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NUMERICAL SIMULATION OF GAS DYNAMICS OF IN-FURNACE CHAMBER

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ABSTRACT

This article discusses dynamics of gas phase in basic furnaces applied upon the melting stage of sulfide polymetallic ores and concentrated nonferrous metals containing copper and nickel. The patterns of gas flow in flash smelting furnace, the Vanyukov furnace, in the Ausmelt process were determined by numerical simulation in nonstationary mode. The obtained solutions of the Navier-Stokes equations are in good agreement with practical operation of these facilities. This article also describes numerical simulation of an alternative jet rotation apparatus which allows to increase significantly specific blasting load with formation of cyclone effect in gas phase, which suppresses dust entrainment and decreases load on dust collectors.

Key words: numerical simulation, gas dynamics, furnaces, cyclone effect, dust

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1. INTRODUCTION

Treatment of lean sulfide ores of nonferrous metals and technogenic raw stuff leads to variation of composition, particle sizes, caloric value of blend materials, violation of technology process up to its complete shutdown.

One of the main reasons of emergency shutdowns was the formation and breakage of ledges which blocked the internal furnace chamber. Thus, the uncontrolled ledge formation occurred in flash smelting furnace (FSF) in 2008 at the smelter (BCL), in 2012 at Nadezhdinsky plant (OAO Norilsk Nickel), in uptake of the Vanyukov furnaces (VF), in the area of tuyere water jackets (VF, Kazakhmys) [1, 2].

Deposition of fine particles from dust gas flow together with ledge formation in internal furnace chamber are mainly attributed to the pattern of gas flow. Variations of vector of inertia forces and flow rate of suspended particles are the factors responsible for ledge formation related with the peculiarities of furnace chamber design of metallurgical facilities [3].

Violation of channel flow of gas phase upon variation of route, eddy formation can be a priori revealed by numerical simulations which require for lower expenses and can be readily reproduced when compared with physical simulations or field studies.

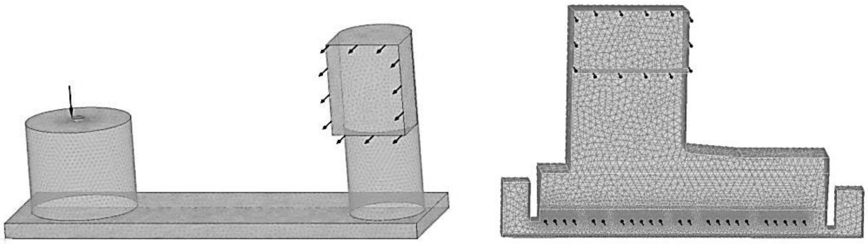
2. METHODS

Gas flow in furnace working chamber was determined using ANSYS CFX. The *k*-*ε* and SST turbulence models were used in the computation [4, 5, 6].

The following assumptions were made:

- process: adiabatic, isothermal, without internal heat sources and chemical transformations;
- computational grid area was not a strict copy of in-furnace gas path;
- gas consumptions were the same at inlet and outlet, no suction at the path.

Such formulation of the problem allowed to decrease computation time. Thus, the computation time at one PC (Windows 64 bit, 8 Gb RAM, 4 cores, processor speed: 3.3 GHz) was from several hours to several days under nonstationary conditions. The regions for determination of gas dynamics in some metallurgical furnaces are illustrated in Fig. 1.



a) b)

Figure 1 Computational grid area:
a) flash smelting furnace; b) VF

3. RESULTS AND DISCUSSION

Flash smelting furnace. Gas flows in flash smelting furnace are formed stage by stage. At first, jet flow from burner with formation of gas blend flows with the temperature corresponding to that of blast heating. Then, along the path of each jet, they are combined into one total flow which completely fills the chamber, is stabilized and moves in channel flow mode. Then, the gas flow rotates by 90°, varies its cross section according to the shape of underroof space, moves in horizontal underroof space above molten bath, again rotates by 90° entering into ascending gas duct, and enters into horizontal section which leads to recovery boilers. The velocity field of gas phase is illustrated in Fig. 2.

