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A. V. Lychev , E. N. Vinogradov, I. V. Loginov
Lengipromez, Severstal Metallurgical Works
alychev@yandex.ru

On the blast losses in the blast furnace practice

Development of the ironmaking practice in the last decades is characterized by a steady improvement of the raw material and coke quality, by use of various coke-substituting materials injected into the blast-furnace hearth (coal dust, natural gas, fuel oil, etc.) with a high-temperature oxygen-enriched blast jet, as well as charged via the furnace top (nut coke, thermoanthracites). Introduction of the latest advanced technologies resulted in a substantial stabilization of the gas-dynamic and thermal conditions of the blast-furnace smelting process, and, as a consequence, in a considerable reduction of the specific coke rate per unit of iron made. The increased number of the practicable process control parameters, on the background of the further development of the computer technique in general, not only makes the monitoring process by no means more complicated, but what's more, allows to select the optimum combinations of all these factors for the particular conditions of each furnace.

The control and forecast systems for the thermal conditions of the smelting process, which use in their software algorithms the information pertaining to the top gas composition from the gas-analytical systems of high precision, do not have available the data on the quantity of hydrogen involved in the indirect iron reduction reactions ($V_{H_2O_i}$). These data are introduced into the system by means of calculations of the hydrogen imbalance in the furnace, and the above calculations are often based on incomplete, and what's more, inadequate information about the hydrogen content in some materials. Essential inaccuracies in calculation of $V_{H_2O_i}$ reduce drastically the effectiveness of operation of the automatic control system of the thermal conditions of the smelting process (ACS TC).

In this connection, creation of a reliable in operation additional autonomous channel providing the ACS with a reasonably fair forecast for the thermal state of the blast-furnace hearth, which shall be based on some other principles and not use the information on the top gas composition, seems to us to be a burning problem the solving of which will contribute to the further improvement of the blast-furnace process. We propose to accept the data about the volume of hot blast delivered into the blast furnace as a source of information for an alternative monitoring and control channel.

An attractive Alternative for determination of the rate of blowing into the furnace is its direct measurement. But to carry out the measurement of the hot blast flow rate (t_b = =1200÷1300 ^oC) is very complicated from the engineering point of view, and the cold blast flow measured by means of an orifice plate prior to entering of blast air into the hot-blast stoves differs considerably from the heated blast volume delivered into the blast-furnace hearth.

It has been noticed long ago already that the major blast losses occur at non-tight closed chimney valves of the Cowper stoves [1, 2], that is the consequence of their extreme operating conditions. The blow-through points at these valves, apart from a loosely fitting of the valve disk to its seat, are also the flanges connecting the valve cover with the valve case, the case with the hot-blast stove pipe connection and the valve case with its base, the seal failure of which is caused by an action on these flanges of variable forces resulting from the hot-blast stove wind operation or gas operation. During the gas period there is a thermal growth of the hot-blast stove casing by height, and due to this, the chimney valve, which is rigidly connected with the pipe connection of the hot-blast stove, moves in the vertical plane, as well. This results in extension of the bolts connecting the valve case and the base, and, as a consequence, the air leaks via the sealing cord between the valve case and seat occur [3]. The operating experience of the hot-blast stoves suggests that these losses make up 5÷20 % [4]. The losses are individual for each hot-blast stove unit and may vary in the process of their operation.

Before the breakdown of the former USSR the data on the cold blast losses at the enterprises had to be obtained in compliance with the existing at that time «Instructions for Determination of the B.F. Gas Yield and B.F. Blast Losses» elaborated by YuVEnergometallurgprom. But even at that time already not every enterprise followed strictly all the instructions. Thus, at the Makeevsky Metallurgical Works and «Zaporozhstal» Metallurgical Works the amount of air that was lost when passing through the duct from the blowing engines to the air-relief valve was determined as a difference between the indicated values of the flow meters at the blowing engines and of the flow meters upstream of the air-relief valve. And the hot blast losses were determined by the difference between the indicated values of the flow meter before the hot-blast stoves and the theoretical flow rate of the air delivered into the blast furnace. Today as before it remains a pressing problem to find proper procedures for a precise determination of the blast losses because the blast losses in the cold-blast main may be determined more or less precisely, while the accuracy of figures pertaining to the blast losses in the hot-blast main is doubtful as no reliable information about the volume of blast that reaches the blast furnace is available.

