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SPATIALLY-ORIENTED AIR-BLAST SUPPLY IN THE AUGMENTED MODE

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ABSTRACT

Based on the analytical review we have identified the possibility of multiple increase of specific productivity of the copper-nickel matte converting process. The possibility of increasing the performance of the autogenous apparatus is limited by factors of physical impact of the air jets on the molten medium. Combination of dynamic pressure, thermal expansion forces of gases in the melt, and Archimedes buoyant force, which pushes the gas bubble from the depth of melt, results in massive releases of melt from the apparatus workspace. The air-blast supply method causes a certain limit air-blast load. When using a new method of air-blast supply to melt, the specific load twice exceeded the maximum level of air-blast load of converter. The method of spatial-oriented air-blast supply into the molten matte, which allows greatly increasing specific air-blast load, was confirmed experimentally. In the experiment, the specific air-blast load twice exceeded limit value of the Peirce-Smith converter, while did not cause emissions and melt foaming. In the suggested embodiment of the spatially-oriented air-blast supply, heat and mass transfer throughout the volume of the molten mass approaches the operating conditions of an ideal mixing reactor due to the rotational motion of the melt that is generated by the kinetic energy of several tangentially directed blowing jets. Combination of heat generation and heat transfer zones reduces unnecessary heat loss, increases the overhaul period, while the "cyclone" effect of the gas phase above the melt suppresses massive emissions of the latter from the apparatus workspace, as well as prevents the flue dust.

Keywords: pyrometallurgy, autogenous processes, air-blast supply, air-blast load, matte, copper, nickel.

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1. INTRODUCTION

Metallurgical production is based on two major technological directions – pyrometallurgy and hydrometallurgy. The pyrometallurgy is characterized by much more high rates of physical and chemical interactions in comparison with the hydrometallurgy processes. This provides the higher specific productivity of pyrometallurgical processes compared to hydrometallurgical ones. Despite significant advances in contemporary hydrometallurgical technology, especially when using autoclaves, oxygen, various intensification techniques, and application of electrolysis, pyrometallurgy is ahead of hydrometallurgy in terms of the scale of enterprises, volumes of processed raw material, and the number of products. Pyrometallurgical technologies have overwhelming advantage in ferrous metallurgy.

A variety of properties of both numerous metals and mineral raw materials used to produce them, determines the huge variety of metallurgical furnaces design and their operating conditions.

2. GENERAL CHARACTERISTICS OF AUTOGENOUS PROCESSES IN NONFERROUS METALLURGY

Autogenous processes and devices that have received wide circulation resulting from the development and production of oxygen on an industrial scale are playing a special role in nonferrous pyrometallurgy. The use of oxygen in metallurgy has created all the prerequisites for the intensification of oxidation reactions of sulfide materials, enhancing efficiency of devices, controlling the degree of desulfurization, producing mattes with a high content of non-ferrous metals, high-sulfur gases suitable for recycling, as well as technological processes automation. However, the potential opportunities of the oxidative processes are still implemented not in full.

Firstly, a common characteristic of all the pyrometallurgical processes of oxidation type which are running based on "gas-melt" system is a direct dependence of their productivity on the air-blast supplied per unit of time. The amount of air-blast supplied to the melt through injection lances of various designs into devices having different structures, is limited by the onset of massive emissions of the melt from the workspace of the apparatus when exceeding a certain amount of air-blast. For different air-blasting options there are limit values for the amount of air-blast supplied per 1 m^3 of apparatus workspace. These limits range from 0.067 to 0.22 m3/s m3 (Table 1) [1]. This circumstance explains the relatively low productivity of the autogenous apparatus and determines the possible option to improve oxidation technologies by increasing the specific air-blast loads

Secondly, the elevated content of magnetite and nonferrous metals in slag of autogenous smelting indicates a certain incompleteness of slagging reactions in the formation of final products [2, 3]. For example, the distribution of copper between separated melts depends not only on the degree of their approximation to equilibrium, but also on structural design of autogenous process (Fig. 1).

