring of the gas temperature. The information obtained may be used to assess and correct the furnace's batch-charging program. However, the readings change with change in batch level on account of the mixing and deflection of the gas flux. Thermal probes are most effective in controlling the radial batch distribution in blast furnaces with nonconical charging systems, when the level of the furnace charge is not used in regulating the batch distribution. To obtain reliable and stable readings, as a rule, the thermal probes are placed at a distance of ~0.50 m from the surface of the charge [1].

We compare blast furnace 3, with a nonconical charging system, and blast furnace 5, with a standard charging system, at Yenakiieve Iron and Steel Works (EMZ). The furnaces are equipped with four Ukrainian-made nitrogen-cooled thermal probes. In contrast to most imported thermal probes, these instruments permit objective monitoring of the peripheral gas flux: the distance from the charge-hole wall to the extreme peripheral thermocouple is 50 mm; and the distance to the second thermocouple in the region near the wall is 310 mm.

In the literature, contradictory information is found regarding the influence of cooling on the readings of the thermal probes. For example, experiments in which the nitrogen supply to the thermal probes was periodically turned off showed that the cooling did not significantly distort the thermocouple readings in [2]; however, this disagreed with the findings in [3]. Cooling of the thermal probes only affects the readings of the extreme thermocouple at the wall (on account of the departing nitrogen), according to [4]. This conclusion requires further study, with brief interruptions of the coolant supply. The mean values recorded by the two extreme thermocouples in the wall region may be used for objective assessment of the temperature of the peripheral gas flux in the blast furnace. Cooling of the thermocouples is essential when using hot sinter in the blast furnace; without it, stable long-term operation of the probes is impossible.

Research on blast furnaces equipped with thermal probes of rectangular cross section (larger than 200 mm) shows that, when the batch is introduced by a nonconical charging system, its flux is distorted on contact with the thermal probes; azimuthal nonuniformity of the batch appears [5, 6]. When the batch flux is in contact with the thermal probes, depressions larger than 0.5 m are formed in the furnace sectors under the probes, resulting in nonuniform batch and gas distribution over the furnace periphery. The thermal probes installed in blast furnaces 3 and 5 at EMZ are narrower and may be used to monitor the surface temperature of the charge without distorting the incoming batch flux [4, 5]. Note that, as of 2016, the thermal probes at blast furnaces 3 and 5 have operated for more than 1.5 years, with steady readings.

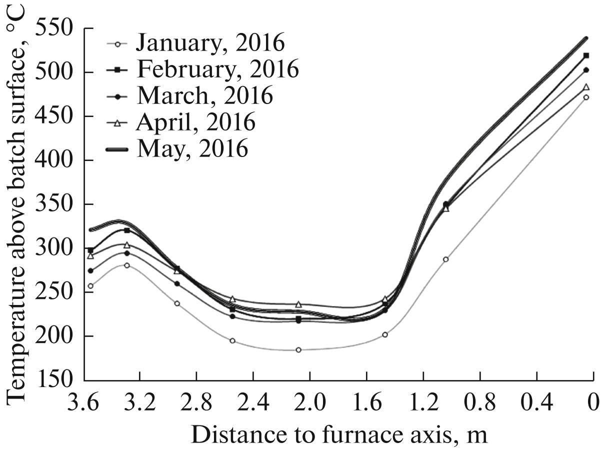

Fig. 1. Temperature distribution of the gas flux above the batch surface for a single radius of blast furnace 3 (January–May 2016).

