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THE STRUCTURE OF STREAM AND TEMPERATURE DISTRIBUTION IN THE REACTION SHAFT OF THE FLASH SMELTING FURNACE – COMPUTER SIMULATION

STRUKTURA TOKA I TEMPERATURSKA RASPODELA U REAKCIONOJ KOMORI PLAMENE TOPIONIČKE PEĆI – RAČUNARSKA SIMULACIJA

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- computer simulation
- temperature field
- velocity field

Abstract

Irregularity of the rate field during the formation of streams in the reaction shaft of the flash smelting furnace is not enough investigated because of the influence of recirculation volumes. The uniform method of approach is not established for assessing their influence. These difficulties are raised from the lack of adequate and detailed description of physical-chemical, heat and kinetic processes running in the high temperature heterogeneous flame and short timescale of the particles with autonomic behaviour in the examined medium.

In this paper, the results from the simulation of the combustion process with the aid of ANSYS CFX are presented enabling visualization of the velocity and temperature fields in the reaction volume of the Outokumpu furnace.

Ključne reči
- plamena topionička peć
- računarska simulacija
- temperatursko polje
- brzinsko polje

Izvod

Nepravilnosti u brzinskom polju pri formiranju tokova u reakcionoj komori plamene topioničke peći nije dovoljno istraženo zbog uticaja recirkulacionih zapremina. Nije utvrđena objedinjena metoda pristupa za procenu njihovog uticaja. Ove poteškoće nastaju usled nedostatka adekvatnog i detaljnog opisa fiziko-hemijskih, toplotnih i kinetičkih procesa koji se odvijaju unutar visokotemperaturskog heterogenog plamena i kratkotrajnih čestica sa spontanim ponašanjem u razmatranom medijumu.

U ovom radu su predstavljeni rezultati simulacije procesa sagorevanja pomoću ANSYS CFX, preko kojih je data vizuelizacija brzinskog i temperaturskog polja u reakcionoj komori peći Outokumpu.

INTRODUCTION

Modelling of industrial fuel systems and furnaces requires the inclusion of a number of common occurrences based on the analogy of the impulse, mass and heat transfer as well as the major laws for conservation of energy and matter. The gas phase is very sensitive toward the exact modelling since it can spin. On the other hand the modelling of multicomponent turbulent fluid, including the reacting in between particles, complicates the problem since the particles carry their own impulse, so their movement should be regarded separately from the gas phase. The time of stay of these particles in the reaction volume depends on their movement in the furnace as well as from the chemical interaction consisting the change of their mass (volume), which determines the technology in total.

The specifics of the torch fusion are due to the fact that some particles reach full combustion while other remain unreacted. Because of this specificity, it is difficult from the mathematical point of view to apply the laws of chemical kinetics for describing the fusion process.

For the performed modelling investigations and computer simulations, /1-6/, the main conclusion is made concerning the fact that the sulphide charging particles along the flame periphery possess a higher possibility to react with the gas phase than these particles in the centre of the stream, since in this area they are heated faster in the presence of oxygen with higher concentration. This fact is confirmed by analogical investigations during the combustion of coal dust, /7/.. It is also proved that this occurrence is due to the presence of temperature and concentration gradients in the fluids, which confirms the hypothesis for the presence of intensive recirculation of the fluid in the examined areas. The way of scattering and the massiveness of the charging particles are basic for modelling the flame in the flash smelting furnace. Similar computer simulations for investigating the work of charging burners are presented in /8-11/. These authors have established the presence of recirculation volumes only beneath the space of the burner and the reaction volume of real aggregates in performed simulations are not included. The obtained temperature profiles, the transfer of momentum and velocity in the charging burners resembles to the data presented in technical literature, /2, 12-16/, and can be accepted as a basis for further investigations.