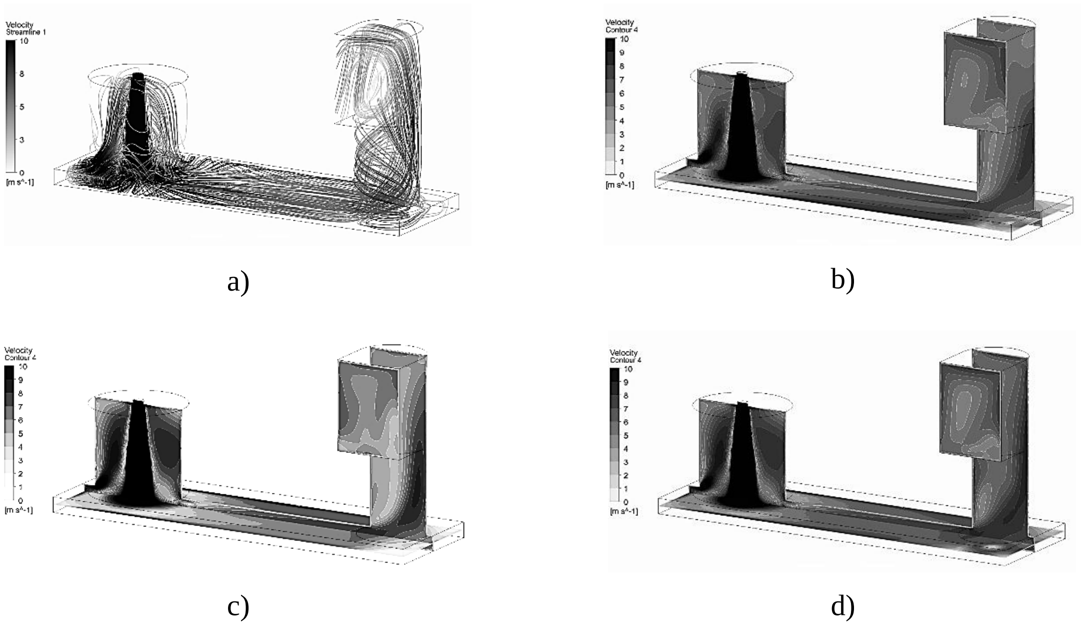


Figure 2 Gas dynamics of flash smelting furnace:

a) gas flow in fluid lines at t = 30 s;

b), c), d) flow rate distribution in time, at t = 10, 20, and 30 s, respectively

Formation of cyclone effect in gas phase due to asymmetric position of uptake is justified in terms of suppression of dust entrainment and subsequent decrease in load on gas collectors. However, the same eddy promotes deposition of particles under centrifugal forces and ledge formation in local area.

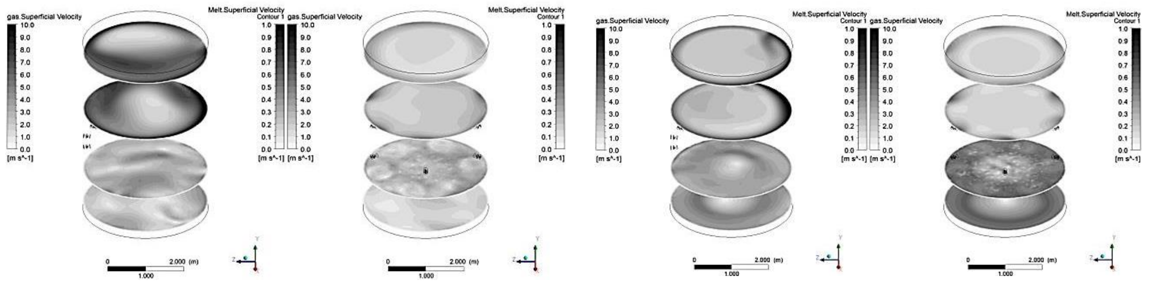
Computed flow of gas phase demonstrates variation of shape and position of eddy flow base in uptake positioned at about 20 m from the axis of gas blend burner, that is, far from heat generation area.

