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MATHEMATICAL MODELLING OF CHANGE TECHNOLOGY THE PURE OXYGEN BLOWING ON SURFACE OF LIQUID BATH BY ADDITIONAL OXYGEN FUEL BURNER IN METALLURGICAL AGGREGATES

MATEMATICKÉ MODELOVÁNÍ ZMĚNY TECHNOLOGIE DMÝCHÁNÍ ČISTÉHO KYSLÍKU NA HLADINU TEKUTÉ LÁZNĚ POMOCI PŘÍDAVNÉHO HOŘÁKU V HUTNICKÝCH AGREGÁTECH

Abstract

This paper describes possibility of numerical solution of multiphase flow in metallurgical aggregate for steelmaking by software Fluent 6.3.26. In the first part method of mathematical modeling multiphase flow is described. Model of furnace contains liquid steel and gaseous phase 1 (clean oxygen) which is blown on surface of liquid bath through the gaseous phase 2 (air) by means of refine nozzles and additional fuel oxygen burner. One or two oxygen nozzles are used in operating condition. In the second part of paper is defined change of technology the pure oxygen glowing on surface by one or two oxygen fuel burners. Contribution includes information about velocity field distribution inside of furnace by using two variants of pure oxygen blowing on surface.

Abstrakt

Tento příspěvek popisuje možnosti numerické simulace vícefázového proudění v hutnickém agregátu pro výrobu oceli pomoci software Fluent 6.3.26. V první fázi je popsána metodika matematického modelování vícefázového proudění. Model nístěje obsahuje tekutou ocel a plynnou fázi 1 (čistý kyslík), která je dmýchána na hladinu tekuté lázně skrz plynnou fázi 2 (vzduch) pomocí zkujňovacích trysek. V provozním stavu se používá jedna nebo současně obě zkujňovací trysky. V druhé fázi příspěvku je definována změna technologie dmýchání čistého kyslíku na hladinu použitím jednoho nebo dvou přídavných hořáků. Příspěvek obsahuje informace o rozložení rychlostního pole v nístěji při použití dvou variant dmýchání čistého kyslíku na hladinu.

1 INTRODUCTION

In metallurgical industry various types of metallurgical furnaces and vessels (thermal or metallurgical reactors) are used for production and subsequent secondary processing of liquid steels. Gaseous phase may be supplied thought the bottom of thermal reactor or by means of nozzle on surface of liquid phase and now and then also thought side wall of reactor [3]. In present days combined method of blowing gas phase is used in different combination. Then in specific moment of process melt inert gas (argon, nitrogen) is blowing instead of pure oxygen from reasons of better homogenization of liquid bath. In this paper effect of the blowing oxygen process on surface of liquid iron (steel) in furnace is described. In working process pure oxygen is supplied by means of nozzles on the surface, where gas phase interactions with liquid phase. On the one nozzle there are four jets. Depending on smelting technologic process, type and size of furnace it is possible to utilize lay-out with one or more oxygen nozzles [4],[5].

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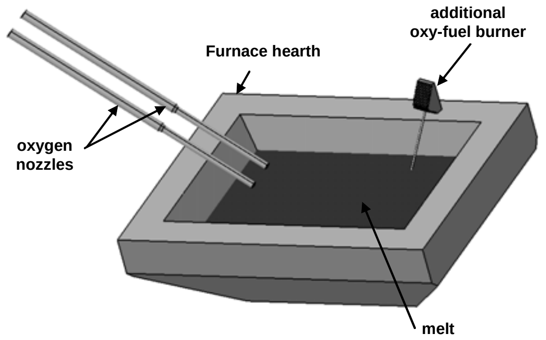


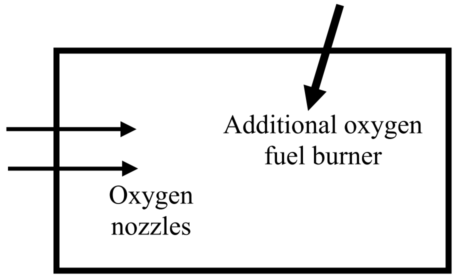


Fig. 1.1 – Position of oxygen nozzles and additional oxygen fuel burner over the surface of melt in furnace

Fig. 1.2 – Scheme of using additional oxygen fuel burner and position in furnace

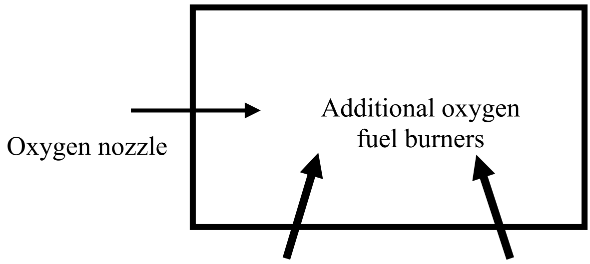


Fig. 1.3 – Scheme of using two additional oxygen fuel burners and position in furnace

In this paper the comparing of variants oxygen blowing on surface is presented with using additional oxygen fuel burners. Two variants of organize additional oxygen fuel burners are presented. First variant with using two oxygen nozzles and with one additional oxygen fuel burner is on the Fig 1.1. Scheme this variant is showed on the Fig. 1.2. Next variant is using two additional oxygen fuel burners with one oxygen nozzle, viz. Fig. 1.3. Working variant is same as on the Fig. 1.1 only without additional oxygen fuel burner.