The only papers devoted to the generalization of the whole complex of the blowing facilities from the air blower up to the blast furnace are the publications of M. P. Belikov [4÷6] in which the author has mentioned the methods applied for metering previously, defined the boundaries of their application and proposed his own procedure for determination of the blast losses by superposition of characteristic curve of the system and characteristic curve of the blowing engine. It should be emphasized that the methods demonstrated by M. P. Belikov are being applied in one or another modification in the blast-furnace shops at the metallurgical works till now.

Direct method of losses measurement. This method is the simplest among the existing methods, in compliance with this method, the volume of air flowing through the blast main is measured in two points of the system, and the difference between these measurements will represent the air losses at the length between these two points. The air flow meters are usually installed at the blowing-engine house and before the Cowper stoves. Taking into consideration the high temperatures of the blast air there is no reason to install the air flow meters at the hot-blast mains as it would result in complication of the servicing and in inadequate indicated values.

Method of losses measurement by blowing-down. In this case the to-be-tested section of the system is disconnected and air is forced into it till achievement of the working pressure; this pressure is maintained at a constant level during a certain time period. The revealed throughput of the blower will define the air leakage per unit of time. Determination of leaks by this method is possible with a less or more simplicity depending on the type of being used blowing engines. The leaks in a system with turbo-blowers are always less than their throughput at the surging boundary under the working pressure and at the minimum rpm. Therefore, to prevent surging it is necessary to release a part of the being forced into air to the atmosphere, in doing so, its volume should be controlled in such a way that the working pressure in the pipeline is maintained.

Method of losses measurement by «filling-up». The drop of the increased pressure in the closed section of the system per unit of time defines the amount of blast air flowing out of the system via the leakages. If a blast main filled with air under pressure will be quickly disconnected, the air pressure will fall because of leaks. The time t during which the initial pressure P_i shall fall down to P_f depends on the amount of leaks and on the temperature T of the air in the blast main. The quantity of air in a reservoir with a volume V at a pressure P and temperature T shall be equal to:

$$m_i = \frac{P \cdot V \cdot M}{R \cdot T}, kg.$$

During the time t via the leakages the following amount of air shall flow out of the system:

$$\Delta m = m_i - m_f = \frac{V \cdot M}{R} \cdot \left(\frac{P_i}{T_i} - \frac{P_f}{T_f} \right), \text{ kg of air.}$$

Method of losses measurement by «superposition of characteristic curves of the system and of the blower» (Method of M. P. Belikov). One and the same blower at the constant rpm may supply the different quantities of air depending on the resistance to air-flow which is offered. If the characteristic curve of the system which shows the air resistance versus air flow rate relationship of this system is plotted against the characteristic curve of the blower, then the blower mode shall be defined as the crossing point of the blower characteristic curve at the given rpm with the characteristic curve of the system.

The blast losses may be determined if the characteristics of the stove blower are known as well as the characteristics of the system with losses and of the same system without losses are available. Let's illustrate this by an example.

If the stove blower is free of losses (it's quite normal for the turbo-blowers), then all the air leaks occur in the system, along its flowing path. The leakages cause the loss of head that may be measured practically in the discharge pipe connection of the stove blower. If there is a system without any leaks (i.e., the coefficient of the air resistance of the system is known and the blower rpm is constant), point 1 should be considered as the working point (Fig. 1). At operation with a leaky system, because of the pressure drop, the working point shall be point 2, i.e., the stove blower shall adapt itself for a leaky pipeline and rise its throughput.