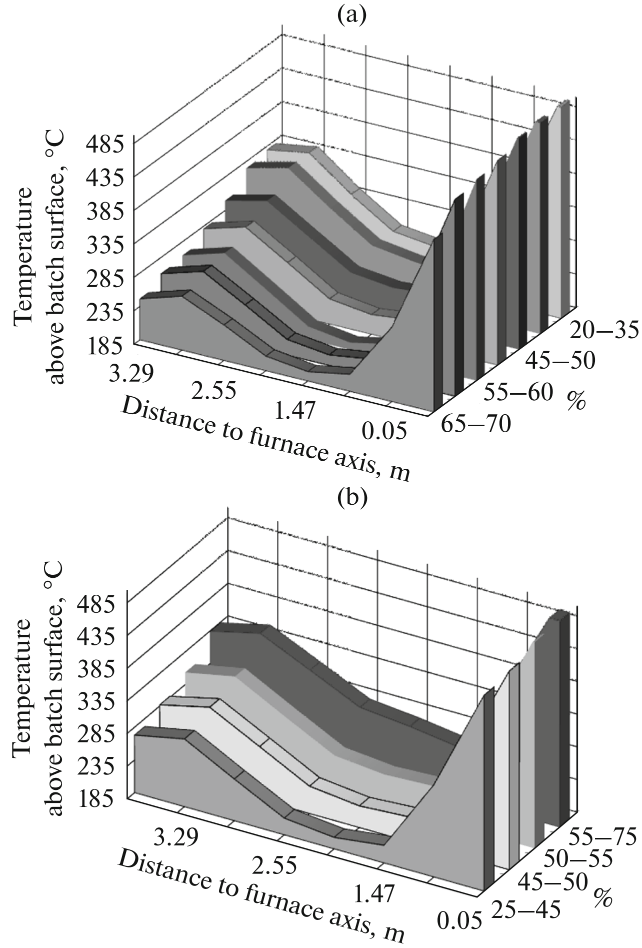

Fig. 2. Temperature distribution of the gas flux above the batch surface at blast furnace 3 with different proportions of pellets (a) and sinter (b) in the batch (January–May 2016).

The batch distribution over the furnace radius mainly determines the distribution of the gas-flux temperature above the batch surface [7]. No changes were made in the charging program at blast furnace 3 over the five-month period here considered. Therefore, it is of interest to determine the influence of various factors on the temperature distribution of the gas flux in that period. Analysis of the temperature variation over one furnace radius shows that in January 2016, in contrast to the other months, the gas temperature was lower, with practically the same distribution over the radius (Fig. 1). This is associated with the higher content of pellets (58.6%) in the ore component of the batch at blast furnace 3 in that period. As already noted, literature data regarding the influence of the temperature of the incoming batch on the thermal-probe readings are inconsistent. Accordingly, we analyze the influence of the composition of the iron ore introduced at different temperatures in the blast furnace on the temperature distribution of the gas flux above the batch surface.

In Fig. 2, we show the temperature distribution of the gas flux with different proportions of pellets and hot sinter in the batch. Since the iron-ore component used in May 2016 contained 19.8% of imported sinter from the Southern Mining and Processing Plant, charged into the blast furnace at considerably lower temperatures than local sinter, the influence of the batch composition on the temperature distribution of the gas flux is investigated separately for periods with variable proportions of pellets (Fig. 2a) and hot sinter (Fig. 2b) of local origin.

It follows from Fig. 2 that, with constant batch distribution over the radius and varying proportions of pellets and hot sinter in the batch, the temperature distribution of the gas flux over the furnace radius is practically the same. Only the absolute temperatures increase with increase in hot-sinter content in the batch.

Analogous analysis of the temperature distribution of the gas flux for blast furnace 5 (Fig. 3) shows that, in January, in contrast to the other months, the gas temperature was lower, with practically the same distribution over the radius. This is again associated with the higher content of pellets (68.0%) in the ore component of the batch at blast furnace 5 in that period. For blast furnace 5, the changes in the temperature distribution of the gas flux above the batch surface with different proportions of hot sinter in the batch are the same as for blast furnace 3 (Fig. 4). This indicates that temperature variation of the batch charged in the blast furnace does not interfere with the monitoring of the gas-flux distribution and subsequent selection and application of control measures. As confirmation, we may note the dependence of the radial temperature distribution of the gas flux on the content of hot local sinter in the ore component of the batch for blast fur-

