PROPANE-BUTANE SUPPLY FOR COKE OVEN AND BLAST FURNACE GAS ENRICHMENT IN REHEATING FURNACES

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Received 07 March 2023
Accepted 02 May 2023
DOI: 10.59957/jctm.v59.i1.2024.10

ABSTRACT

This article proposes organizational and technical measures to reduce energy consumption of re-heating furnaces section of hot rolling mill 1700 in hot rolling shop No.1 of "ArcelorMittal Temirtau" JSC, such as fuel combustion quality management, performed and presented calculation of energy consumption per unit of production. The industrial experiment was performed there. As it is known, one of the features of re-heating furnaces is the fact that the minimum specific fuel consumption takes place when burning it with the maximum possible pyrometric effect. To solve the research tasks, a fundamentally new 3D model of combustion products motion with the possibility of parameters correction to calculate and optimize the energy-efficient operation of the furnace was applied. Experimental data were obtained on high-precision stationary and portable equipment, metering devices passed state inspection, which excludes the unreliability of the data obtained.

Keywords: propane-butane, metal, coke oven gas, gas, metal.

INTRODUCTION

Currently, the main problems of industrial development are unsustainable, slow growth in previous years, reduction of the most important indicators of production efficiency, slow improvement in the structure of industrial production and exports, rather high physical and moral wear of basic production assets, high level of resource costs. The main factor restraining the growth of industrial production and positive structural shifts is the low competitiveness of domestic products. This is primarily due to the low investment and innovation activity in the industry. The solution of these problems requires an industrial policy aimed at stepping up investment and innovation activities, modernizing equipment, introducing new and advanced technologies, increasing the efficiency of production and competitiveness of Russian industry through the transition to an innovative path of development [1 - 11].

High productivity of rolling mills and good quality of finished products is only possible with high-capacity heating furnaces that heat the metal well with minimum oxidation and decarburization. We strive to increase heating and rolling temperatures because steel ductility increases with increasing temperature, strain resistance, energy consumption, and roll and equipment component failures decrease. Due to the reduction of strain resistance, the reduction of rolling and, consequently, the mill's productivity can be increased.

One of the most important problems nowadays is to save energy. Existing re-heating furnaces have high specific fuel consumption - coke oven and blast furnace gas mixture. The primary conditions for obtaining high quality products and improving the efficiency of re-heating furnaces is the correct organization of their heat work and compliance with the temperature regimes of slab heating [12 - 20].

The situation is aggravated by high wear and tear of coke-chemical equipment, which in consequence gives us fluctuations of calorific value in the range of 1100 - 1400 kcal m^{-3} with a design capacity of 1600 kcal m^{-3}. The pressure of coke oven and blast furnace mixture is added in the range of 800 - 1400 mm w.c. with a design pressure of 1600 mm w.c. There is a factor of high temperature differential across the slab (up to 100ºC). Efficiency of re-heating furnaces in Kazakhstan is 35 %, which is low in comparison with foreign partners.

Experimental research in a production environment requires a significant investment, and is a long and time-consuming process. Modern 3D models of temperature distribution for slab heating and the flow of combustion products in the working zone of the furnace, as well as advanced computer technology and means of mathematical support allow to obtain more accurate, in comparison with previous years, and extensive information to optimize the parameters of the furnace, which significantly reduces the time and cost of developing the optimal thermal regimes of the furnace.

The practical value of the work is to study the thermal operation of an industrial re-heating furnace for heating slabs for further rolling. New experimental data on the dynamics of heating, the duration of heating, accounting for scale formation, the effect of leaky furnace in the process of slab heating were obtained; data on the use of liquefied gas mixture to maintain the heat of combustion of coke oven and blast furnace mixture were obtained. Start-up works were carried out after the reconstruction of melting zone roof, the results of which established compliance between the actual performance of the furnace with the design, and the correctness of calculation methods.

EXPERIMENTAL

At present, there is a need to increase the calorific value of coke oven and blast furnace gas used for re-heating furnaces in hot rolling shop No.1 by adding propane-butane to the existing coke oven and blast furnace gas pipeline DN 2.500 mm.

