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MODELLING OF STIRRING LIQUID BATH BY GASEOUS PHASE IN REAL CONVERTER WITH BOTTOM BLOWING

MODELOVÁNÍ PROMÍCHÁVÁNÍ TEKUTÉ LÁZNĚ PLYNNOU FÁZI V PROVOZNÍM KONVERTORU SE SPODNÍM DMÝCHÁNÍM

Abstrakt

Tato studie popisuje numerické řešení dvoufázového proudění v kyslíkovém konvertoru s tekutou oceli pomoci software Fluent 6.1.18. Model konvertoru obsahuje tekutou ocel a argon je vstřikován skrz trysky, které jsou umístěné ve dně nádoby. K řešení byl použit dvoufázový Euler-Euler model. Změna hybnosti zahrnuje vliv odporových, vztlakových a turbulentních sil. Závěry numerického řešení jsou vyhodnocený pomocí složek vektorů rychlosti v příčném a podélném řezu.

Abstract

The present paper deals with a numerical solution of two-phase flow in a oxygen converter with liquid steel by software Fluent 6.1.18. The model of converter contains liquid steel and argon which is injected through jets. Jets are situated in the converter bottom. Two-phase Euler-Euler model was used for solution. Influence of drag, lift and turbulence forces was included in change of momentum. The components of velocity vectors are evaluating in axial and radial direction.

1 Introduction

A few kinds of reactors exist in metallurgical industry for make of steel in oxygen converters and for post-final repair. Different types of reactors are characterized especially by construction of supply systems and by using gaseous media General fact is that gaseous phase (oxygen, inert gases) with liquid phase (molten iron) are influenced each other. Gaseous phase can be injected through the bottom of reactor (Fig. 1.1) or by supply tube on the surface liquid phase (Fig. 1.2) or sometimes gas can be injected also through side wall of reactor. The flow in oxygen converter with bottom blowing is characterized as multiphase flow. Multiphase model of converter present bubble through of gaseous phase (oxygen or inert gases) in liquid phase (molten iron) [5], [6].

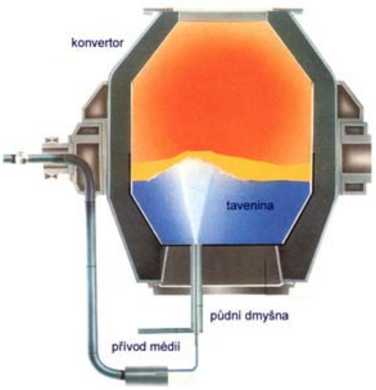

Fig. 1.1 – Oxygen converter with bottom blowing

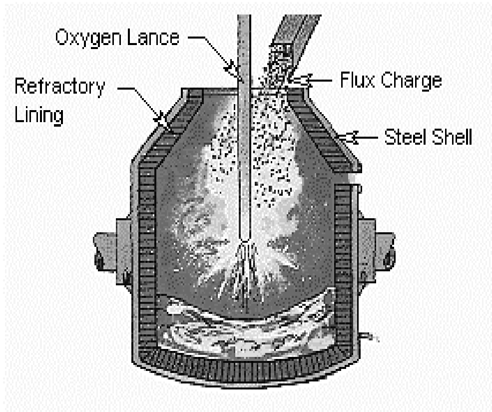

Fig. 1.2 – Oxygen converter with blowing on the surface

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The basic is created correspond mathematical model for good simulation of flow or another phenomenon. It means such model, which affect all basic phenomenon and factors (temperature, viscosity, pressure, turbulence). Some factors we can ignored because factors complication of stability and convergation of solution. Then the model is simplified and particular accuracy is kept. On the second side another factors have to be ignored from reason of software Fluent version 6.1.18 (we can not consider flow of species and definition of chemical reactions). The important factor which is observed in oxygen converter is intensity of stirring liquid iron. Result is effectively burn of carbon and homogenization of liquid bath. Restriction of chemical reactions is acceptable because intensively stirring is also information for effectively burn of carbon. Factor which can be ignored is that isothermal flow is considered (values of physical properties correspond to temperature of liquid steel – 1630°C. Heat transfer is ignored because liquid steel has constant temperature during time of melt.