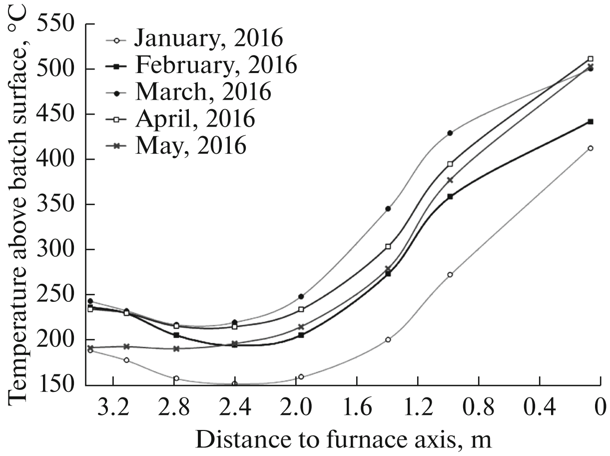

Fig. 3. Temperature distribution of the gas flux above the batch surface for a single radius of blast furnace 5 (January–May 2016).

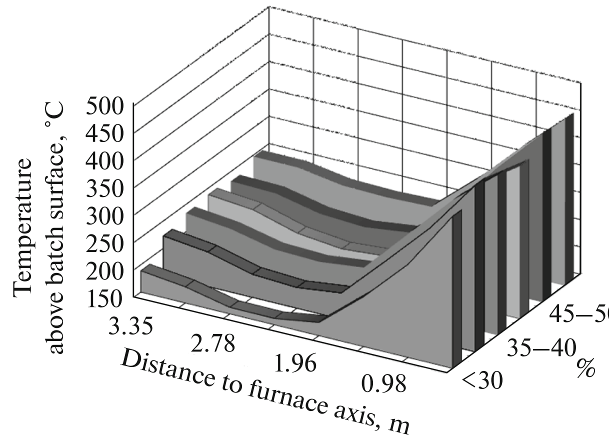

Fig. 4. Temperature distribution of the gas flux above the batch surface at blast furnace 5 with different proportions of EMZ sinter in the batch (January–April 2016).

nace 3 (Fig. 5). The results for blast furnace 5 are analogous (Fig. 6).

The next step is to determine the best temperature range of the gas flux over the furnace radius on the basis of information from new thermal probes of the same type installed in blast furnace 3 in September 2015 after guniting of the shaft. (The previous thermal probes lasted two years.) The analysis is based on mean daily temperatures for a single radius in October 2016, the month with best mean daily hot-iron output at blast furnace 3 in the course of five years of operation. Preliminary analysis of the thermal-probe data, recorded twice per minute, eliminates operating periods with low batch levels. Temperatures outside the range 100–950°C are also eliminated. Then the mean hourly and daily temperatures are determined.

The distribution of the gas flux is assessed in terms of the following ratios:

—$K_1 = T_{pe}/T_{me}$, where T_{pe} is the peripheral temperature (the mean temperature of thermocouples 1 and 2 at the wall) and T_{me} is the mean temperature over the radius);

—$K_2 = T_{ce}/T_{me}$, where T_{ce} is the temperature of the central zone (thermocouple 8);

—$K_3 = T_{int}/T_{me}$, where T_{int} is the temperature of the intermediate zone (the mean temperature of thermocouples 3–6);

—$K_4 = T_{ce}/T_{ax}$, where T_{ax} is the temperature of the axial zone (thermocouple 7).

To determine the best ranges of these ratios, we consider the smelting efficiency $e = P_{rel}/F_{rel}$, where P_{rel} is the daily productivity of the blast furnace relative to the mean for the given period; and F_{rel} is the adjusted fuel consumption (the consumption of coke +0.9 of the coke-nut consumption +0.95 of the pulverized-coal consumption +0.9 of the natural-gas consumption) relative to the mean for the given period. From the daily mean characteristics of the gas-flux distribution and the efficiency e, when $e > 1.0$, we determine the mean values of K_1–K_4. The best ranges of K_1–K_4 are determined in the form $K_i \pm \sigma$ ($i = 1$–4),