Thirdly, in oxidative type metallurgical aggregates operating even at air-blasting, the separation of heat generation and heat transfer areas causes thermal overload of individual structural elements, reducing their operating service life or leading to unavoidable heat losses through water-cooled elements [1]. The validity of this statement is proved by repeated unsuccessful attempts to use in horizontal converters the submerged air-blasting enriched with oxygen [4].

Table 1 Limiting air-blast load in the autogenous devices of various designs

Autogenous apparatus	Blowing method	Limiting air-blast load, $m^3/s \times m^3$
Bessemer converter	Bottom blowing	0.067-0.083
Vertical oxygen converter	Top non-submerged blowing	0.1-0.133
Kaldo converter	Inclined non-submerged blowing	0.117-0.15
Horizontal converter	Side submerged unilateral blowing	0.125-0.22
Vanyukov furnace	Double-sided submerged blowing	0.133-0.167

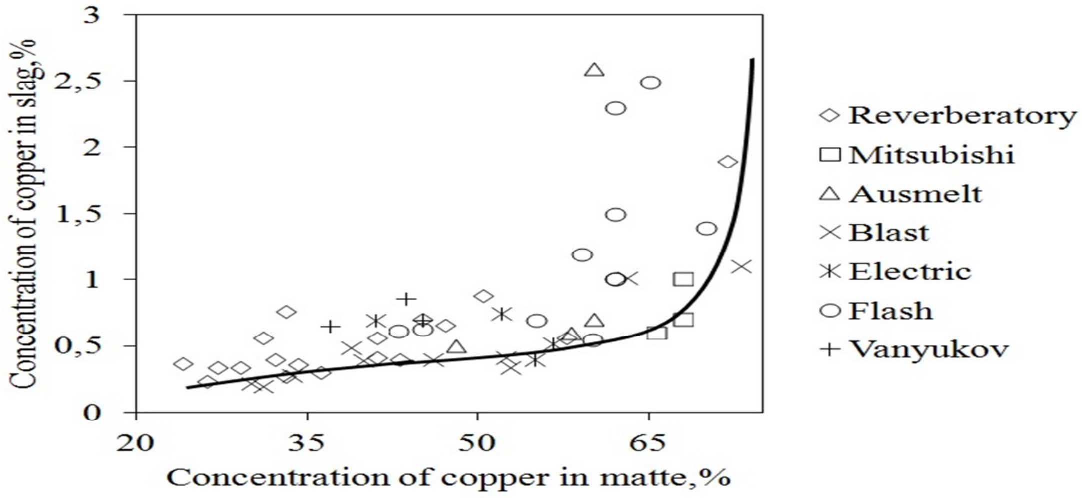

Figure 1 Copper distribution between slag and matte (solid line characterizes the equilibrium distribution)

The method of air-blast supply into the melt through injection lances, placed in the copper caissons of the Vanyukov furnace (VF), also raises some doubts, since there are no conditions for the formation of a stable skull protection, as evidenced by the analysis of emergency situations arising at the Balkhash Copper Smelter (Table 2). The most critical shutdowns of the VF were caused by the destruction of the belt caissons and malfunction of the flue gas system. In this situation, the first shutdown is characterized by a leak of the caissons and the formation of flaws, while the second shutdown is caused by stopping the operation of the recovery boiler and the formation of accretions in the furnace workspace and its uptake.

In the end, for the calendar period of 6288 hours, the performance under air-blast of the VF amounted to 0.80 and 0.95, without taking into account the time of overhaul.

The oxygen vertical converter (OVC) with a vertical supply of the oxygen jet into the melt (cast iron or matte) is not optimal from the standpoint of technology and heat transfer. In this case, a local area of rapidly occurring physical, chemical, electrical and mechanical processes is formed in the central area of the device. Mass transfer in the peripheral areas of the bath is of a stochastic nature. Thermal and chemical fields in the bulk of melt are highly uneven.