2 Characterization multiphase Eulerian model

The Eulerian multiphase model [7], [8] in Fluent allows for the modeling of multiple separate, yet interacting phases. The phases can be liquids, gases, or solids in nearly any combination. An Eulerian treatment s used for each phase, in contrast to the Eulerian-Lagrangian treatment that is used for the discrete phase model. For bubbly, droplet and particle-laden flows in which the phases mix and/or dispersed-phase volume fractions exceed 10% use Eulerian model. To change from a single-phase model, where a single set of conservation equations for momentum, continuity and (optionally) energy is solved, to a multiphase model, additional sets of conservation equations must be introduced. In the process of introducing additional sets of conservation equations, the original set must also be modified. The modifications involve, among other things, the introduction of the volume fractions $\alpha_1, \alpha_2, ...\alpha_n$ for the multiple phases, as well as mechanisms for the exchange of momentum, heat, and mass between the phases. Volume fractions represent the space occupied by each phase, and the laws of conservation of mass and momentum are satisfied by each phase individually.

Fluent 6.1.18 solves system of following differential equations for time steady and isothermal flow:

The volume of phase q, V_q is defined by

$$V_q = \int_V \alpha_q dV \tag{1}$$

where

$$\sum_{q=1}^{N} \alpha_q = 1 \tag{2}$$

The effective density of phase q is

$$\rho = \alpha_q \rho_q \tag{3}$$

where ρ_q is the physical density of phase q.

The continuity equation for phase q is

$$\frac{\partial}{\partial t}\left(\alpha_q \rho_q\right) + \nabla \cdot \left(\alpha_q \rho_q \vec{v}_q\right) = 0 \tag{4}$$

where $\vec{v}_q$ is the velocity of phase q.

The momentum balance for phase q is

$$\frac{\partial}{\partial t}\left(\alpha_q \rho_q \vec{v}_q\right) + \nabla \cdot \left(\alpha_q \rho_q \vec{v}_q \vec{v}_q\right) = -\alpha_q \nabla p + \nabla \cdot \overline{\overline{\tau}}_q + \alpha_q \rho_q \vec{g} + \sum_{p=1}^{n} \vec{R}_{pq} + \alpha_q \rho_q \vec{F}_{lift,q} \tag{5}$$

where $\overline{\overline{\tau}}_q$ is stress-strain tensor.

The important term is the third from the right-hand side in the equation (5). It is an interaction force between phases which cause the transfer of momentum between relatively moving phases. The drag force is calculated between phases p a q as follows:

$$\sum_{p=1}^{n} \vec{R}_{pq} = \sum_{p=1}^{n} K_{pq}\left(\vec{v}_p - \vec{v}_q\right) \tag{6}$$

where K_{pq} ($= K_{qp}$) is the interphase momentum exchange coefficient between phases.

The exchange coefficient for gas-liquid mixture can bee written in the following general form: $K_{pq} = \dfrac{\alpha_q \alpha_p \rho_p f}{\tau_p}$ where f, the drag function is defined differently for the different exchange coefficient model and τ_p, the particulate relaxation time is defined as $\tau_p = \dfrac{\rho_p d_p^2}{18\mu_q}$ where d_p is the diameter of the bubbles of phase p. The drag function f includes a drag coefficient C_D that is based on the relative Reynolds number Re.