If we draw a horizontal across point 2, we shall obtain point 3 at its crossing with the characteristic line of the system which indicates the volume of air that, in the best case, shall enter the blast furnace, and the difference between the x-coordinates of these points shall give the value of the air losses in the system. But as it is practically impossible to obtain the characteristic curve of the system in case of absence of the losses, it is not feasible to determine the absolute values of losses by the above-mentioned method; only the *relative* values indicating increase or decrease of losses in

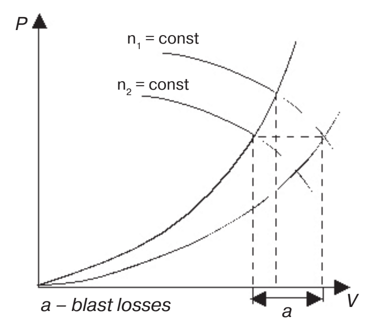

Fig. 1. Determination of blast losses in the system

comparison with the previous observations may be obtained by means of this method.

It is also possible to take another approach to determination of the true amount of blast entering the blast furnace: its true flow rate may be determined on the basis of information about the hot blast flow per each tuyere. A great number of papers devoted to this approach include numerous investigations of monitoring and control of the «blast –to – natural gas» ratio over the blast-furnace tuyeres [7].

A bottleneck restraining a wide implementation of these systems is, now as before, the hot blast flow control, and the measurement of the rate of blowing through the blast-furnace tuyeres by means of the pressure drop measuring at the tuyere apparatus elements seems to be a rather unreliable method. There are several reasons for this.

First, availability in the blast of superheated water vapour and mineral dust that, when moving at a high velocity, causes changing of the flow area and shape of the measuring section, especially, at the blast furnace «back-drafting».

Secondly, because of absence in the tuyere apparatus of the straight linear portions of the required length, the throttle units should be calibrated together with the tuyere apparatus, and this is a rather complicated and labour-intensive operation actually inconsistent with the production conditions.

Thirdly, the obligatory condition for an accurate measurement of the hot blast flow is that the coefficients of resistance of the measuring sections should be the known, and, what is most important, the time-independent quantities. But in the process of operation of the measuring sections, due to deterioration, their resistance is sharply changed and becomes an unknown quantity.

A method of control of the resistance coefficients changes of all the measuring sections of the tuyere apparatus directly at the operating blast furnace proposed in paper [8], made it possible to solve a problem of determination of the *relative* rate of blowing over the tuyeres, but does not allow to determine the absolute quantity of blast that reaches the blast furnace*. The error in its measurement will be integrated as before in the total hot blast consumption value, resulting in this way in overestimated figures of rate of blowing as per each tuyere. Moreover, the correction factors should be introduced which depend on the unequal value of blast losses in different hot-blast stoves which are stable only for a relatively short time periods.

Efficiency of use of information about the hot blast flow rate in the blast furnace.

Use of V_{cb} (w/o consideration of blast losses through the chimney valves) for the technological calculations is accompanied by noticeable errors in determination of the smelting parameters. Thus, for instance, for calculation of the theoretical combustion temperature the *D-index* – the natural gas rate in m^3/m^3 of dry blast – is used. Therefore, a foreman who has no other information except V_{cb}, will underestimate the *D-value* during its calculation:

$$D = \frac{V_{ng}}{V_{cb}} < \frac{V_{ng}}{V_{hb}}.$$

For example, if $V_{hb} = 0.85 \cdot V_{cb}$, then the *D-value* will be underestimated by 1.176 times. The error in determination of *D* will result in an error at calculation of the theoretical combustion temperature (Δt_T, °C):

D,%	Δt_T, °C at ΔV_{cb}^{loss}, %			
	0	5	10	15
5	0	14	30	48
10	0	28	60	93
15	0	42	90	140

According to the approximate calculations results the blast losses in the blast furnace shop at «Severstal» Metallurgical Works (January÷April 1997) made 0÷10 %, and the highest losses were observed at BF № 3. The difference between C_t^{calc} and C_t^{actual} varied from 0 to 37.4 kg/t of hot metal. It should be noted that the results of these calculations refer to the monthly averaged indicators, and the current variations of the blast losses were, without any doubt, even more substantial.

In this way, the use of data pertaining to the flow rate of cold blast produced by the blower (V_{cb}), due to considerable losses (~ 0÷10 %) at the whole length of the duct from the blowing engines up to the blast-furnace tuyeres caused by leakages of the cutoff valves and flange connections of the pipelines, considerably reduces the informational value of the technological calculations which are followed, because of this reason, by evident errors in determination of the smelting parameters. For a reliable prediction of the smelting thermal conditions and their timely adjustment it is required to know the *actual* rate of blowing into the blast furnace which defines the coke carbon rate of coke which is burning-off at the tuyeres (C_t).