Parameters of coke oven and blast furnace gas at TOP are:

- Gas volume up to 240.000 $m^3 h^{-1}$;
- Calorific value 1100 - 1300 kcal m^{-3};
- Pressure (overpressure) 0.015 - 0.018 MPa;
-Temperature 30 - 50°C.

Propane-butane parameters at TOP to the coke oven and blast furnace gas pipeline are:

- Gas volume up to 4000 $m^3 h^{-1}$;
- Calorific value 21000 - 24000 kcal m^{-3};
- Pressure 0,2 - 0,45 MPa;
- Temperature 30 - 60°C.

Diameter of the supply pipeline (after the gas distribution unit) is DN400 mm. After mixing, the calorific value of mixed gaseous fuel should be 1400 - 1500 kcal m^{-3}.

It is necessary to determine the parameters of gas flows ensuring uniform mixing (distribution) of propane-butane in the coke oven and blast furnace gas flow without precipitation of the liquid phase of propane-butane at propane supply through the hole Ø 150 mm in the mixed gas pipeline Ø 2500 mm.

The calculation was performed using the Flow Simulation package of SolidWorks CAD. In Flow Simulation the motion and heat exchange of fluid medium are modeled using Navier-Stokes equations describing the laws of conservation of mass, impulse and energy of this medium in unsteady mode. In addition, the equations of state of fluid medium components are used, as well as empirical dependences of viscosity and thermal conductivity of these medium properties on temperature. These equations model turbulent, laminar and transient flows (the transition between laminar and turbulent is determined by the critical value of the Reynolds number). To model turbulent flows (they occur most often in engineering practice), the mentioned Navier-Stokes equations are averaged over Reynolds, i.e. the influence of turbulence on flow parameters averaged over a small time scale is used, and large-scale temporal changes of the averaged over a small time scale gas dynamic flow parameters (pressure, velocities, temperature) are taken into account by introducing appropriate time derivatives. As a result, the equations have additional Reynolds terms, and to close this system of equations, Flow Simulation uses the turbulence kinetic energy transfer and dissipation equations within the k-ε turbulence model.

This system of equations of conservation of mass, impulse and energy of unsteady spatial flow, as well as a more detailed description of the package and the mathematical model of Flow Simulation can be found in the book “Solid Works [21].

Input data for the calculation are:

- coke oven and blast furnace gas pipeline - DN2500;
- propane-butane gas pipeline - DN400
- coke oven and blast furnace gas flow rate - up to 240.000 m^3 h^{-1};
- coke oven and blast furnace gas temperature 50°C;
- pressure in the coke oven and blast furnace gas pipeline - 18 kPa;
- propane-butane flow rate - up to 4,000 m^3 h^{-1};
- propane-butane temperature 50°C.

The industrial experiment was performed on the recovery re-heating furnace of pusher (nonimpact) type of 1700 hot-rolling mill in hot rolling shop No. 1 of “ArcelorMittal Temirtau” JSC.

RESULTS AND DISCUSSION

The purpose of the calculation is to determine the flow rate characteristics when propane is supplied through the hole Ø150 mm in the mixed gas pipeline Ø 2500 mm, to determine the pressure control range before the mixing unit to select the appropriate equipment. Mixing calculations were made for different flow rates of coke oven and blast furnace gas and propane-butane (coke oven and blast furnace gas: 40000 - 240000 m^3 h^{-1}; propane-butane: 665 - 4000 m^3 h^{-1}).

Fig. 1 and Fig. 2 show the velocity distribution in the

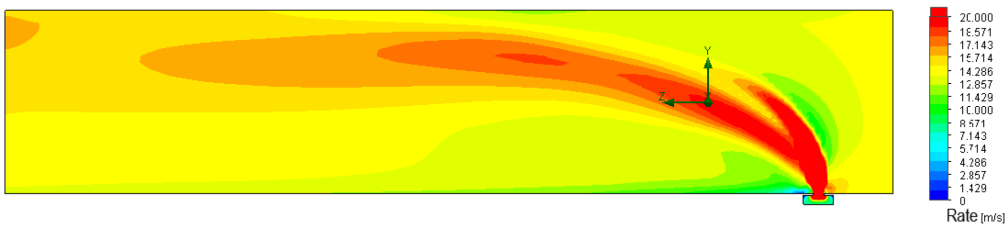

Fig. 1. Velocity distribution in the longitudinal section of coke oven and blast furnace gas pipeline.