Table 2 Shutdown statistics of the Vanyukov furnace

The reason for the shutdown	Number	Time, hours
Preventive maintenance	8	38
Destruction of caissons	17	97
Interruption of power supply	18	30
Interruption of oxygen-air mixture supply	8	28
Failure in flue gas system	34	90
Technological and transport interruptions	14	31
Total overhaul	1	974
Total:	100	1289

Thermal overstress effects of the reaction shaft were revealed in the flash smelting furnaces at the Nadezhdinsky Metallurgical Plant that necessitates cooling of its hull. This will cause an unjustified loss of energy and at the same time, a heat deficiency in the bath of the furnace, especially at the slag end of the bath [5, 6].

Fourthly, unstable nature of the physical, chemical and aerodynamic factors that shape the dust and gas flow, leads to the formation of accretions in the furnace unit and complicates the disposal of the dust-gas mixture [7].

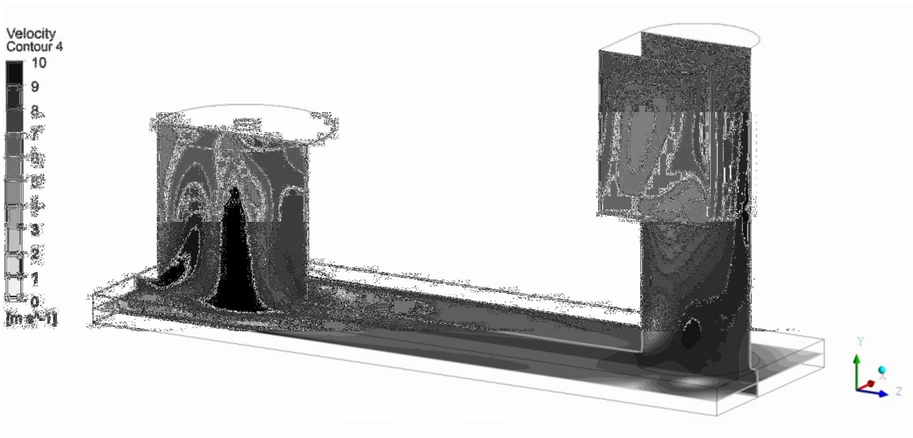

Figure 2 The nature of the gas-dynamic flow in the flash smelting furnaces

For example, gas flow in the flash smelting furnace forms in several stages (Fig. 2). At the first stage, the air jet flow from the burners develops to form gas and charging material streams having a temperature corresponding to the blast-heating temperature. Next, along each jet they merge into one common stream acquiring at the expense of heat exchange with the heated walls of the shaft a temperature at which the sulphide particles ignite initiating the oxidation process. Gas flow completely fills the shaft, stabilizes and moves in the "streamflow" mode. Next, the gas flow turns at 90^o, changing cross section according to "underroof space" configuration, continues flowing in a horizontal "underroof space" above the molten bath, again rotates at 90^o, entering the rising flue gas duct, and turns into the horizontal section leading to the heat-recovery boilers, and then enters the sulfur dioxide recovery devices. Not surprisingly, that the complicated nature of the dust-gas mixture flow leads to the formation of refractory accretion in the gas pipeline system and complicates the draft regime up to the emergency shutdown of the unit [8-10].

The design of the VF space and its uptake also does not meet the complexity of the hydrodynamic processes occurring in the furnace. This relates at the beginning to almost vertical gas breakthrough from the melt depth, then merging the individual craters in the total gas flow and finally, flowing together with dust and gases along geometrically imperfect trajectory. This results in appearance of stagnant zones in the gas space, as well as vortices, deposition in different parts of accretions, including those, which are called the "hourglass" [11].

Lastly, any "autogenous" equipment requires the input of additional energy at the expense of traditional heat sources, as well as pre-heating of air-blast or enriching it with oxygen. At the same time heat is lost irrevocably due to following reasons (relative to the total heat input): the loss to the external environment (10-20%), enthalpy of solid and liquid products (15-35%), and the heat lost with exhaust gases (70-80%) [12, 13].

These are the main contradictions between the potential opportunities and the above circumstances related to the operation of autogenous apparatus.

In consequence of exploratory study we have formulated the main idea, which consists in the possibility of multiple increasing in the maximum amount of air-blast supplied per 1 m^3 of workspace of autogenous apparatus. Searching the other options of using the dynamics of the non-submerged high-pressure jets was based on large-scale experiment carried out at the Pechenganickel steel plant (“Kolskaya Gmk OAO”) to create intensive mass transfer of a melt by several tangentially directed non-submerged jets.