The drag function f is defined as:

$$f = \frac{C_D \,\mathrm{Re}}{24} \tag{7}$$

where $C_D = 24(1 + 0.15\mathrm{Re}^{0.687})/\mathrm{Re}$ for $\mathrm{Re} \le 1000$ $\quad C_D =$ $\quad$ for $\mathrm{Re}\rangle 1000$, Re is relative Reynolds number. The relative Reynolds number for the primary phase q and secondary phase p is obtained from the expression

$$\mathrm{Re} \quad \frac{\rho_q \left|\vec{v}_p \quad \vec{v}_q\right| d_p}{\mu_q} \tag{8}$$

The final drag force is calculated as follows

$$\sum_{p=1}^{n} \vec{R}_{pq} = \sum_{p=1}^{n} \frac{3C_D}{4d_b} \alpha_q \alpha_p \rho_q \left|\vec{v}_p - \vec{v}_q\right| \left(\vec{v}_p - \vec{v}_q\right) \tag{9}$$

Then the lift forces are important for transfer momentum between moving phases that are proportional to the relative velocity between the phases and the local liquid vorticity. The lift force acting on a secondary phase p in a primary phase q is computed from

$$\vec{F}_{lift} = -C_L \rho_q \alpha_p \left(\vec{v}_q - \vec{v}_p\right) \times \left(\nabla \times \vec{v}_q\right) \tag{10}$$

where the lift force coefficient C_L can take values between $0.01 \div 0.5$

$C_L =$.

The effect of the dispersion of bubbles is taken into account in turbulent liquid flow by $k - \varepsilon$ turbulence model. Equations above are filled in to equations for turbulent kinetic equation k and dissipation ε

3 Application of Eulerian model on the stirring liquid bath by gaseous phase in real converter with bottom blowing

Input dates for definition of multiphase mathematical model were offered from literature (constructional characteristic of converter and boundary conditions the regarding of blowing gas). Argon is used exclusively as gaseous medium but nitrogen is used also during specific period of melt. Gases are blowing by nozzles which are situated on the bottom of converter. Using of argon to nitrogen is achieved better homogenization during melt process. Constructional characteristic of converter is showed in figure Fig. 3. Figure introduces view at the bottom of converter. Cross-section of computational region is showed in figure Fig.5. Coordination of inlet nozzles is showed in figure Fig. 3. We can see eight inlet nozzles which are situated on the ellipse.

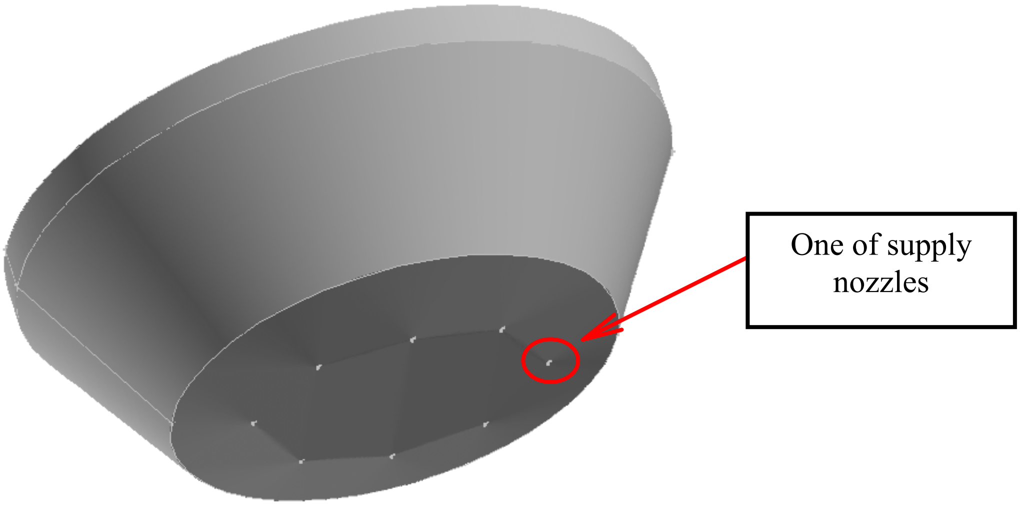

Fig. 3 – Constructional of converter

3.1 Physical properties of phases and boundary conditions

Physical properties of phases are introduced in Tab. 1

		Density [kg/m^3]	Dynamic viscosity [kg/m.s]
Liquid phase	Liquid steel	7000	0.0042
Gaseous phase	Argon	1.6228	2.125e-05