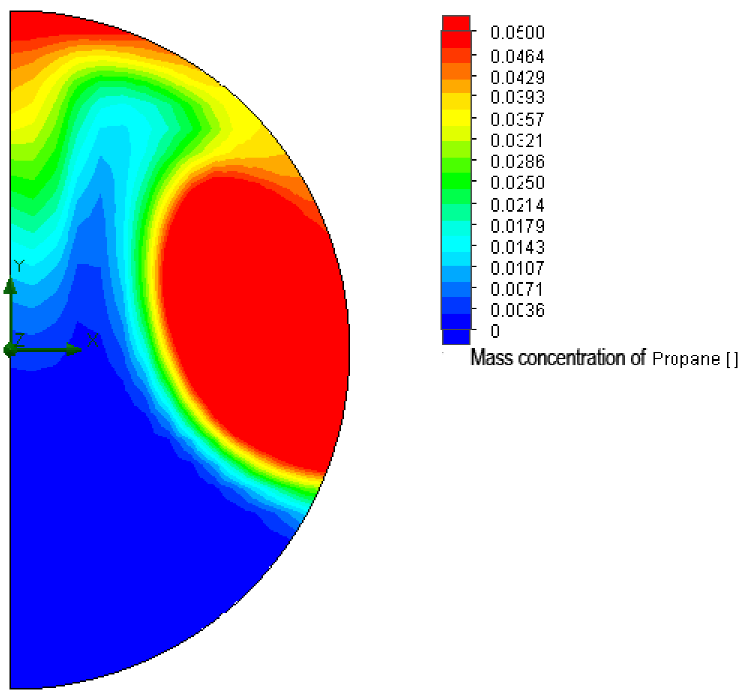

Fig. 2. Mass concentration of propane in the cross section of coke oven and blast furnace gas pipeline at a distance of 10 m.

longitudinal section of the coke oven and blast furnace gas pipeline in the plane Ø 150 mm hole and the mass concentration of propane in the cross section of the coke oven and blast furnace gas pipeline at 10 m from Ø 150 mm hole (here and below on the scale 0.025 corresponds to perfect mixing) at the flow rate of coke oven and blast furnace gas: 240000 $m^3 h^{-1}$; propane-butane: 4000 $m^3 h^{-1}$.

Fig. 3 shows the design flow rate characteristic of Ø 150 tapping.

This flow characteristic is a calculated one (for a pressure in the coke oven and blast furnace gas pipeline of 18 kPa) and may differ from the actual. That is, the pre-tap pressure cannot be used to determine the exact flow rate of propane-butane (PB). Taking this into account, as well as the pressure losses in the section of gas pipeline from the control center to the tapping, the regulating equipment shall provide the ability to regulate the pressure in the propane-butane gas pipeline in the range of 15 - 50 kPa.

To verify compliance with the condition that prevents the creation of conditions for PB condensation, let's calculate the decrease of PB temperature during throttling at the gas distribution unit (GDU).

Throttling is expansion of gas when passing through the throttle - a local hydraulic resistance (valve, tap, pipeline constriction, etc.), accompanied by a change in temperature. Throttling is a thermodynamic process characterized by constant enthalpy (i = cps).

Gas temperature decreases during throttling of real natural gas as it flows through the fitting, gate valve, pressure regulator, shutoff valve. The greater the pressure drop, the greater is the drop in gas temperature.

The temperature change of gases and liquids during isenthalpic expansion is called the Joule-Thomson effect. For real gases, the larger the size of molecule (molar mass), the stronger this effect (μ, K/MPa is the Joule-Thomson coefficient, which shows by how much the gas temperature will change when throttled with a pressure loss of 1 MPa).

Calculation is performed for the maximum pressure drop (from 0.45 MPa to 18 kPa when using a tapping Ø 150) and for the PB composition with the highest molar mass (40 % propane, 60 % butane).

Input data for calculation are:

- pressure before the throttle (hereinafter the pressure is absolute) P_1 = 0.551 MPa;
- pressure after throttling P_2 = 0.119 MPa;
- PB temperature before the throttle T_1 = 323.2 K (50°C);
- PB mixture composition: 40 % C_3H_8, 60 % C_4H_{10}.