3. METHODS

Theoretical studies were based on known physical and chemical regularities of the processes occurring at the stage of oxidative pyrometallurgical processing of sulphide polymetallic raw material. Experimental studies were carried out on the scaled pilot plant of "Kolskaya Gmk OAO". Analytical data of the chemical composition were obtained by x-ray method. The gas phase composition was determined by chemical analysis. Technical measurements were carried out using standard thermocouples and pressure gauges fitted with disc diaphragms.

4. ARRANGING THE EXPERIMENT

Benchmark data needed to the project development on air-blast unit of pilot plant for converting the matte at the upper spatially-oriented arrangement of blowing jets have been based on the following considerations.

1. Current system of air-blast supply in horizontal converters almost never uses the kinetic energy (dynamic pressure) of air jets. This energy is suppressed by the "frontal" impact of the tuyere jet when it outflows into the melt. Density of this jet is 2500 times higher than the density of air in the air jet (5000 kg/m^3 and 2 kg/m^3, respectively). Therefore, an intense mass transfer process is formed only in the vicinity of the tuyere area (no more than 1/6 of the total volume of the melt in the converter). Because the processes the exothermic discharge occur right here, a local center of very intense thermal and physical-chemical processes is formed in the tuyere area that results in destructive impact on its masonry. The main forces acting on the melt in the tuyere area are the Archimedes force, which pushes gas bubble from the depths of the bath to the surface, and the forces of thermal expansion of gases with initial temperature of supplied air (30-60^oC) to the temperature of the melt (1200-1350^oC). On the one hand, these forces are not enough to initiate a vigorous mass transfer throughout the bulk of the molten bath, while, on the other hand, they are excessive for the limited volume of the bath, which is exposed to the impact of these forces. This circumstance leads to a restriction of air-blast supply into the converter in order to avoid low frequency oscillations of the molten bath and mass emissions of the melt through the neck occurring at higher blast loadings. Limit amount of air-blast supply is 0.125-0.22 m^3/s per 1 m^3 of the converter barrel workspace.

At non-submerged air-blast supply the blowing jet is formed in the mode of free submerged jet having a high kinetic energy, which can be used to create a directional controlled mass transfer process when converting matte. This converting option may be exercised based on the combination of a vertical cylindrical body of the apparatus and the air-blast unit, creating blowing jets, spatially oriented in such a way as to provide regular rotational movement of the entire bulk of the melt. The initial ideas about the design of such a device and the main regularities of interaction of the non-submerged jets with liquid bath have been obtained by means of physical models [1].

The objective of the current phase of the work consisted in conducting full-scale experiments with real matte using the installation of representative scale.

The body of the device for such installation was designed based on the existing matte ladle, lined with refractory in such a thickness as to create the desired workspace. The air-blast unit was designed together with the lid covering the peripheral area of the ladle. Lid was required not only as a screen to prevent from the emission of a melt at blowing, but also as a condition necessary to form rotational motion of gases above the melt that created the centrifugal effect and reduced these emissions.

2. **Choosing the experimental mode.** With regard to the workspace volume of the converter of Pechenganickel, equal to 60 m^3, and a maximum air-blast load of 0.125-0.22 $m^3/s \cdot m^3$, limiting air-blast flow rate in the converter can reach 60 (0.125÷0.22)=7.5-13 m^3/s. Let us take the maximum flow rate to be equal to 13 m^3/s. Assuming the maximum filling degree of convertor workspace with melt (matte with the slag) to be equal to 0.4, we obtain the melt volume equal to $60 \cdot 0.4 = 24$ m^3. We assume the average density of the melt (matte and slag) equal to 4500 kg/m^3. Then the mass of the melt will be $24 \cdot 4500 = 108000$ kg, or about 100 tons.

Thus, a limit air-blast supply per 1 ton of the melt will be 13/100 = 0.13 $m^3/s \cdot t$.