Tab. 1 – Physical properties of phases

3.2 Boundary conditions

Argon enters by nozzles of diameter $d = 9.5\ \mathrm{mm}$ to the region. Mass flow rate is $Q_V =$ ( ) for one supply nozzle. Then inlet velocity is $\left(\upsilon = \frac{4 \cdot Q_V}{\pi \cdot d^2} \right)$ $\upsilon = 58.8\ \mathrm{m/s}$. The gas volume fraction is set to one and the liquid volume fraction is zero at the inlet. Along the wall, the velocities satisfy the no-slip condition and stationary condition. Gas bubbles, but not the molten metal is allowed freely flow out in the normal direction to the surface. Argon is defined as secondary phase, when the bubble size is given by the following equation [1]

$$d_B = 0.54\left(V_g d_n^{0.5}\right)^{0.289} \qquad (11)$$

and liquid steel is defined as primary phase. The time step size was $\Delta t = 0.001\,s$

$t = 2.63\,s$.

3.3 Results of numerical simulation

Software Gambit was used for creation of computational grid. Total number of cells were 949 461. The grid was adapted for better stability and convergation of solution. It was made in regions where we assume move of secondary phase (gaseous) as it is showed in Fig.5.

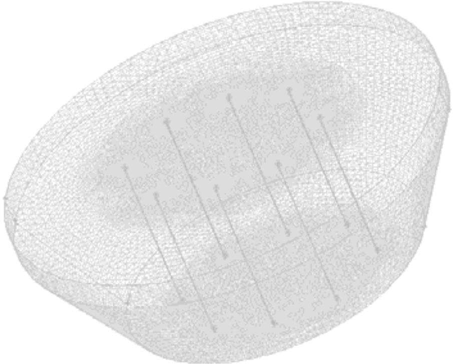

Fig..4 – Computational grid of converter

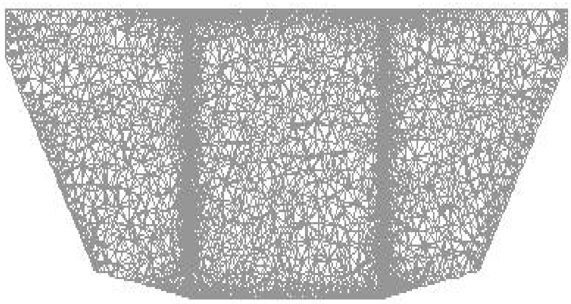

Fig.5 – Cross-section through of converter

It was mentioned that the inlets of argon (total number 8) are situated on the ellipse (Fig **6**) at the bottom of converter. Individual cross-sections were made for evaluation of flow quantity because we can get image about flow inside the converter. Four cross-sections were made for this reason (Fig.7) which those are symbolized by red colour. Three cross-sections and one lengthwise-section were created. The lengthwise-section is leaden through axis of converter and through axis of inlets (Fig **6**). A cross-sections are situated at the distance (0.3 m, 1.2 m a 1.5 m) from the bottom of converter. Evaluation the model of stirring liquid steel is aimed primarily at the monitoring the flow field of liquid phase because the homogenization of melt process is associated with intensity of stirring. Movement of the melt is showed in figure Fig.8. by velocity vectors of liquid phase in direction of converter axis (normal to the surface).