For a given average pressure, we find the Joule-Thomson ratio for propane and butane by interpolating the table data [22]:

$$\mu_{C3H8} = 13.9 \frac{K}{MPa};$$

$$\mu_{C4H10} = 21.7 \frac{K}{MPa}.$$

Joule-Thomson ratio of the mixture:

$$\mu_{mix} = \frac{40 \cdot \mu_{C3H8} + 60 \cdot \mu_{C4H10}}{100} = 18.6 \frac{K}{MPa}$$

Temperature drop during throttling:

$\Delta T = (T_1 - T_2) = \mu_{см} \cdot (P_1 - P_2) = 8.0$ K

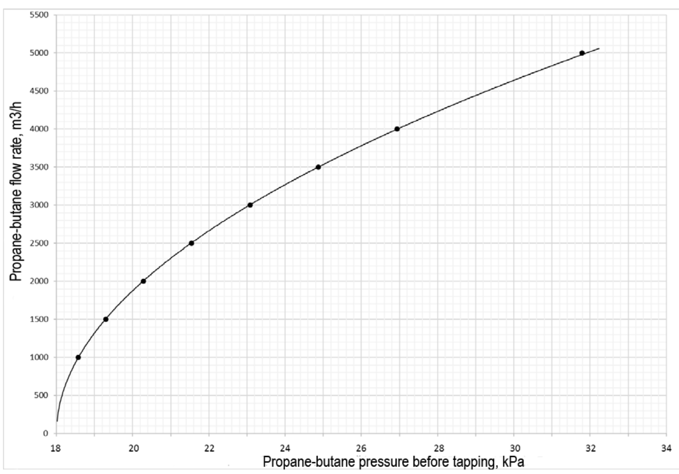

Fig. 3. Design flow characteristic of tapping Ø150 at mixed gas pressure of 18 kPa.

Temperature after throttling:

$t_2 = T_1 - \Delta T - 273{,}2 = 42°C$

From the calculations we can conclude that the temperature drop during throttling is insignificant. The propane-butane (PB) temperature after throttling is much higher than the temperature at which PB condensation occurs at these pressures.

This temperature drop can be neglected in case if PB gas pipeline is heated.

To maintain the set parameters in manual mode, the mixing unit shall be equipped with at least: pressure sensors (or pressure gauges) of propane-butane and coke oven and blast furnace gas or differential pressure gauge between pressures of propane-butane and coke oven and blast furnace gas, properly selected damper with manual or electric actuator on the propane-butane gas pipeline before the mixing unit.

Tables 1 and 2 show the mixing parameters of coke oven and blast furnace gas (mixed gas) and PB at calorific values of 1100 kcal m^{-3} and 1300 kcal m^{-3} of mixed gas, respectively.

Based on Tables 1 and 2, the flow characteristic of tapping Ø 150, diagrams (Figs. 4, 5) were made to determine the PB pressure before the mixing unit by mixed gas flow rate. Figs. 6 and 7 show diagrams to determine the PB flow rate from mixed gas flow rate. Also, like the tables, there are diagrams for the calorific values of mixed gas 1100 and 1300 kcal m^{-3}. When calorific values of mixed gases are between these values, the parameters are found by interpolation.

The horizontal lines on the right side of the diagrams mean that the highest technically possible PB flow rate (4000 m^3 h^{-1}) has been achieved at this pressure.

As an example, let's find PB pressure, which needs

Table 1. For calorific value of mixed gas 1100 kcal m^{-3}.

Mixed gas flow rate, m^3 h^{-1}	PB calorific value, kcal m^{-3}	PB flow rate, m^3 h^{-1}		PB flow range[1]), m^3 h^{-1}	Pressure differences range between mixed gas and PB[2]), Pa
		for the mixture with calorific value of 1400 kcal m^{-3}	for the mixture with calorific value of 1500 kcal m^{-3}		
40000	21000	610	820	610 - 170	200 - 290
	24000	530	710		
60000	21000	920	1230	920 - 1065	450 - 630
	24000	795	1065		
80000	21000	1225	1640	1225 - 1420	830 - 1150
	24000	1060	1420		
100000	21000	1530	2050	1530 - 1780	1270 - 1800
	24000	1325	1780		
120000	21000	1835	2460	1835 - 2135	1920 - 2590
	24000	1595	2135		
140000	21000	2145	2870	2145 - 2490	2600 - 3450
	24000	1860	2490		
160000	21000	2450	3280	2450 - 2845	3400 - 4550
	24000	2125	2845		
180000	21000	2755	3690	2755 - 3200	4220 - 5720
	24000	2390	3200		
200000	21000	3060	> 4000[3]	3060 - 3555	5200 - 7000
	24000	2655	3555		
220000	21000	3365	> 4000[3]	3365 - 3910	6280 - 8470
	24000	2920	3910		
240000	21000	3675	> 4000[3]	3675 - 4000	7500 - 8900
	24000	3185	> 4000[3]		