As shown by model experiments, at the top non-submerged blowing in the form of oriented high-pressure jets, limit amount of air-blast supplied before the onset of massive emissions of liquid increases several times comparing to the side submerged blowing. This circumstance serves a prerequisite of possible significant increase in the productivity of the device. Exactly this should be tested in the full-scale experiment. For the experimental conditions, we assume a twofold increase in the air-blast load per unit mass of the melt in the ladle, i.e. $0.13 \cdot 2 = 0.26$ $m^3/s \cdot t$. Choosing the scale of the experiment, we assume that the minimum ladle volume is equal to 0.8 m^3. Thus this volume contains about 4 tons of melt. In this case, the air-blast load should be a minimum of $0.26 \cdot 4 = 1.04$ m^3/s. This air-blast supply mode can be provided by 6 nozzles, each 8 mm in diameter at a pressure of 0.35-0.45 MPa.

3. **The main structural elements of the experimental setup** (Fig. 3). The matte ladle (1) is lined with bricks (2) to provide the workspace sufficient for pouring about 1 m^3 of matte, leaving also the distance from the injection lances (3) to the matte surface equal to 300 mm with some margin left for the crusts formation. Melt mirror (4) has a diameter of 1200 mm, while the depth of the cavity (5) is 1000 mm. Brick masonry is covered on top with a ring (6) made of sheet steel (15-20 mm thick) with hole diameter of 1160 mm. The ring is welded to the ladle and serves as both a support for solid masonry at the turns of ladle, and the joint plane with lid. It is envisaged that one of the ladle nozzles is left in working condition. Lid is made of 15 mm steel sheet. Air-blast is supplied from an air manifold (7) through 6 lances (8) with a special design having 8 mm nozzles [14, 15].

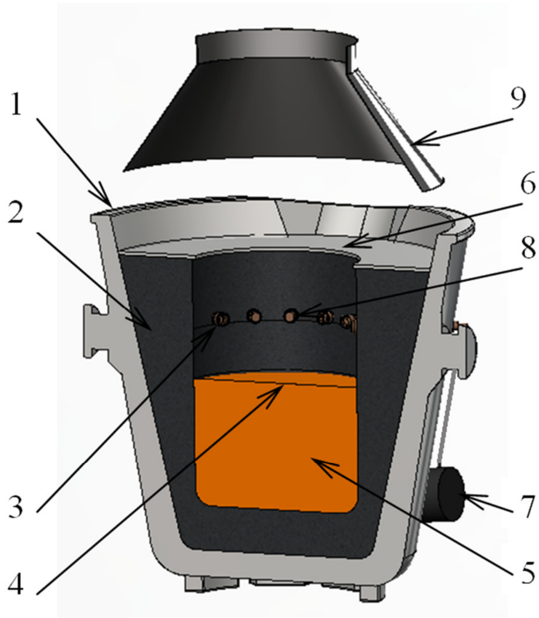

Figure 3 The main structural elements of the experimental setup.

In the course of the experiment, lined matte ladle was heated preliminary by coke combustion during the previous day. The ladle was installed under a ventilation system (9), had a lid with a set of tubes for gas sampling and temperature measurement. The air-blast pressure in the system was of 0.38 MPa. Five minutes after the start of blow, the concentration of sulfur dioxide gas sampling taken under the hood was 1.2-1.8%, where there was intense forcing out of the gas phase to the peripheral part of the setup (in the area between the ladle edges and the bottom of the lid). In subsequent measurements, the concentration of sulfur dioxide was not detected, and the process was terminated. When the lid was lifted, we observed formed solid crust. Reasons for "non rotation" of the mass were cold (insufficiently heated) ladle, the mass of the cooled matte, and insufficient air-blast supply.

The experiment was repeated. The same ladle was well heated by molten mass when pouring it from the converter. The experiment was repeated with the enriched converter mass having the following composition: Cu – 9.0%, Ni – 15.5%, Fe – 40.3%, and S – 21.6%. The air pressure in the blast system was increased up to 0.45 MPa, the flow rate of the blast made up 10.35 m^3/s. In this case the process started and was accompanied by a rapid emission of sulfur gases. The ventilation system was able to remove no more than 50% of the released gas, while remaining gas got into the workshop indoor environment. The gas sampling was conducted simultaneously by two parallel systems: one gas sampling line was implemented using PRU-4 air blower, while another – by the ejector.

