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SIMULATION OF AERODYNAMIC FLOWS OF GAS WITHDRAWAL FROM COKE BATTERIES

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coke, coke batteries, simulation, aerodynamics, chimney shafts, calculating hydrodynamics, emissions in the atmosphere

ABSTRACT

The modern level of the development of computer engineering and software allows to simulate the processes with different degree of complication and to solve the problems connected with aerodynamic features of turbulent flows of withdrawn gases both in entrance and exit of coke batteries. The paper presents the results of aerodynamic simulation of gas medium using Ansys program in order to determine the temperature field above the surface of coke battery chimney shaft, as well as the results of registration of speed of withdrawn gases for adjusting the flame level. Realization of operation of continuous monitoring systems directly on chimney shaft makes it possible to control thermal state of a coke battery in general and provides lowering of harmful emissions in the atmosphere.

Solving the ecological problems in the coke-chemical production is one of the main priority tasks for the modern level of technical development. Chimney shafts of coke batteries are the main source of industrial emissions in the atmosphere [1-3]. It is impossible to provide their efficient operation with minimization of harmful effect on the environment and surrounding territories without usage of advanced monitoring remedies, allowing to estimate character and volume of the main emissions withdrawn in the atmosphere with a flow of exhaust gases [4–6]. Realization of continuous monitoring systems with their mounting directly on chimney shafts is considered as one of the possible variants for forming instrumental measurements of harmful emissions in the atmosphere [7, 8]. Correct choice of location places for measuring sensors providing completeness and presentability of a registered parameter or value is the decisive condition of stable operation and receiving of trustworthy information from this monitoring system. Thereby, it is necessary to have information about features of variation of gas flows, both in the body of a coke battery chimney shaft itself and in its exit, in order to ensure rational mounting of the system of control and monitoring of exhaust gases [9].

It seems impossible to register practically and to determine the temperature field in the top part of a chimney shaft, as well as to determine experimentally temperature fields, speeds of flows and distribution of substances in a dynamically varying volume. Thereby, the calculated computer-aided simulation is the only method for examination of aerodynamics.

This article includes description of conducted aerodynamic simulation using Ansys software complex in order to determine the temperature field above the surface of a chimney shaft.

The simulation algorithm consists on the three consequent stages:

1. creation of 3D-model of a gas duct where exhaust gases of preset composition are moving; its geometrical dimensions should correspond to the calculated data;

2. building of the calculating net for solving of Navier-Stokes differential equation and heat conducting equation;

3. choosing and setting the initial and boundary conditions, development of operating algorithm, 3D-solving of differential equations.

Differential equations describing motions of exhaust gases out of chimney shafts are composed along three directions and describe aerodynamic parameters of moving flow [10, 11].

$$\frac{du}{d\tau}=-u\left(\frac{\partial u}{\partial x}+\frac{\partial u}{dy}+\frac{\partial u}{\partial z}\right)+$$
$$+v\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{dy^2}+\frac{\partial^2 u}{\partial z^2}\right)-$$
$$-\frac{1}{p}\left(\frac{\partial p}{\partial x}+\frac{\partial p}{dy}+\frac{\partial p}{\partial z}\right), \quad (1)$$

where u – projections of vector of moving flow speed on coordinates axes, m/s; c – density of moving fuming gases, kg/m[3;] p – fluid pressure, Pa; $н$ – toughness of moving medium, kg/(m·s); $ф$ – variation of time, occurring during medium moving, s;

Heat conducting equation (2) describes thermal processes, occurring in gas mixture.

$$\frac{\partial t}{\partial\tau}=\frac{\lambda}{C\rho}\left(\frac{\partial^2 t}{\partial x^2}+\frac{\partial^2 t}{dy^2}+\frac{\partial^2 t}{\partial z^2}\right)+\frac{q_v}{C\rho}, \quad (2)$$

t – system temperature, K; τ – variation of time, occurring during medium heating, s; λ – heat conducting coefficient of lining material, W/(m·K); c – density of lining material, kg/m³; C – thermal capacity of lining material, J/(kg·K); $\frac{q_v}{C\rho}$ – coefficient accounting internal sources of thermal energy.