Table 2. For calorific value of mixed gas 1300 kcal m^{-3}.

Mixed gas flow rate, m^3 h^{-1}	PB calorific value, kcal m^{-3}	PB flow rate, m^3 h^{-1}		PB flow range[1]), m^3 h^{-1}	Pressure differences range between mixed gas and PB[2]), Pa
		for the mixture with calorific value of 1400 kcal m^{-3}	for the mixture with calorific value of 1500 kcal m^{-3}		
40000	21000	205	410	205 - 355	15 - 50
	24000	175	355		
60000	21000	305	615	305 - 535	30 - 190
	24000	265	535		
80000	21000	410	820	410 - 710	90 - 290
	24000	355	710		
100000	21000	510	1025	510 - 890	120 - 420
	24000	440	890		
120000	21000	610	1230	610 - 1065	200 - 630
	24000	530	1065		
140000	21000	715	1435	715 - 1245	300 - 900
	24000	620	1245		
160000	21000	815	1640	815 - 1420	400 - 1150
	24000	710	1420		
180000	21000	920	1845	920 - 1600	450 - 1450
	24000	795	1600		
200000	21000	1020	2050	1020 - 1780	600 - 1800
	24000	885	1780		
220000	21000	1120	2255	1120 - 1955	750 - 2150
	24000	975	1955		
240000	21000	1225	2460	1225 - 2135	830 - 2590
	24000	1060	2135		

**PB flow rate range to maintain the required mixture calorific values (1400-1500 kcal m^{-3}) at calorific value of mixed gas 1100 kcal m^{-3} (for Table 1) or 1300 kcal m^{-3} (for Table 2) in the whole range of possible PB calorific values (21000 - 24000 kcal m^{-3}); Pressure difference range between mixed gas and PB to maintain PB flow according to column 4. For example, if the required pressure difference is 7.5 - 8.9 kPa and the pressure in the mixed gas pipeline is 18 kPa, the pressure before the mixing unit shall be 25.5 - 29.9 kPa (7.5 + 18 kPa .... 8.9 + 18 kPa), for details see description of diagrams (Fig. 4 - 5) below; PB flow rate required to achieve a mixture calorific value of 1500 kcal/m^3 shall be higher than the maximum technically possible today (4000 m^3/h).*

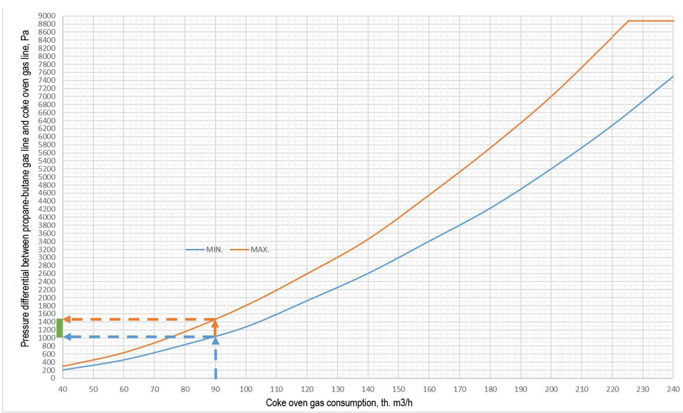

Fig. 4. Diagram of determining the pressure before the tapping by mixed gas flow rate) (at mixed gas calorific value = 1300 kcal m^{-3}).