Therefore, sharp variation of velocity gradient in the eddy, lack of thermal energy, suction of cold air in uptake and its natural cooling will promote dust depositions.

More detailed computations with fine tuning were performed in the scope of investigations carried out by Gipronickel institute, Norilsk Nickel, and St Petersburg Polytechnic University [2]. Total pattern of gas dynamics corresponds to the data reported in these investigations.

Alternative jet rotation apparatus. Another pattern is observed in the jet rotation apparatus proposed by Shalygin [7], where spatially oriented blast supply forms regular controlled rotation of molten bulk. In this case the gas dynamics above the tuyere level obtain steady cyclone eddy located in the vicinity of heat generation sources above the bath surface. Due to such mass exchange there are no massive emissions and frothing of the melt even upon multifold increase in blast load [8, 9].

The mathematical simulation was confirmed by experiments at cold and working facilities [9, 10].



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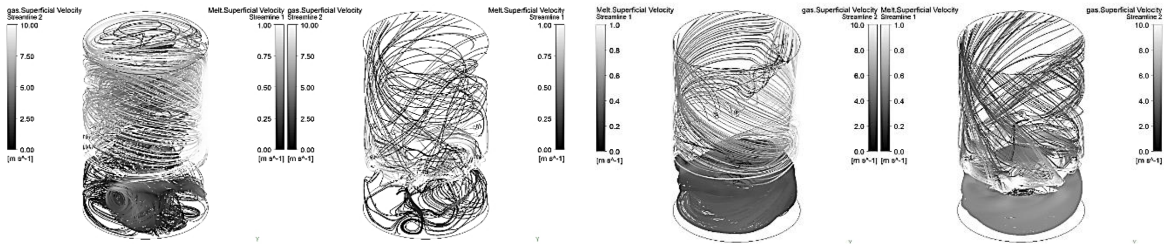
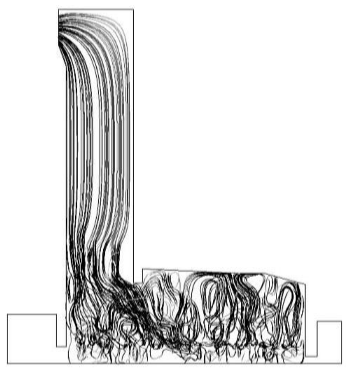


t = 10 s t = 90 s

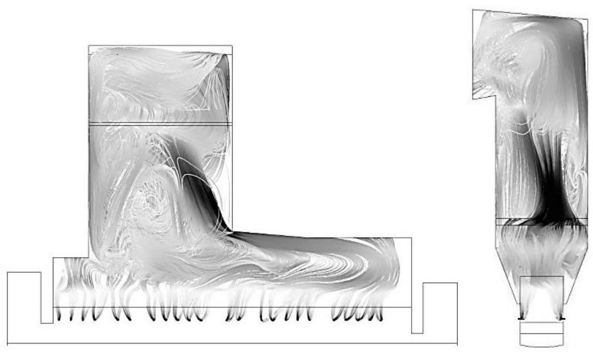
Figure 3 Spatially oriented blast supply, tuyere angle:
a) –120°, b) –360°

Figure 3 illustrates the results of mathematical simulation of two-phase fluid flow under the impact of kinetic energy of six spatially oriented blast jets with tuyeres positioned along 120° arc and uniformly along cylinder circumference. Steady pattern of cyclone gas flow is achieved only in 1.5 min.