Multiphase model of furnace presents of blending liquid phase (molten steel) by gas phase (oxygen) which is going through gas phase (air) on the surface. For good simulation of flowing or other phenomenon it is substantial to create corresponding mathematical model. It means to create such model, which incorporate all substantial phenomena and factors (temperature, viscosity, pressure, turbulence, flowing regime, etc.), which influence process on real installation. Some factors it is possible to neglect, because they complicate stability and convergence of solution. That will simplify given model and at the same time it will save results accuracy. One of the most important factors, that is monitored at process of steelmaking is agitation intensity in molten steel. As a result of intensive agitation of molten steel is more effective process of passing chemical reactions and homogenization of molten steel. For that reason the restriction concerning chemical reactions is acceptable, because more intensive agitation is at the same time certain information about intensity of passing chemical reactions. Values of physical properties respond to temperature of liquid steel (appr.1630°C). Heat transfer is neglected. It means that isothermal flowing is studied.

2 CHARACTERIZATION OF MULTIPHASE VOLUME OF FLUID (VOF) MATHEMATICAL MODEL, DEFINE OF BOUNDARY CONDITIONS AND PHYSICAL PROPERTIES

For mathematical modeling of melt steel flow in furnace was defined multiphase VOF mathematical model [1], [2]. Mathematical model can be described as:

One primary liquid phase is molten steel inside the furnace and two second secondary gaseous phases. The blowing oxygen is one from secondary phases. Oxygen is source of motion the molten steel. Second secondary phase is steady gaseous environment up to surface bath. For this application is substituted by air. The VOF model formulation relies on the fact that two or more fluids (or phases) are not interpenetrating, in reflecting of time steady isothermal flow. Mathematical model solve set of differential equations.

The continuity equation for the general phase (liquid) q*th* has the following form

$$\frac{\partial \alpha_q}{\partial t} + \vec{v} \cdot \nabla \alpha_q = 0 \tag{2.1}$$

Then for primary phase – molten steel, the differential equation is not solved, but just express by condition

$$\sum_{q=1}^{N} \alpha_q = 1 \tag{2.2}$$

The momentum balance is defined by following differential equation

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla p + \nabla \cdot \left[\eta \left(\nabla \vec{v} + \nabla \vec{v}^T\right)\right] + \rho \vec{g} + F \tag{2.3}$$

Numerical solution of momentum balance is provided tracking of volume fraction each phase in the system.

Then from momentum balance is expressed the evident function dependence of distribution the velocity fields on the volume fraction individually phases of mixture. The dependence is presented by densities (ρ) and dynamic viscosities (η). The volume-fraction-averaged density (ρ) and volume-fraction-averaged dynamic viscosities (η) of mixture from N-phase system are defined by following relations:

$$\rho = \sum_{q=1}^{N} \alpha_q \rho_q \quad , \quad \eta = \sum_{q=1}^{N} \alpha_q \eta_q \tag{2.4}$$

The distribution of velocity fields of monitoring quantities are shared by considering phases of mixture and quantities represent volume-fraction-averaged of.

Define of boundary conditions and physical properties

Program Fluent 6.3.26 defines many variants of boundary conditions from characterization of problem [1]. From connection of fixed problems on the exits of individual jets of oxygen nozzles and exits of additional oxygen fuel burners define constant velocity condition on the defining values. Constant value of velocity defines on the cross-section. Next possibility is defined mass flow on the inlet. If we consider compressibility flow we can use this condition by program Fluent. Position of exits individual jets of oxygen nozzles correspond to real position. While real position exits of additional oxygen fuel burners is in height 1,5 from surface of melt but in numerical simulation position of exits are defined in height 200mm. Magnitude of velocity on the exit is recalculated on the height 200mm from surface. Boundary conditions are defined in Tab. 2.1. Normal vector of velocity is necessary defined except of magnitude of velocity. Scheme of normal vectors of velocity is showed on the Fig. 2.1.

Tab.2.1 – Boundary conditions for individual variants

Testing variants	Velocity conditions on the individual exits from defining source of oxygen
Variant with two oxygen nozzles and with one additional oxygen fuel burner	All jets of oxygen nozzles: v=488,7m/s Exit from additional burner: v=130m/s
Variant with one oxygen nozzle and with two additional oxygen fuel burners	All jet sof oxygen nozzle: v=518,3m/s Exit from additional burners: v=130m/s

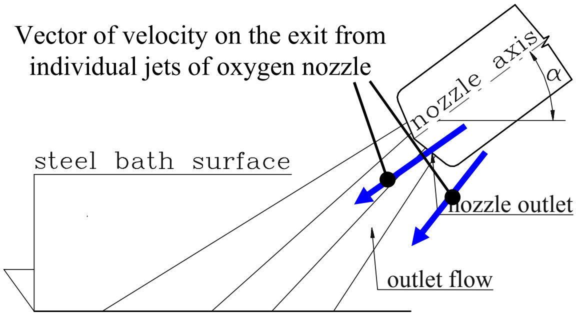


Fig. 2.4 – Scheme of exits streams from oxygen nozzle

Last step from define of mathematical model is determined physical properties individual phases. Important is define physical properties of liquid phase (liquid steel) by temperature (1630°C). Complete resume of physical properties individual phases is showed in Tab. 2.2.