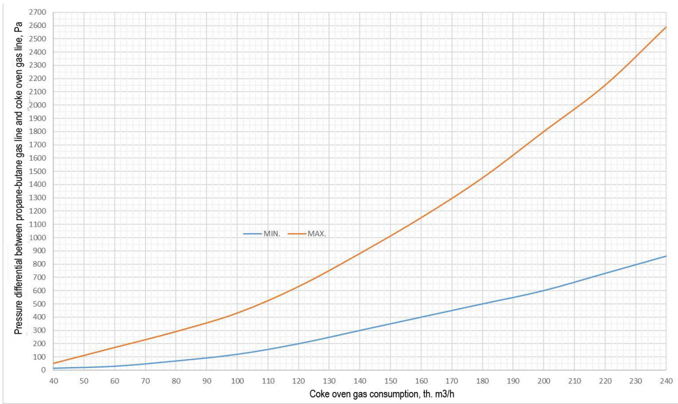

Fig. 5. Diagram of determining the pressure before the tapping by mixed gas flow rate) (at mixed gas calorific value = 1300 kcal m^{-3}).

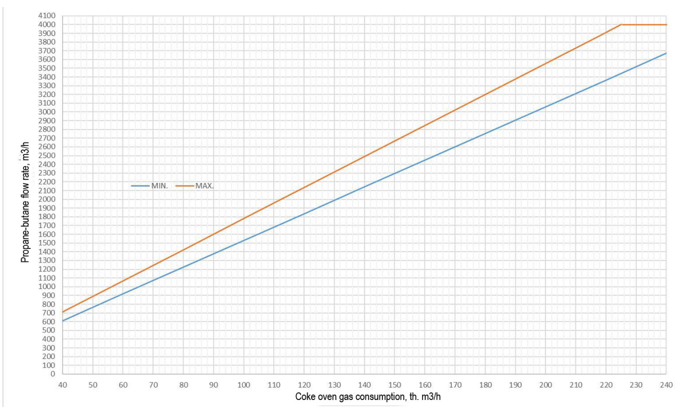

Fig. 6. Diagram for determining the propane-butane flow rate by coke oven and blast furnace gas flow rate (at mixed gas calorific value = 1100 kcal m^{-3}).

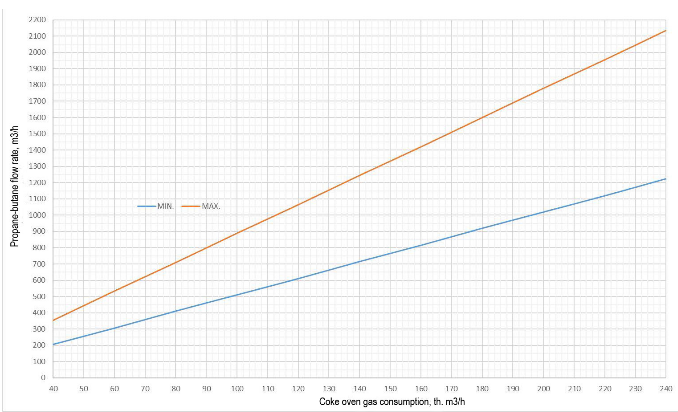

Fig. 7. Diagram for determining the propane-butane flow rate by coke oven and blast furnace gas flow rate (at mixed gas calorific value = 1300 kcal m^{-3}).

to be maintained before tapping ø 150 to provide the required mixture calorific value of 1400 - 1500 kcal m^{-3} at the flow rate of mixed gas 90 ths. m^3 h^{-1} and its calorific value of 1100 kcal m^{-3} and the pressure in the mixed gas pipeline of 16 kPa (16000 Pa). The diagram shown in Fig. 3 is used for this purpose. On the axis of mixed gas flow we find the required value (90 ths. m^3 h^{-1}), draw a vertical line to the intersection with the lines MIN. and MAX. From the intersection points draw lines to the ordinate axis (pressure difference in PB gas pipeline and mixed gas pipeline) we obtain the pressure difference range in PB gas pipeline and mixed gas pipeline (1000 - 1500 Pa). In the case of a differential pressure gauge installed between the sections of PB and mixed gas pipelines, these differential pressure gauge readings shall be maintained by changing the position of the damper on the PB gas pipeline to obtain the required calorific value of the mixture before the consumer. on the PB and mixed gas pipelines as control devices, then these values shall be added to the mixed gas pressure sensor readings (in the example it is 16000 Pa), and the resulting PB pressure values before the mixing unit (17000 - 17500 Pa) shall be maintained by changing the damper position on the PB gas pipeline to obtain the required mixture calorific value before the consumer.