Problem solving and engineering implementation.

To be able to determine the true volume of blast delivered into the blast furnace it is necessary to introduce some additions into the scheme of measurement of the rates and temperatures of the air flows due to which the following information will be available:

– cold blast rate via the mixing air pipe;

– cold blast temperature in the mixing air pipe downstream of the measuring diaphragm plate;

– hot blast temperature immediately upstream of the mixing apparatus (in the blast flow direction).

* It should be emphasized that this paper was of great importance for solving of a problem of equipotential air-and-fuel mixture supply over all the blast-furnace tuyeres, and just this task was facing the authors of this paper, in particular.

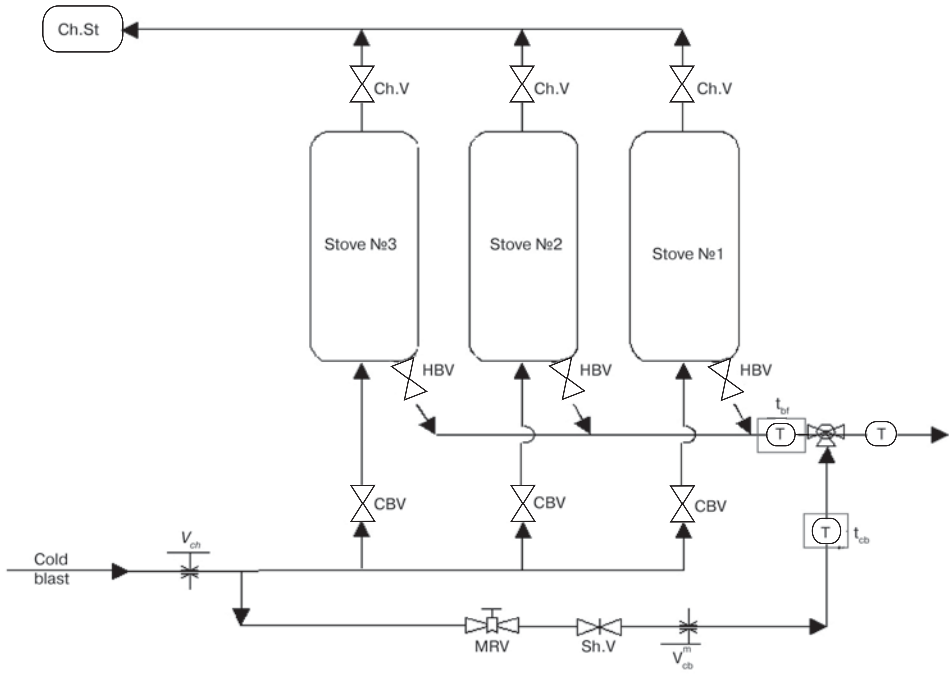

Fig. 2: Evaluation of the results of tests conducted upon a partial reconstruction of the blast temperature and flow rate control system
Stove – hot-blast stove; Ch. St. – chimney stack; HBV – hot-blast valve; CBV – cold-blast valve; Ch. V – chimney valve; MRV – mixer regulating valve; Sh. V – shutoff valve; V_{cb} – cold blast rate to hot blast stove, m³/min; – cold blast rate via the mixing air pipe, m³/min; – cold blast temperature; t_{hb} – hot blast temperature downstream of the stove upstream of the mixer, °C; t_{bf} – temperature of blast entering the blast furnace, °C

The balance of the air flows and their enthalpies (Fig. 2) allows to find the true blast flow rate. The mass balance of the blast flows is as follows:

$$V_{bf} = V_{hb} + V_{cb}^{m}. \quad (1)$$

The heat balance of the flows is:

$$V_{bf} = V_{cb}^{m} \cdot \frac{i_{hb} - i_{cb}}{i_{hb} - i_{bf}}. \quad (2)$$

The blast losses along the blast delivery system to the blast furnace will make, %:

$$\delta = 1 - \frac{V_{cb}^{m}}{V_{cb}} \cdot \frac{i_{hb} - i_{cb}}{i_{hb} - i_{bf}}. \quad (3)$$