Fig. 1 presents 3D-model being the axial symmetric tube part together with air space above the tube; it has been created in the subprogram Ansys DesignModeler,.

Generation of the multi-area calculating net is conducted using Ansys Meshing subprogram. Net building is realized with account of near-wall gas dynamics in the chimney shaft hole and special features of air flows motion in the cap area. Afterwards initial and boundary conditions as well as parameters of emission process of fuming gases out of chimney in the atmosphere are set in the Ansys Fluent program.

Climatic parameters of the atmosphere should be considered for the most hot day in the year, when maximal elevation of a cloud consisting of fuming gases takes place and maximal amount of atmosphere air is required for cooling of these gases [12]. The free-air temperature 37 °C and wind speed 2 m/s will correspond to these conditions.

The air located near ground surface is heating and rising up, owing to decrease of its density, while more cold and dense air is lowering down. If the heated air is adiabatically expanding during elevation (without heat exchange with surrounding air masses), then its temperature is lowering approximately by 1 °C per each 100 m of height. This value is accepted as the adiabatic temperature gradient. If the temperature gradient is vertical and equal to adiabatic one (or a little smaller), then air volume that is rising up will be characterized by the same properties at each level that surrounding air masses have, thereby it won't have additional acceleration. Such state of the atmosphere is named neutral and it is accepted as initial conditions for simulation.

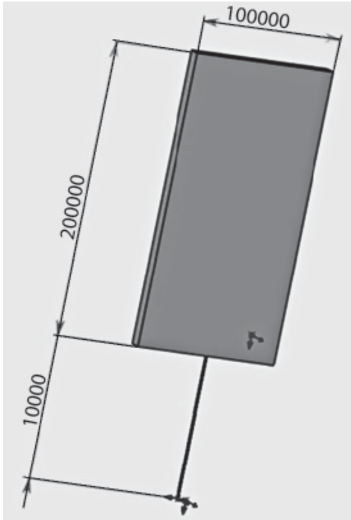

Fig. 1. 3D-model of the tube and atmosphere section (mm)

The results of simulation are presented on the **fig. 2** and **fig. 3**.

After coke batteries, gases are entering a gas duct section with the temperature 460 °C, the length of this section makes 15 m. Adulteration of atmosphere air occurs in this point, thereby gradual cooling of technological gases down to 190 °C takes place. Distribution of exhaust gases in the atmosphere above the chimney shaft occurs more than by 150 m from the chimney arch, without the effect of any essential aerodynamic oscillations in the atmosphere. At the same time the temperature of fuming gases in the chimney shaft exit constitutes 180 °C what corresponds to