SIMULATION PROCEDURE

The combustion process of sulphide charge in the reaction shaft of a flash smelting furnace is simulated. Complete computer simulation of similar multicomponent medium requires a large capacity of computer hardware. The mathematical description and numerical decision of such medium require varied information. Ansys–CFX is a medium in which at the given initial conditions there is a possibility the fluid to be considered as a self-random. Considering the fact that the charging-air stream can be obtained after the preliminary mixing in the charging burners and this fluid is insufflated into the working volume at a temperature equal to this of the environment, it follows that the fluid at the entrance of the reactor possesses constant density. Besides, as based on data in literature, the fluid can be accepted as incompressible, /17/, where its average velocity is below 100 m/s.

In the performed simulation the following is accepted:

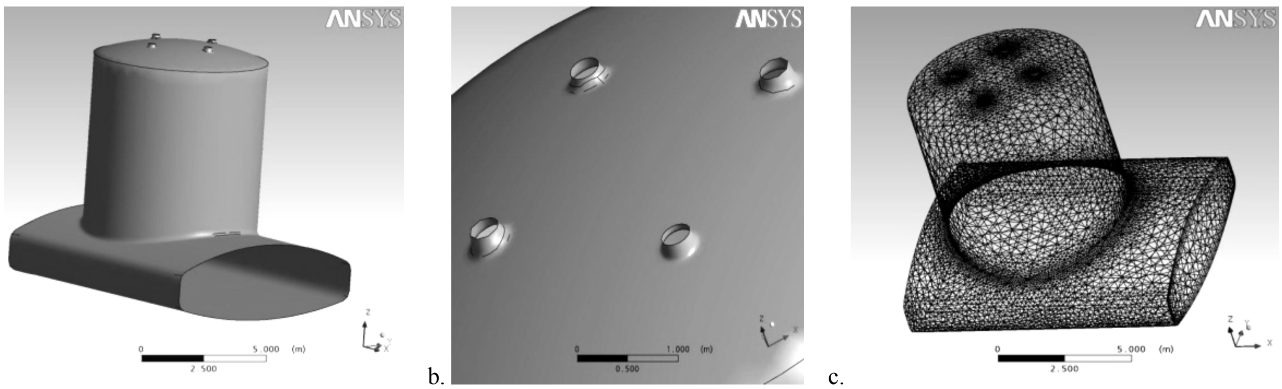
- Combustion of the sulphide charge by reaction:

$$2CuFeS_2 + 4O_2 + SiO_2 = Cu_2S + Fe_2SiO_4 + 3SO_2$$

  with thermodynamical parameters determined from the programme HSC Chemistry 4.0;
- Four burners form the flame;
- Hard particles are uniformly distributed in the fluid and possess a spherical shape and massiveness 100 μm;
- Mass transfer during the interaction between the particle and the wall of the reactor, as well as during the collision between particles, is neglected;
- The radiation heat transfer based on properties of components participating in the process is calculated and is given by particular coefficients of absorption, emission, anisotropy distribution and turbulence that are included in the packet P1 standard radiation model;
- Literature data used in order to determine the activation energy and the pre-exponential factor in the kinetic equation of Arrhenius;
- The standard k-ε turbulent model and Eddy Dissipation combustion model are chosen.

The geometric model of the investigated furnace is presented in Fig. 1a and the location of nozzles of the burners is in Fig. 1b. The elements mesh is presented in Fig. 1c.

Because of the complexity of heat-transfer in the investigated volume and the specific features of the brickwork and cooling elements, the heat transfer from the fluid through the furnace walls is not investigated. They are accepted as adiabatic limits.



a. b. c.

Figure 1. Geometric model: a) corpus; b) situation of the initial sections of the burners; c) elemental mesh.
Slika 1. Geometrijski model: a) telo; b) detalji u početnim presecima gorionika; c) mreža elemenata.

RESULTS – ANALYSIS AND DISCUSSION

Results form the simulation of the velocity field at the outlet of the burners

The velocity distribution in the investigated volume at the outlet of the charge burners is presented in Fig. 2b. The illustration of the spinning of the fluid at the outlet of the burners in the under burner space of the reaction shaft is presented in Fig. 2a-b. The analysis of these figures shows that immediately under the burner space of the reaction shaft, four powerful spinning zones are formed which occupy the whole model volume. The velocity in these zones is lower than the main velocity.