Air-blast supply was conducted during 16 minutes. Further the air-blast was stopped for filling quartz sand. The air-blast was resumed 10 minutes after the loading of the flux and continued during another 11 minutes. Figure 4 shows the map of experimental measurements of the sulfur dioxide content in the gas phase.

Further, air-blast supply was stopped again to download the second portion of a quartz flux and then continued again during 12 minutes. The gas temperature was 1240-126^{0}C.

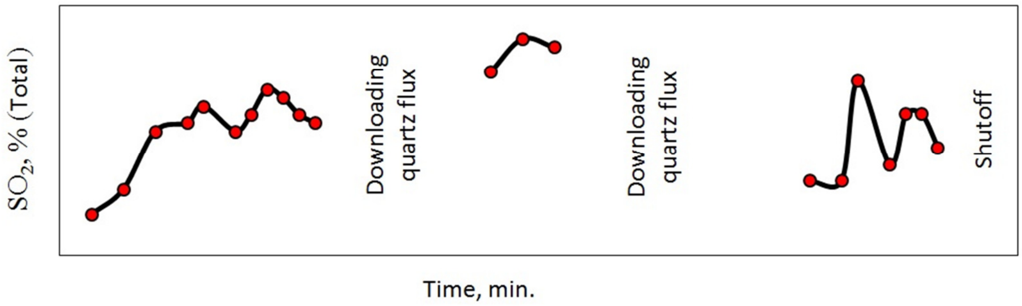

Figure 4 Experimental measurements of the sulfur dioxide content in the gas phase.

5. RESULTS

The possibility of increasing the performance of the autogenous apparatus is limited by factors of physical impact of the blowing jets on the molten medium. Combination of dynamic pressure, thermal expansion forces of gases in the melt, and Archimedes buoyant force, which pushes the gas space from the depth of melt, result in massive releases of melt from the apparatus workspace. The air-blast supply method causes a certain limiting air-blast load. When using a spatially-oriented method of air-blast supply to melt, the specific load twice exceeded the maximum level of air-blast load of the horizontal converter.

Visual observations allowed determining the diameter of blast nozzles with sufficient accuracy, as well as allowed identifying the steady course of the process under conditions of intense rotation of the melt and the absence of emissions. The blowing process and the content of sulfur dioxide in gases have confirmed the possibility of their effective utilization. In this case gas phase above the melt was characterized by presence of "cyclone" effect that prevented the melt and dust from emissions.

Possible increase in air-blast load and, hence, enhancement of relative productivity will significantly affect the heat balance structure of the apparatus that in particular will extend opportunities of conducting autogenous oxidation processing of sulphide polymetallic raw material in non-ferrous metallurgy, since the reduction of the external heat losses due to the increase in productivity can compensate for some reduction in the "heat of exothermic reactions" associated with involvement in the processing of ores with reduced sulfur content, and ensure the processing of such ore in autogenous mode without additional input of any fuel.

6. CONCLUSION

A fundamentally new spatially-oriented air-blast supply method has been proposed and experimentally verified at scaled real industrial matte smelting. In the course of experiment, the specific air-blast load was twice or more times greater than that commonly used in well-known autogenous devices. The process was implemented without emissions and melt foaming.

Spatially-oriented air-blast supply method allows to maximally combine heat generation and heat transfer areas due to rotational motion of the melt that is generated by the kinetic energy of several tangentially directed blowing jets. This makes it possible to bring mass transfer in the entire volume of the molten mass in line to the operating conditions of the ideal mixing reactor.

We have proposed new option for sulfide copper and copper-nickel materials processing in augmented autogenous mode based on the spatially-oriented air-blast supply, which allows significantly increasing the specific air-blast load, reducing unnecessary heat loss, flue dust, and losses of non-ferrous metals with slag under optimum conditions of heat and mass transfer.

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