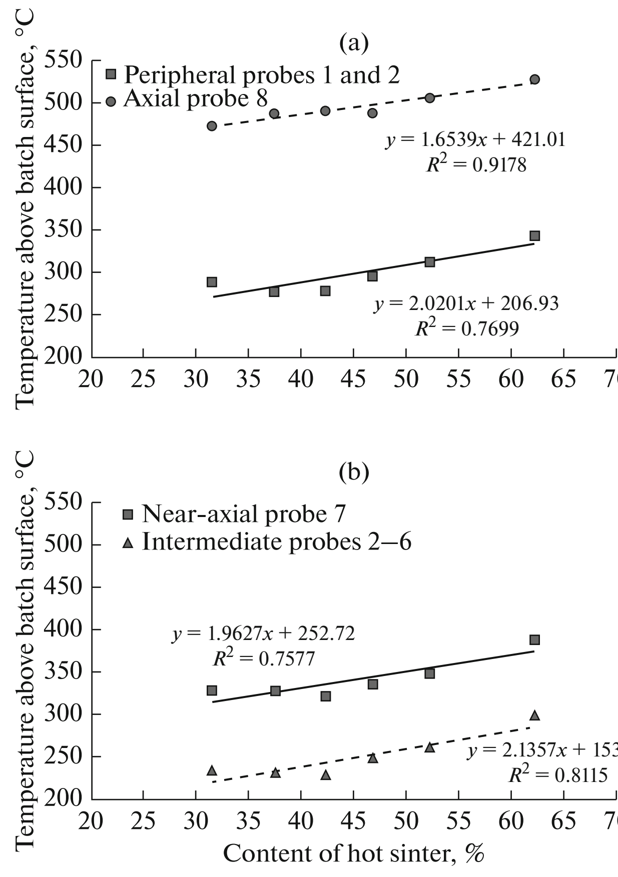

Fig. 5. Temperature distribution of the gas flux above the batch surface for blast furnace 3 with different proportions of EMZ sinter in the batch.

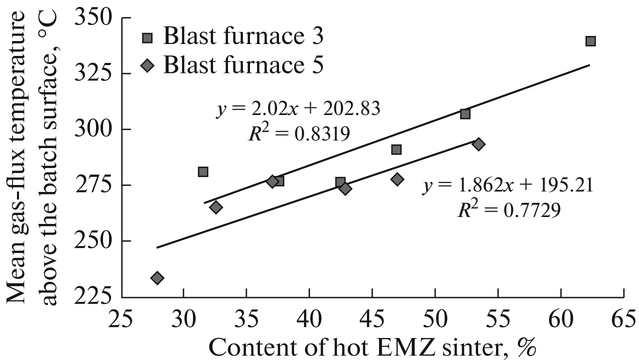

Fig. 6. Dependence of the mean gas-flux temperature above the batch surface in blast furnaces 3 and 5 on the content of EMZ sinter in the batch.

where σ is the mean square deviation from the mean, under the condition that $e \geq 1.0$ for the given sample. The ranges obtained are as follows

$$K_2 = 1.6 - 2.15;\ K_3 = 0.74 - 0.87;$$
$$K_4 = 1.60 - 2.10.$$

These ranges may be interpreted in terms of the stipulations imposed in regulating the gas-flux distribution over the furnace radius with pulverized-coal injection into the hearth, so as to obtain acceptable furnace performance in the conditions typical of EMZ.

(1) The peripheral zone must be sufficiently gas-permeable. Excessive quantities of iron ore may result in jamming of the incoming batch and irregular batch supply. Correspondingly, we specify the ratio of the temperature readings at the wall to the mean temperature over the radius: $K_1 = 0.85–0.95$.

(2) The central gas distribution must be sufficiently developed. Correspondingly, we specify the amount by which the gas temperature above the batch surface at the center of the furnace must be larger than the mean temperature: $K_2 = 1.60–2.15$.

(3) Gas flows must be maintained between the periphery and the center. Correspondingly, we specify the mean gas temperature in the intermediate zone (thermocouples 3–6) relative to the mean temperature over the radius: $K_3 = 0.74–0.87$.