Vanyukov furnace. Chamber design of the VF and its uptake corresponds to complex hydrodynamics. At first, there is bubble-like, close to vertical, gas burst from melt bulk followed then by combination of separate craters into cumulative gas flow, and, finally, there is movement of this flow together with dust along geometrically imperfect path. As a consequence, there are existence of stagnation areas in gas space, vortices, ledge formation in various places.



a)



b)

Figure 4 Snapshot of gas dynamics in VF:

a) Norilsk Nickel at t = 5 s; b) Kazakhmys at t = 15 s

Gas dynamics of smelting in liquid bath at Norilsk Nickel and Kazakhmys are illustrated in Fig. 4.

The VF profile is rather suitable for ledge formation in uptake, it is known as sand glass [2] (Fig. 4, a). At Balkhash copper smelter the ledge formed at the second level of water jackets is referred to as scum [11] (Fig. 4, b).

At present the VF design has no partition due to its abrasion with dust; in addition it increases the occurrence of sand glass.

It is obvious that replacement of rectangular cross section of furnace chamber and its uptake with the circular one would improve conditions of gas removal. Thus, in the case of smelting of copper concentrate after white matte separation, the VF has the shape of polygon close to circular cross section with the same outlet of smelting area to the furnace uptake; recommendations for the uptake modernization are given in [2].

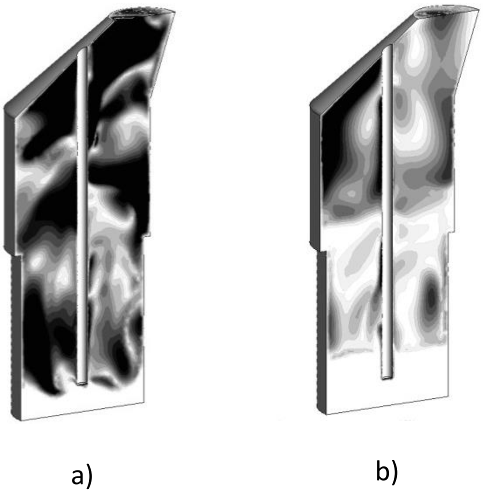


Figure 5 Snapshot of gas flow rate in Ausmelt furnace:
a) time – 7 s; b) time – 15 s

Ausmelt process**.** Working space of the Ausmelt furnace has cylindrical shape with smooth transition in dust scrubber; blasting is supplied by a tuyere submerged into the melt by 150–250 mm (Fig. 5). Dynamic head of gas jet is directed oppositely to the buoyant force displacing the gas phase from the melt. Here, as in the case of the VF, the conditions of bubble uplift are met, herewith, the boiling melt bath is characterized by massive erratic outbursts of slag matte emulsion, especially upon tuyere submersion. Such gas outburst from the melt adds vortex to gas flow in the furnace and outside. This requires for significant height of the furnace working space.

4. CONCLUSION

Application of advanced software makes it possible to obtain numerical solutions of the Navier-Stokes equations, to visualize the obtained data, and to recommend design modifications, for instance, to suppress gas entrainment and ledge formation, to decrease head loss, etc.

Formation of cyclone effect in gas phase of flash smelting furnace due to asymmetric position of uptake is justified in terms of suppression of dust entrainment, though, it will promote ledge formation.

Replacement of rectangular elements of the VF with circular cross section or, for instance, central position of uptake, will lead to more uniform channel flow of gas phase.

The Ausmelt furnace is characterized by bulk erratic splashes of slag matte emulsion. Gas breakthrough from the melt activates eddy motion in furnace. This requires for significant height of working space and capital expenses.

The results of numerical simulation of the alternative jet rotation apparatus are presented, which allows to increase significantly specific blasting load and to form channel flow of gas phase promoting decrease in dust entrainment and in load on gas collectors.

Establishment of regular cyclone flow of gas phase is possible in the initial time after start of melt blowing. Rotation of molten bulk reaches stationary mode during the same time at average rate of 0.6–0.8 m/s.

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