By interpolation of and in the range of 900÷1300 °C and in the range of 100÷300 °C, we obtain relation (2) in the following form:

$$V_{bf} = V_{cb}^{m} \cdot \frac{t_{hb} - 0.85 \cdot t_{cb} - 94.60}{t_{hb} - t_{bf}}, m^3 / \min \cdot \quad (4)$$

As a result of reconstruction carried out in 1999 at BF 1÷3 of «Severstal» Metallurgical Works a flow meter and a temperature sensor for the cold blast have been installed in the mixing air pipe. The experiment after their installation was organized in such a way that after switching-over of the next hot-blast stove to wind operation, prior to opening of the mixing valve, a possibility was provided to record the temperature of blast entering the blast furnace (t_{bf0}), after that the mixing valve was opened. Through the mixer a certain volume of cold blast passed: 230÷240 (Alternative I) and 450÷500 m³ (Alternative II). After the blast temperature reached a new stable level, the mixing valve was closed.

In spite of insufficiency of data for calculation of losses by the proposed method, their quantity may be estimated already with a better accuracy. One of the three assumptions may be used for this purpose:

– the hot blast temperature upstream of the mixer (t_{hb}) is accepted to be equal to the temperature of blast entering the blast furnace (t_{bf});

– the hot blast temperature upstream of the mixer (t_{hb}) is accepted to be equal to t_{bf} + 5 °C [9] *;

– the hot blast temperature upstream of the mixer (t_{hb}) is accepted to be equal to

$$t_{bf} + 5 + 3.5 \cdot \frac{V_{cb}^{m}}{100}$$

(by the authors of paper [9] it is stated that with increasing of the cold blast rate by each 100 m³/min, the blast temperature is decreasing approximately by 3.5 °C).

The results of calculations by the given above algorithm are shown in Tables 1 and 2. Lines 9÷11 correspond to the above-mentioned assumptions.

The obtained data allow to state that the losses at BF № 2 are less than at BF № 1. When in case of the second Alternative at BF № 2 they do not exceed 7.0 % (ΔV_{cb}^{loss} = 151 m³/min), at BF № 1 they reach 12.4 % (ΔV_{cb}^{loss} = 260 m³/min).

A considerable influence of the hot blast temperature value upstream of the mixer (t_{hb}) on the calculated losses value should be emphasized. In Fig. 3 and Fig. 4 the curves of the calculated blast losses versus the hot blast temperature (t_{hb}) at different V_{cb}^{m} for the hot-blast stoves of BF № 1, 2 are shown. As it is seen from the curves, with increase of t_{hb} the amount of losses in the 1st Alternative is increasing much faster than in the 2nd Alternative. This makes it possible to say that the least errors in determination of losses will occur at the maximum opening (~500 m³/min) of the mixer. Moreover, in actual practice one should expect that the hot blast temperature upstream of the mixer in real situation

* The carried out analysis allowed the authors of paper [9] to arrive at conclusion that the heat losses via the lining are small and make about 0.06÷0.16 °C/m. In doing so, the thickness of the refractory lining has only an insignificant influence on the blast temperature reduction over the delivery system, and therefore losses are equal to 0.6÷1.6 °C/10 m.

Table 1. Calculation of the blast losses at BF № 1 and № 2 (V_{cb}^{m}= 230÷240 m^3/min)