The recirculation zone, relatively of large size is formed around the axis of symmetry of the shaft, close to the burner. The change of form of the fluid results from the effect of the vault arch geometry of the shaft. On the other hand, the model walls are accepted as absolutely smooth. Because of these reasons, the intensity of re-circulation in the investigated areas is major.

After the insufflation in the reaction volume, the movement of the part of the fluid is directed through the model walls as in the centre of the shaft four conical main streams are formed, where the fluid recirculates along their periphery.

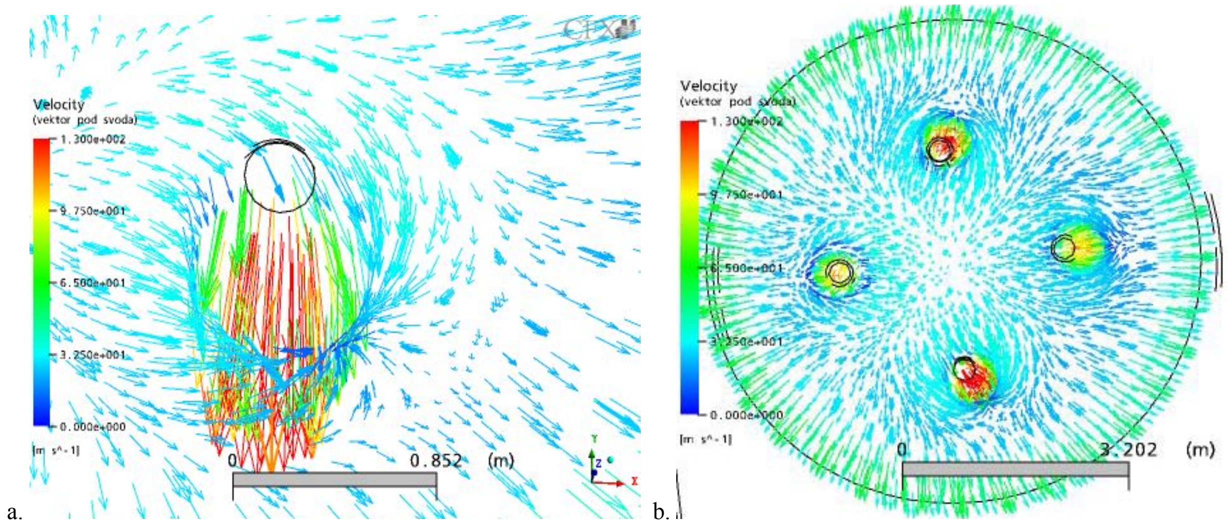


Figure 2. Spinning of the fluid at the outlet of the burners in the under vault arch space of the reaction shaft.
Slika 2. Vrtloženje fluida na izlazu iz gorionika u prostoru ispod lučnog svoda reakcione komore.

Results from the simulation of the velocity and temperature filed in axial direction

Figure 3a shows an illustration of the velocity field in the reaction shaft of the investigated aggregate in the axial direction along the axis *xz*. Figure 3b represents an illustration of the velocity field in the reaction shaft of the investigated aggregate in the axial direction along axis *yz*, respectively, for streams formed by two charging burners. Figure 4 represents an illustration of the temperature field in the reaction shaft. The illustrations show that there are recirculating volumes with high intensity in the areas between formed streams, between streams and neighbouring model walls. Along the direction *yz* a very strong recirculation around the outgoing outlet of the model is observed. That is the area from the real furnace where the gas phase leaves the zone of the technological process. Strong and pronounced recirculation, around neighbouring edges in the lower part of the model are observed. Aerodynamic analysis of shape changing and mixing of streams during their interaction gives the reason for the fluid to be divided into three areas:

- Initial area – situated between the initial section of the charge burners and the distance where the four streams occur. This area is situated on a relatively small distance from the model vault arch, since free circulating volumes in this area possess high intensity.
- Transitional area – in this area the shape change of the streams started as a result of the acted strengths of deformation caused by the contact between the streams and the influence of the recirculation. This is the largest area in size.
- Main area – in this area one common stream is formed. This area is the weakest pronounced during the simulation procedure because of the strong recirculation in the lower part of the reactor. Actually, this is one of the main problems during the operation of the furnace since the length and width of the flame is determined by the spinning. While the deformation during the fusion of the stream is becomes larger, the length of the flame becomes smaller. This is due from the effect of recirculating volumes.