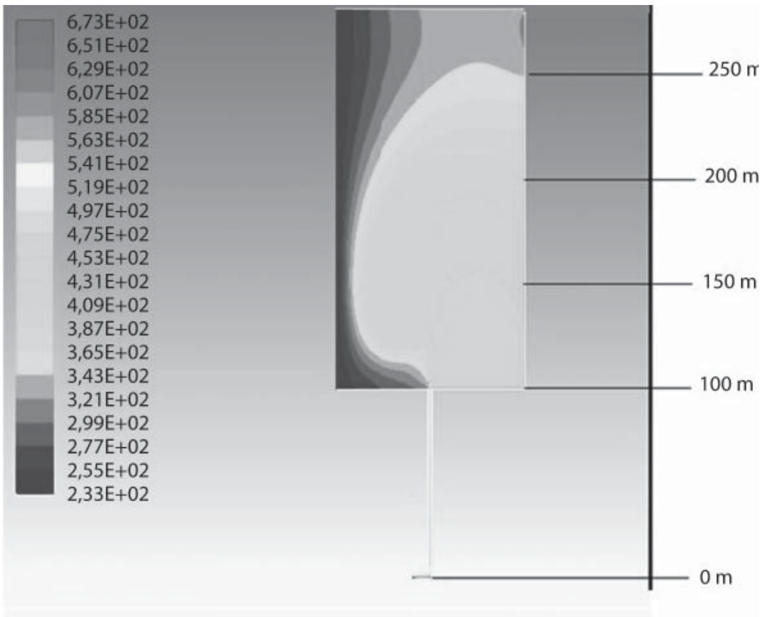

Fig. 2. Temperature contour of the chimney shaft and atmosphere

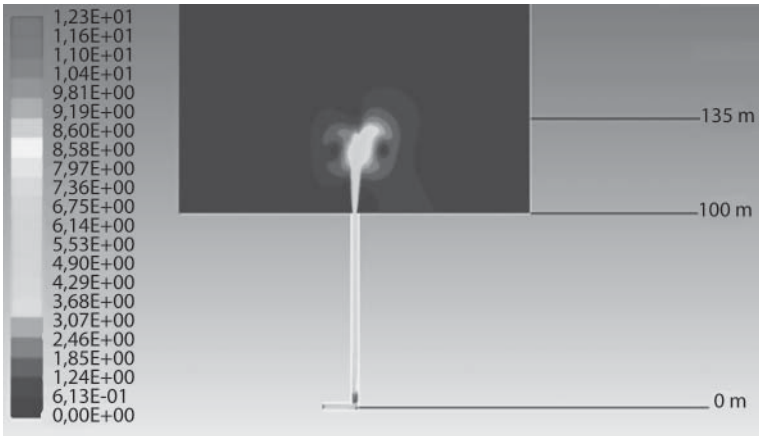

Fig. 3. Speed contour above the surface of chimney shaft

the temperature conditions of exhaust gases [13, 14]. The temperature contour (see fig. 2) has a flame-shaped form with shift to the side of air masses motion. As soon as air masses distribute in the atmosphere at the preset climatic conditions, rather uniform lowering of the temperature and cooling of a gas flow down to 60 °C occurs at the height 250 m above the ground level. It should be mentioned here that the features of air masses motion at these height values retards essentially and practically the temperature gradient of a gas flow will be more harsh.

Speed of exhaust gases makes 6.53 m/s. Rising height of a flame of exhaust gases makes 35 m from chimney arch and respectively 135 m from its zero level.

In this case, at neutral state of the atmosphere, mixing intensity decreases and so-called cone-shaped jet is observed (see fig. 3). Distance to the maximal value of a ground level concentration is larger in this case, than the same value at unstable conditions, while maximal concentration of impurities in fuming gases is lower. It is shown that fan jet with small angle of flame opening in vertical plane is forming in the conditions of atmosphere stratification. It is concluded that a tortuous trajectory of impurity motion in horizontal direction is typical for such jet at weak vertical and transversal of its dispersion due to variability of wind direction.

Impurity dispersion in the conditions of different classes of atmosphere stability has its own featured [1] forming the typical appearance of a chimney jet. E.g. wave-shaped jet, presenting combination of smoke clouds transferring by large vertical vortexes, can be observed at clear and warm weather, but in unstable conditions [15, 16]. As soon as mixing intensity will be large in this case, gas smoke clouds will reach the ground and ground level concentration of impurities will have a distinct maximum located not far from the source.

Sustainable stratification can’t be consider as unfavourable meaning contamination of a ground level air layer for emissions out of high chimney shafts connected to large production capacities. In this case flame usually rises rather high and maximal value of ground level concentrations is located relatively far from the source. Ground level concentrations of impurities are lower than in the conditions of unstable and indifferent stratifications. It is important to mention that weak turbulent exchange during flame motion finalizes in transfer of impurities for long distances (sometimes for hundreds of kilometers), without reaching ground surface. At the same time different transformation processes of harmful impurities take place, as well as their interaction with precipitations; finally it leads to undesirable consequences (so-called acidic rains, effects of NO_2 large concentrations) [17].