№	Parameters		Blast Furnace № 1			Blast Furnace № 2		
			Hot-blast stove					
			1	3	4	5	6	6[a]
1	Dome temperature, °C		1280	1190	1305	1300	1320	1340
2	Blast temperature at the closed mixer, t_{bf0}, °C		1170	1030	1095	1185	1185	1190
3	($t_{dome} - t_{bf0}$), °C		110	160	210	115	135	150
4	Cold blast rate, V_{cb}, m^3/min		2250	2200	2250	2080	2150	2090
5	Cold blast temperature, t_{cb}		190	190	190	170	170	170
6	Rate of blowing through the mixer, V_{cb}^{m}, m^3/min		243	230	240	240	230	230
7	Blast temperature at the open mixer, t_{bf}, °C		1065	940	995	1070	1080	1080
8	($t_{dome} - t_{bf}$), °C		215	250	310	230	240	260
9	Blast losses[1*] (V_{cb}^{loss}) with the proviso that ...	$t_{hb1} = t_{bf0}$	135/6.0	222/10.1	237/10.5	107/5.1	79/3.7	102/4.9
10		$t_{hb2} = t_{bf0} + 5$	220/9.8	314/14.3	321/14.3	179/8.6	162/7.6	179/8.6
11		$t_{hb3} = t_{bf0} + 5 + 0.035 \cdot V_{cb}^{m}$	348/15.5	444/20.2	448/19.9	288/13.8	282/13.1	289/13.8
12	Relative error at the blast losses calculation, %	$t_{hb} = t_{hb1}$	13.3	13.6	13.1	12.4	13.4	13.0
		$t_{hb} = t_{hb2}$	12.8	13.1	12.6	12.0	13.0	12.5
		$t_{hb} = t_{hb3}$	12.1	12.3	11.9	11.5	12.3	11.9

* In the numerator – m^3/min, in the denominator – %

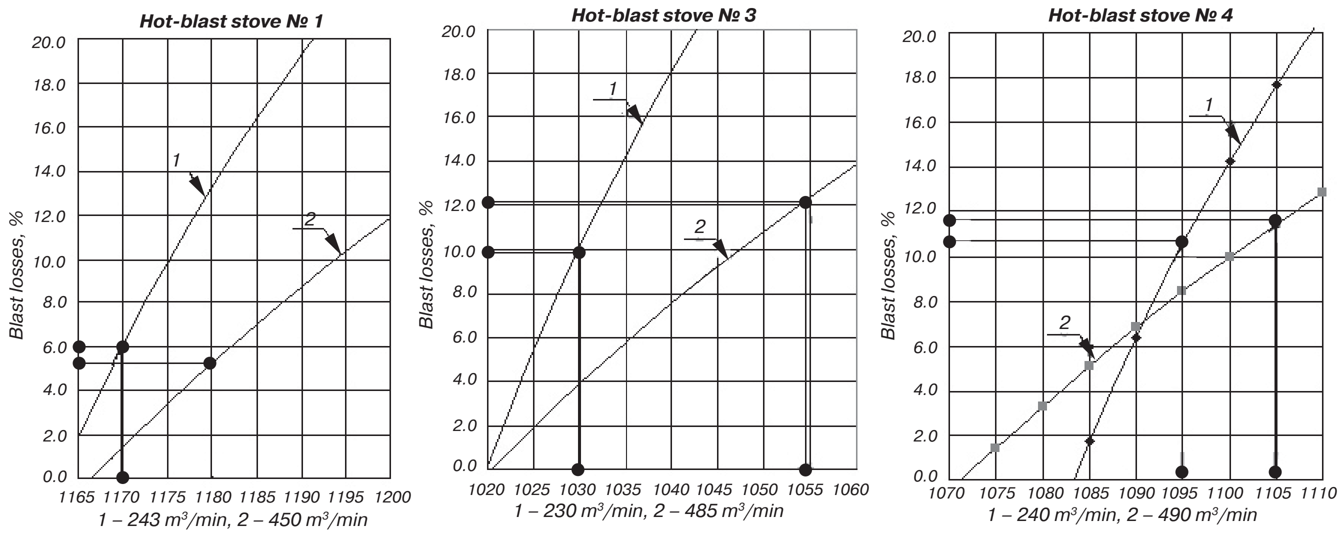

Fig. 3. Influence of the hot-blast temperature value upstream of the mixer (X-coordinate) on the calculated values of blast losses for hot-blast stoves of BF № 1

will be higher than , i.e., the losses at a level of 10÷15 % are to be expected.

Of interest is the assessment of error in determination of the blast losses (V_{cb}^{m}) by formula (4) with due consideration of measurement errors of the included variables.