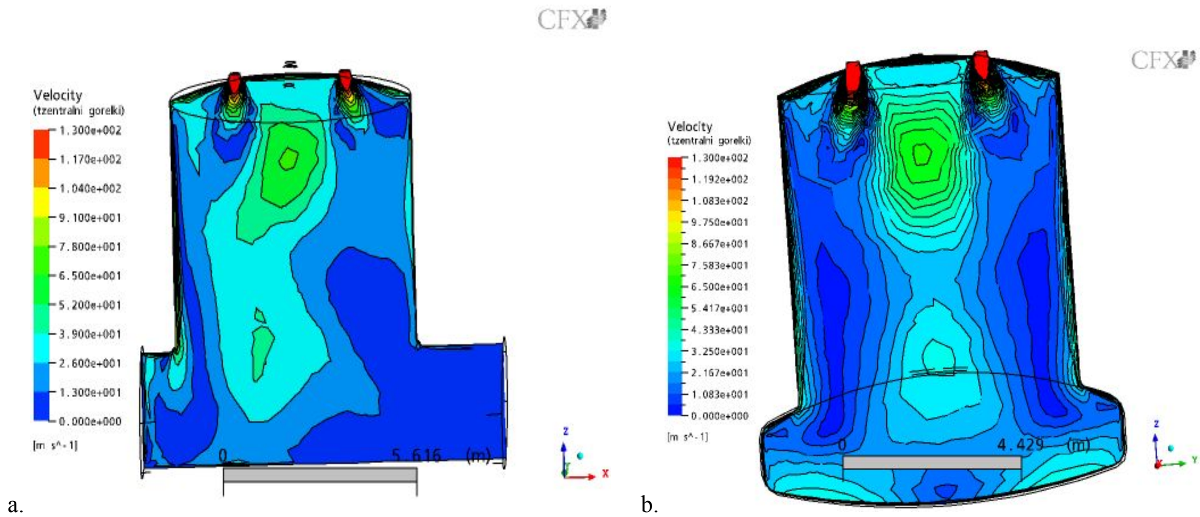


Figure 3. Visualization of the velocity field formed by two oppositely situated burners in an axial direction.
Slika 3. Vizuelizacija brzinskog polja koji formiraju dva suprotno postavljena gorionika u aksijalnom pravcu.