Tables 1 and 2 and the diagrams in Fig. 3 and Fig. 4 are based on calculated data and should be checked/corrected during commissioning according to calorimeter readings.

We recommend that with such a large number of parameters (mixed gas flow rate, mixed gas pressure, mixed gas calorific value, mixed gas temperature, propane-butane calorific value, temperature of propane-butane) to use the recommended scheme of automatic calorific value control.

Figs. 8 and 9 show verification aerodynamic calculations of the tapping Ø150 at different flow rates of mixed gas and PB. The flow rates of mixed gas and PB correspond to columns 1 and 4 (upper limit of the range) of Table 1.

Fig. 8 shows the distribution of velocities in the longitudinal section of the coke oven and blast furnace gas pipeline at different flow rates for tapping hole Ø 150. Fig. 9 shows the mass concentration of propane in the cross section of the gas pipeline of coke oven and blast furnace gas at a distance of 10 m at different flow rates for tapping hole Ø 150.

The results of check calculations show that tapping Ø150 provides uniform distribution of propane-butane over the cross-section of the coke oven and blast furnace gas pipeline at gas flow rates from 60.000 to 240.000 m^3 h^{-1} and propane-butane up to 4000 m^3 h^{-1} in the pressure range from 18.15 to 30 kPa. The nature of mixing and distribution of the jet does not change significantly with changes in flow rates. The flow velocity changes only.

Given the fact that any local resistance, including the pipeline bend, is to some extent the turbulence of the flow, if a long enough section of gas pipeline from tie-in to the consumer (30 m or more) with several turns, the lack of mixing when supplying propane-butane through a single hole is mitigated by diffusion mixing, which in turbulent flow occurs much faster than in laminar flow.

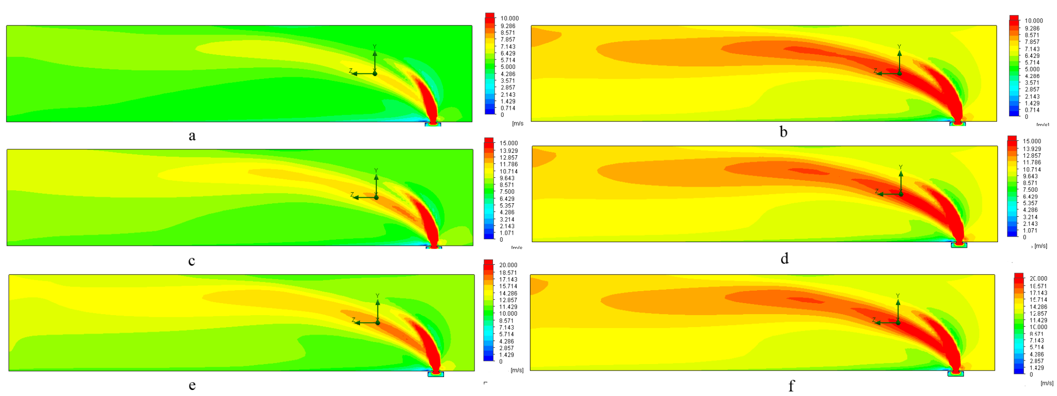

Fig. 8. Distribution of velocities in the longitudinal section of coke oven and blast furnace gas pipeline at different flow rates for tapping Ø150: a - mixed gas 90000 m^3 h^{-1}, PB 1600 m^3/h; b - mixed gas 120000 m^3 h^{-1}, PB 2135 m^3 h^{-1}; c - mixed gas 150000 m^3 h^{-1}, PB 2650 m^3 h^{-1}; d - mixed gas 180000 m^3 h^{-1}, PB 3200 m^3 h^{-1}; e - mixed gas 210000 m^3 h^{-1}, PB 3750 m^3 h^{-1}; f - mixed gas 240000 m^3 h^{-1}, PB 4000 m^3 h^{-1}.