Using the relationship between the error in determination of a function and the errors in determination of arguments [10], we obtain the following expression for *:

* $V_{cb}^{loss} = V_{cb} - V_{bf}$

Table 2. Calculation of blast losses at BF № 1 and № 2 (V_{cb}^{m} = 450÷500 m^3/min)

№	Parameters		Blast Furnace № 1			Blast Furnace № 2		
			Hot-blast stove					
			1	3	4	5	6	6a
1	Dome temperature, °C		1290	1200	1310	1310	1320	1340
2	Blast temperature at the closed mixer, tbf0, °C		1180	1055	1105	1190	1195	1190
3	($t_{dome} - t_{bf0}$), °C		110	145	205	120	125	150
4	Cold blast rate, V_{cb}, m^3/min		2180	2100	2130	2150	2075	2150
5	Cold blast temperature, t_{cb}		190	190	190	170	170	170
6	Rate of blowing through the mixer, V_{cb}^{m}, m^3/min		450	485	490	490	490	500
7	Blast temperature at the open mixer, t_{bf}, °C		975	840	880	960	955	950
8	($t_{dome} - t_{bf}$), °C		315	360	430	350	365	390
9	Blast losses[2*] (V_{cb}^{loss}) with the proviso that ...	$t_{hb1} = t_{bf0}$	115/5.3	260/12.4	245/11.5	106/4.9	106/5.1	151/7.0
10		$t_{hb2} = t_{bf0} + 5$	154/7.1	291/13.9	275/12.9	139/6.5	136/6.6	182/8.4
11		$t_{hb3} = t_{bf0} + 5 + 0.035 \cdot V_{cb}^{m}$	264/12.1	386/18.4	370/17.4	242/11.3	231/11.1	280/13.0
12	Relative error at the blast losses calculation, %	$t_{hb} = t_{hb1}$	7.9	7.1	7.1	7.3	7.1	7.1
		$t_{hb} = t_{hb2}$	7.8	7.0	7.0	7.2	7.0	7.0
		$t_{hb} = t_{hb3}$	7.4	6.7	6.7	6.9	6.8	6.7

* In the numerator – m^3/min, in the denominator – %

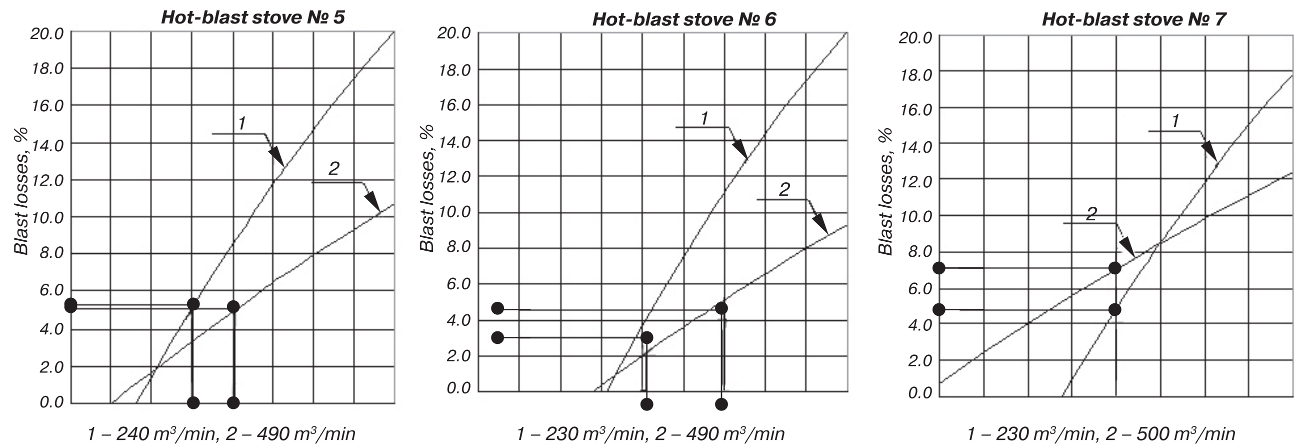

Fig. 4. Influence of the hot blast temperature value upstream of the mixer (X-coordinate) on the calculated values of blast losses for hot-blast stoves of BF № 2