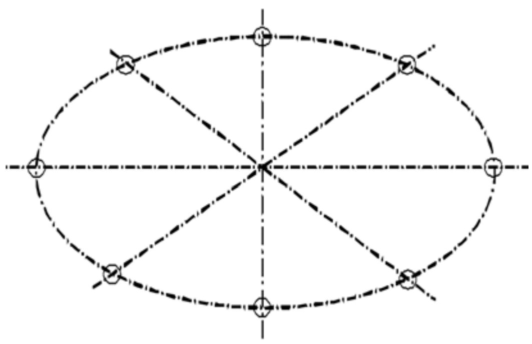	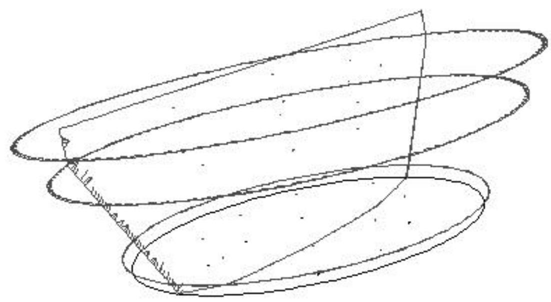
Fig 6 – Configuration of inlets for gas phase	obr. 7 The cross-sections through the converter for evaluation

Range of velocity is limited $\langle -0.04 \div 0.1 \rangle$ m/s for reason detailed interception of region where we can see circulation of melt (Fig.8). Minus velocity values are corresponds to opposite direction of flow. For regions is made zoom (Fig.8) because we can see detailed the circulation of liquid phase. Detailed view those regions are in Fig.9, Fig.10 and Fig.11. Circulation of melt is visible in Fig.9 and Fig.11. Two regions of circulation are seen inside the converter (Fig.10), which are low than two another regions. Also intensity and dimension of circulation is smaller. We can see four regions circulation of melt for reason blowing of gas phase inside all region of converter.

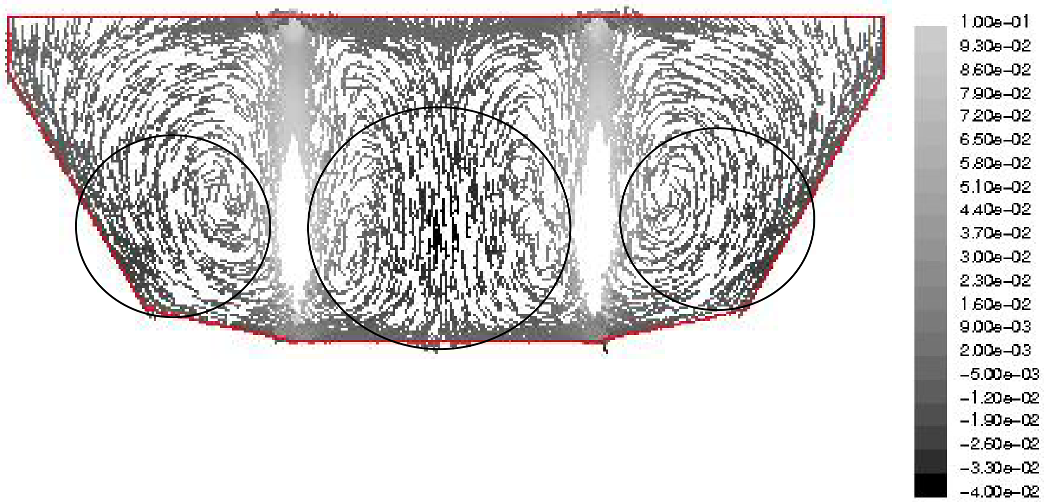

Fig.8 – Velocity field of liquid phase (axis components of velocity)

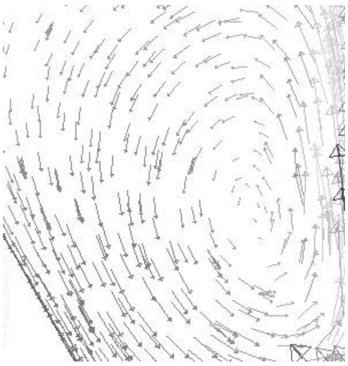

Fig.9 – Detail the velocity field of liquid phase (axis components of velocity)