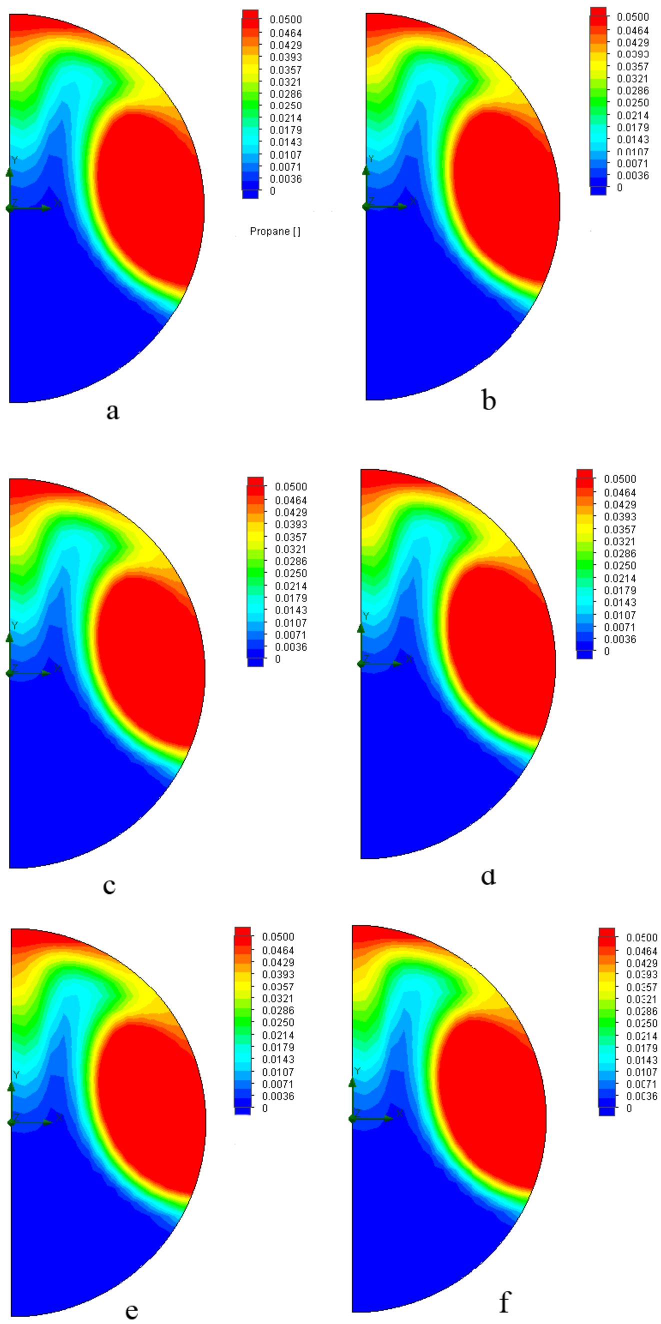

Fig. 9. Mass concentration of propane in the cross-section of coke oven and blast furnace gas pipeline at a distance of 10 m at different flow rates for tapping Ø150: a - mixed gas 90000 m^3 h^{-1}, PB 1600 m^3 h^{-1}; b - mixed gas 120000 m^3 h^{-1}, PB 2135 m^3 h^{-1}; c - mixed gas 150000 m^3 h^{-1}, PB 2650 m^3 h^{-1}; d - mixed gas 180000 m^3 h^{-1}, PB 3200 m^3 h^{-1}; e - mixed gas 210000 m^3 h^{-1}, PB 3750 m^3 h^{-1}; f - mixed gas 240000 m^3 h^{-1}, PB 4000 m^3 h^{-1}.

CONCLUSIONS

The results of studies show that the addition of propane-butane to coke oven and blast furnace gas makes it possible to increase the calorific value of gas up to the design capacity of 1600 kcal m^{-3}. Based on computer modeling results, we can conclude that the distribution of temperature and velocity fields within the furnace working space is uniform and provides a given thermal and gas-dynamic modes of furnace operation. Industrial experiment on the recovery re-heating furnace of pusher (nonimpact) type of 1700 hot rolling mill in hot rolling shop No. 1 of "ArcelorMittal Temirtau" JSC has confirmed the results obtained in this study.

By request of re-heating furnaces section of hot rolling shop No. 1, a project for reconstruction of the furnace melting zone roof and correction of air-gas ratio for the furnace melting zone according to the content of gases in the furnace was developed and implemented.

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