$$\delta V_{cb}^{loss} = \delta V_{cb} + \delta V_{cb}^{m} + \frac{t_{hb}}{t_{hb} - 0.85\cdot t_{cb}}\cdot \delta t_{hb} + \frac{0.85\cdot t_{cb}}{t_{hb} - 0.85\cdot t_{cb}}\cdot \delta t_{cb} + \frac{t_{hb}}{t_{hb} - t_{bf}}\cdot \delta t_{hb} + \frac{t_{bf}}{t_{hb} - t_{bf}}\cdot \delta t_{bf}, \qquad (5)$$

where: $\delta V_{cb}, \delta V_{cb}^{m}, \delta t_{hb}, \delta t_{cb}, \delta t_{bf}$ – is the accuracy rating of the measuring elements for V_{cb}, V_{cb}^{m}, t_{hb}, t_{cb}, t_{bf}, respectively.

From the manufacturer's engineering manual [11] follows that $\delta Vcb = \delta V_{cb}^{m} = 1.0$ and $\delta t_{hb} = \delta t_{cb} = \delta t_{bf} = 0.5$. Proceeding from this, formula (5) obtains the following form:

$$\delta V_{cb}^{loss} = 2 + \frac{t_{hb} + 0,85t_{cb}}{t_{hb} - 0,85t_{cb}}\cdot 0,5 + \frac{t_{hb} + t_{bf}}{t_{hb} - t_{bf}}\cdot 0,5 \cdot \qquad (6)$$

In Tables 1, 2, in line 12, the calculations of the errors by formula (6) are given for all variants of the made assumptions. It is evident that the error in determination of losses is to a great extent depending on the blast volume passing through the mixer. Thus, the error in the 2nd variant, when V_{cb}^{m} = 450÷500 m^3/min is actually twice as low as the errors of the 1st variant, when V_{cb}^{m} = 230÷240 m^3/min.

In this way, the most reliable information obtained by the system is observed during the first 10÷15 min after switching-over of the hot-blast stove to the wind operation, and its results should be extended to include the whole wind period of the hot-blast stove operation.

Conclusion

1. The informative worth of V_{bf} value lies in the possibility to use it in the smelting thermal conditions control system as it is controlling the coke carbon rate of coke which is burning-off at the tuyeres (C_t, kg/t of hot metal). The C_t value, in its turn, is controlling the level of development of the direct reduction processes in the furnace that gives a perfect forecast for the heat input into the furnace hearth and, hence, shows the furnace tendency to heating-up ($\Delta C_t = C_{t_i} - C_{t_o} > 0$) or cooling-down ($\Delta C_t < 0$). With this information at their disposal the technologists, in addition to the data on the technical condition of the air-blowing facilities, receive an autonomous channel for control of heat input into the blast furnace which shall determine the thermal conditions of the blast-furnace smelting unambiguously and more reliably.

2. The existing instrumental methods of the blast losses determination are not able to give their absolute value. The blast losses are calculated integrally, without separation of losses per each hot-blast stove. This considerably deteriorates the informational worth of V_b value and introduces essential errors into determination of the smelting parameters.

3. A new scheme is proposed for determination of the blast volume delivered into the blast furnace by balance of the air flows and their enthalpies. An analysis of the errors in determination of losses by the proposed method with due consideration of the measurement errors of the included variables has been carried out.

4. Evaluation of the results of tests conducted after a partial reconstruction of the blast temperature and flow rate control system of the Blast-Furnace Shop at «Severstal» Open JSC has demonstrated that the error in determination of the losses by the proposed scheme depends to a great extent on the blast volume passing through the mixer. It makes it possible to state that the least errors in determination of losses occur at the maximum opening (~500 m^3/min) of the mixer, and the most adequate information obtained by the system is observed during the first 10÷15 min after switching-over of the hot-blast stove to wind operation; its results should be extended to include the whole wind period of the hot-blast stove operation.

5. The adequate information on the hot blast flow rate into the furnace hearth will allow to decrease the specific coke rate even at the start, i.e., prior to putting into operation of the smelting thermal conditions control system at the expense of increasing the natural gas-to-blast ratio without any risk of decreasing the theoretical combustion temperature below its critical value.

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