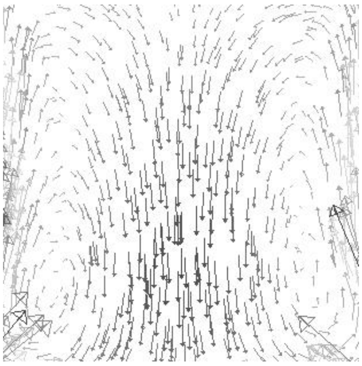

Fig.10 - Detail the velocity field of liquid phase (axis components of velocity)

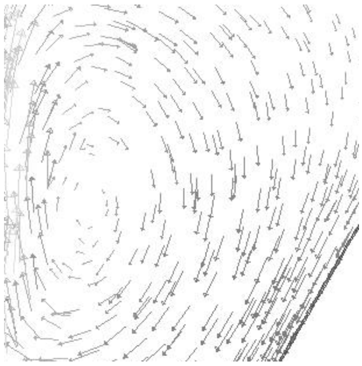

Fig.11 - Detail the velocity field of liquid phase (axis components of velocity)

Image about form of surface is showed in different height of converter (cross-sections, see - scheme obr. **7**) in Fig. **12**. Components of velocity field for liquid phase are evaluated in direction of the axis converter. We can see that in regions of direct influence gas phase occurs to intensive response at the liquid phase. Range of size velocity is limited by maximum of value 0.2 m/s. It is same as in previous evaluation.

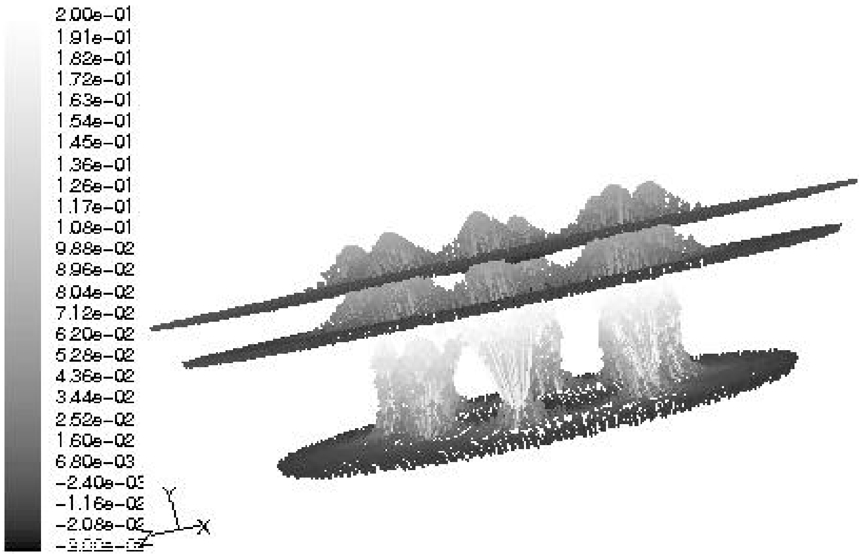

Fig. 12 - Components of velocity field for liquid phase in direction of the axis converter in different cross-sections

4 Conclusions

Numerical simulation showed possibility to solve stirring liquid phase by injection argon through nozzles which are located in bottom of converter by multiphase mathematical Euler model. It was necessary to create correspond computational grid. Computational grid was sufficiently in a high quality adapted in region s of intersection of secondary phase (argon). Defined mathematical model goes out from study interesting of the experimental measuring and numerical solution of simple model [3], [4]. It was necessary assumption to define drag and lift forces. In case of drag force was tested several approaches and it was chosen directive by Schiller Neumann [7]. Next studies will aim to change configuration of nozzle inlets at the bottom. Change of position the nozzles and optimization the process of stirring and homogenization with it related.

Number of project: ***FT-TA/082*** *and title: Investigation, development and modernization the production of steel in „**tandemových pecích**“. It is project Ministry of Industry and Trade of the Czech Republic.*

Reviewer: Doc. RNDr. Kozubková Milada, CSc.

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