Concentration of harmful impurities is determined via solving the equations of turbulent diffusion (1), applying for any state of the atmosphere. When solving the formulated problem, determination of the coefficients of turbulent diffusion and wind speed will be very important.

The obtained results of mathematical simulation can be used for development of practical recommendations for organization of reliable continuous instrumental control and monitoring of harmful emissions of coke batteries in the atmosphere.

5. Conclusions

In solving the problem of simulation of flow motion of exhaust gases for the cases close to the real conditions of distribution of harmful emissions, it is possible to obtain the expression for determination of maximal one-time ground level concentration or a chimney shaft height that is necessary to provide the chosen ground level concentration of harmful impurities.

The conducted simulation has been realized in Ansys software medium and it allows to represent different aerodynamic states of the atmosphere and motion of fuming gases during choosing of the real boundary conditions. It will simplify substantially designing of chimney shaft construction aimed on lowering of harmful emissions in the atmosphere and ground level area.

The results of investigation are directed mainly on examination of distribution of harmful substances out of high chimney shafts of coke batteries; the most part of exhaust gases and coal dust enters the atmosphere through these chimneys.

The features of aerodynamic flows in the chimney shaft exit of coke batteries are revealed; they adjust mixing processes of exhaust gases and atmosphere with simultaneous equalizing of their axial speeds. Realization of continuous monitoring systems allows to control the thermal state of a coke battery in general and provides to decrease harmful emissions in the atmosphere.

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SYSTEM IMPROVEMENT OF VANADIUM HOT METAL PROCESS AT EVRAZ NTMK

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ABSTRACT

Evraz NTMK boosted the rate of its blast furnace process and cut down the coke rate critically over the last decade. This progress was based on the improved design of NTMK blast furnaces themselves, as well as improved process conditions, V staflux practice introduced in the process, higher oxygen in the blast air and use of PCI. The blast furnaces after some upgrades gave a chance to improve certain process parameters of the blast furnace process that uses titanomagnetites. In particular, lower Si in the hot metal at the same temperature level of the hot metal as before was made possible thanks to the pressure of gases boosted inside the furnace. For improvement of burden conditions, it is related to developments of the practice for production and application of V staflux, which took raw materials out of the burden, reduced the number of components and fixed the problem of FeV waste disposal. The staflux implemented in the smelting process improved the venting quality of melting stock column and reduced specific gas output, which created a precondition for intensification and power saving activities without having to worry about any failures in the operation of the blast furnaces to be run smooth. Which is why higher oxygen in the blast air (at least 30%) plus PCI were the next logical steps taken to improve the ironmaking practice.

The higher rate of the smelting process made it possible to shut down the other blast furnaces, which were obsolete and deteriorated, without any critical output loss. At the moment, the blast furnaces of Evraz NTMK show the best performance and cost-efficiency not only in Russia, but also throughout the world.

Using titanomagnetites in the V hot metal process has a few specific features. The final target of titanomagnetite process is to recover vanadium together with iron reduction. If done right, the blast furnace process is to fully transfers vanadium to the hot metal at the minimum loss of vanadium compared to other products of the smelting process.

Vanadium is a hard-reducing element and the key condition for its maximum transition to the hot metal is the higher process temperature. The accepted truth [1] is that the key complications of titanomagnetite process are related to high-melting-point Ti compounds (carbonitrides) generated as an individual phase between the slag layer and hot metal layer, whereas higher heating rate contributes to titanium dioxide recovery and titanium carbide generation in the hearth [2]. This is the principal inconsistency of this process and it makes the relationship of temperature level and vanadium recovery much more complicated. The process conditions are set in the trade-off manner and is determined by vanadium recovery on one side, and the titanium recovery rate on the other side so that to keep an opportunity to run the blast furnace at its normal performance. As the ironmaking process runs with surplus carbon the blast furnace should be operated at the high rate and as cold as possible to prevent over-reduction of titanium. All the values that help the furnace to run smooth at high rate are critical in this case.