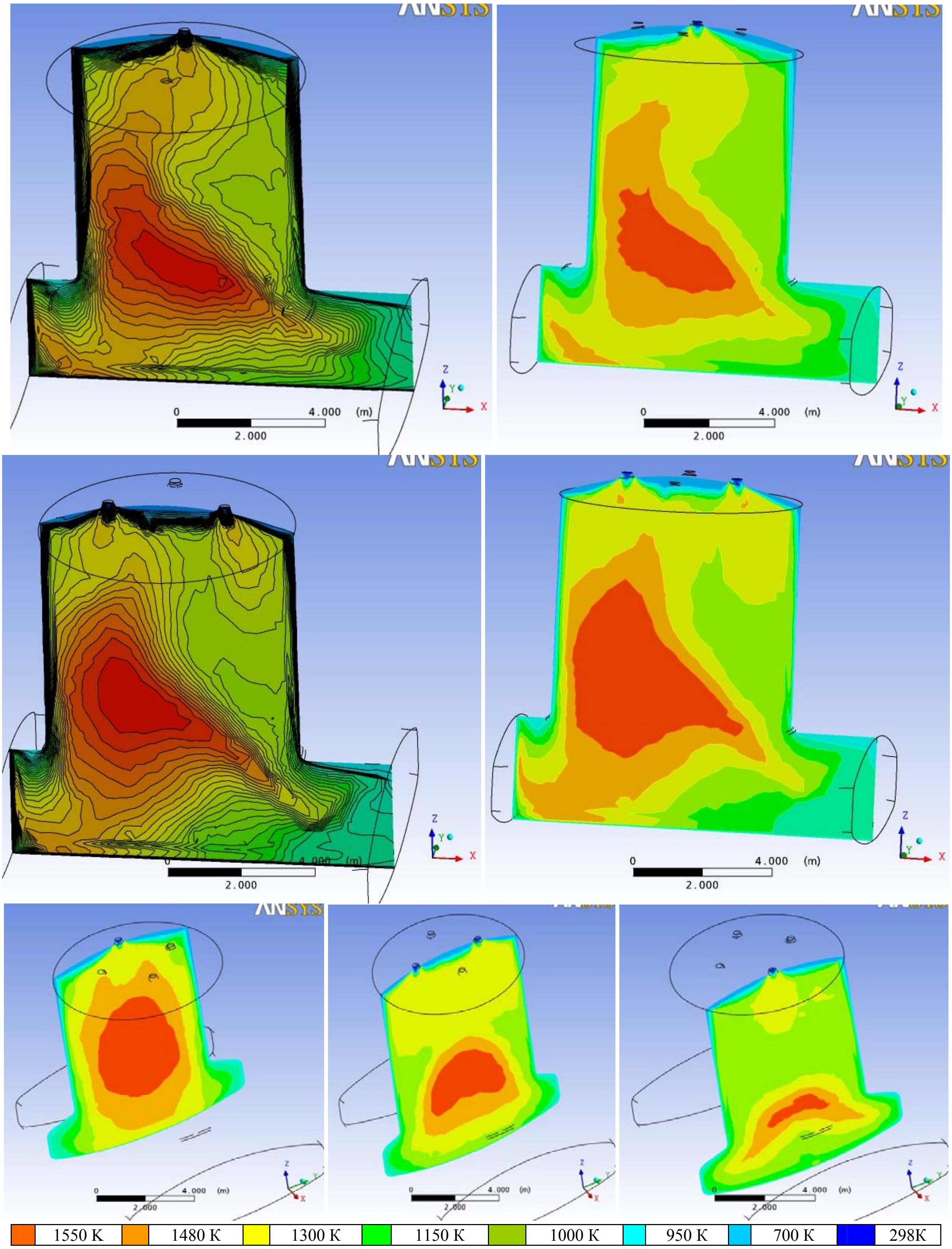


Figure 4. Visualization of the temperature field.
Slika 4. Vizuelizacija temperaturskog polja.

CONCLUSION

The achieved resemblance corresponds to the dependences, that are characterised by the movement of streams with high turbulence as described in the technical literature. The following occurrences that influence the structure of the flame are observed:

- Strong pronounced mixing in areas between neighbouring and opposite streams, mainly due to the recirculation zone located along the axis of the shaft.
- Mixing between the fluid arising from the main stream and the vicinity of the medium for the stream in the presence of large recirculation.

During the performed investigation it is established that the practical chemical reaction is carried out almost immediately at insufflation of the mixture in the reactor. It can be accepted that the self-arbitrary ignition of the mixture is reached as a result of the action of intensive re-circulated masses possessing temperature that is higher than the fluid temperature.

The presence of strong pronounced recirculation of the stream in areas around the settler zone of the model is a result of the geometric features of the investigated aggregate. Influences of recirculation in the obtained illustrations follow that on the melt phase. It can be concluded that the recirculation in these areas affects its components.

It is proved that in the central part of the reactor, the recirculation zone is formed in a large volume.

It is established that the heating zone of the fluid beneath the vault arch of the reactor in practice does not exist.

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