(4) With a developed central gas-flux distribution, a narrow axial coke vent is required to ensure that the process is economical. Correspondingly, the gas temperature above the batch surface at a distance of 1.0 m from the furnace axis must be less than the axial temperature by a specified amount: $K_4 = 1.60–2.10$.

In Fig. 7, we show the mean daily values of K_1–K_4 and e in October 2016. It follows from Fig. 7 that, over the given period, each parameter periodically passes beyond the recommended range. For K_1, K_2, K_3, and

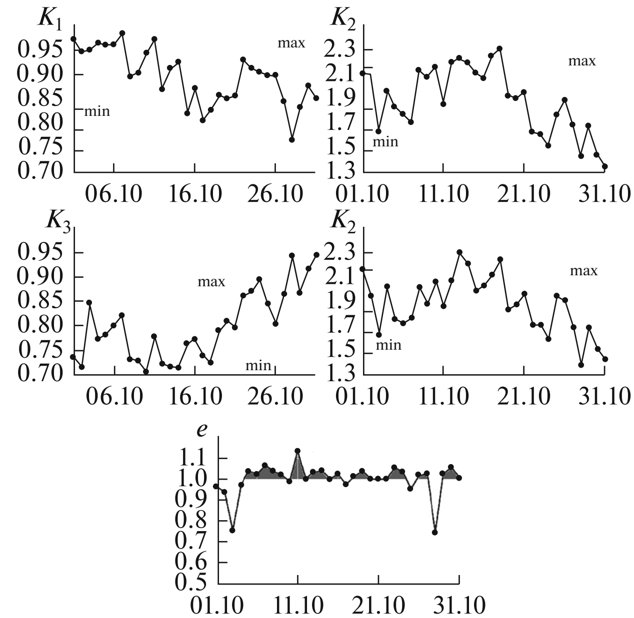

Fig. 7. Mean daily values of K_1–K_4 and e in October 2016.

K_4, the frequency of the recommended values is 61.3, 67.7, 54.8, and 71.0%, respectively.

On the basis of these frequencies, we conclude that, in October 2016, the radial gas-flux distribution corresponded to a satisfactory axial coke vent with sufficient development of the central gas distribution, while the peripheral gas flux was too intense at the beginning of the month, on account of the final conditioning of the furnace after repair. The intermediate zone was the most unstable: until mid-October, radial gas flows were hindered, with low gas temperatures above the batch surface. In the second half of the month, conversely, the temperatures above the batch surface were too high.

Analysis of K_1–K_4 also indicates that, on the whole, they did not deviate from the recommended ranges for periods longer than three days. The exception was K_1 at the beginning of the month. As already noted, its behavior may be attributed to the final conditioning of the furnace after repair. As a general guideline, we may say that the charging program should be modified if the K_1–K_4 values deviate from the recommended ranges for periods of 5–7 days. Further research is necessary to determine more precisely how many days of furnace operation with nonoptimal K_1–K_4 values can be tolerated without modifying the charging program. On the basis of the requirements imposed on the gas-flux distribution and the recommended ranges of K_1–K_4, we have written a manual of charging programs that is included in the technological instructions for blast-furnace operation at EMZ.

In November 2016, after guniting the shaft of blast furnace 5, new thermal probes were installed. Accordingly, it is of interest to establish the best ranges of the K_1–K_4 values and corresponding recommendations for modification of the charging program at blast furnace 5. Given the limitations of the conical charging system, such recommendations will be based on variation of the charge level and the use of different combinations of direct and inverse batch supply.

CONCLUSIONS

We have found that temperature variation of the batch charged in the blast furnace does not interfere with the monitoring of the gas-flux distribution and subsequent selection and application of control measures, because the temperature distribution remains qualitatively the same.

We have developed requirements on the radial gas-flux distribution in furnaces with pulverized-coal injection so as to ensure the specified furnace performance at EMZ.

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Translated by Bernard Gilbert