Tab. 2.2 – Physical properties of phase

		Density ρ_q $[kg/m^3]$	Dynamic viscosity μ_q $[kg/m \cdot s^{-1}]$
Liquid phase	Liquid steel	7000	0.0042
Gaseous phase	Air	1.225	1.7894e-05
Gaseous phase	Oxygen	1.2999	1.919e-05

3 EVALUATING OF VOF MATHEMATICAL MODEL ON THE MIXING LIQUID BATH BY GASEOUS PHASE IN WORKING FURNACE ON THE DIFFERENT BOUNDARY CONDITIONS

Input dates for defining multiphase model were released from Department of Production Machines and Design, concretely for characterization constructional of the furnace, boundary conditions (primarily for oxygen blowing). As gaseous medium is used pure oxygen, which is came by refine nozzles on the surface liquid bath; see Fig. 2.1 for distance 200mm from surface. Outlet profile of refine nozzles are showed from Fig. 3.1 and Fig. 3.2. Four outlet profiles are for one nozzle. Variant with using two oxygen nozzles and with one additional oxygen fuel burner presenting nine exits for which velocity boundary condition is defined on the parameters which it is showed in Tab. 2.1. Characterization of constructional furnace in variant position of two additional oxygen fuel burners and the oxygen nozzle is showed on the Fig. 3.2. For this variant are six exits. On those exits we have to define velocity condition. Angle of incidence stream of oxygen from additional fuel oxygen burner is 45° to surface and angle main axis to axis of furnace is 10°.

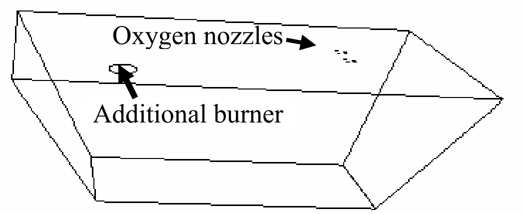


Fig. 3.1 – Furnace with using of one burner

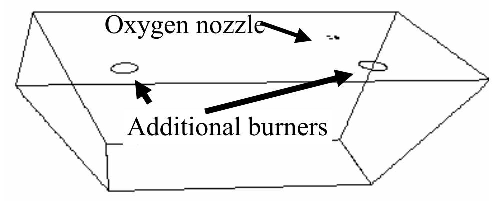


Fig. 3.2 – Furnace with using of two burners

3.1 Evaluating of variants pure oxygen blowing on surface by two oxygen nozzles and with additional oxygen fuel burner

In the first phase was solved variant with two oxygen nozzles and with additional oxygen fuel burner. For evaluating stream field inside the furnace was used two cross-sections. One cross-section was lead through axis of furnace in direction of main oxygen nozzles (Fig. 3.3). Second cross-section was lead in direction of main axis additional burner (Fig. 3.4).

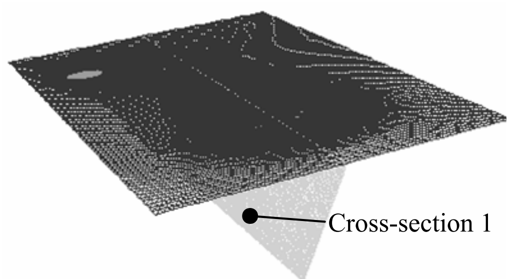


Fig. 3.3 – Cross-section 1 through axis of furnace

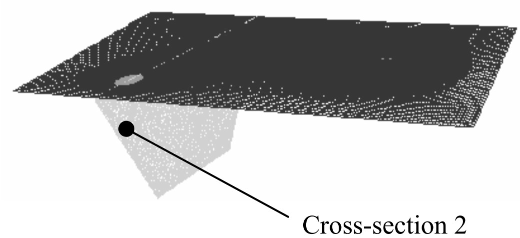


Fig. 3.4 – Cross-section 2 through axis of additional burner

From evaluation and comparison of the structure vectors in individual plane (Fig. 3.3, Fig. 3.4) stream field in blowing by new system we finish to following conclusions:

1. All figure of vector field, which the were selected for analysis distribution of velocity in flow of mixture correspondently flow of oxygen blowing by burners and nozzles and their constant distance up to bath.
2. Current configuration of system two nozzles is in comparison with considering variant (using additional fuel oxygen burner) characterizing by off-centre position couple of nozzles which are build in symmetric to lengthways axis of furnace. Axis is stooped to surface up to angle 35°. Installation those elements make in molten metal typical structure of velocity fields with three-dimensional into the laminar flow along wall of tandem and back flow into the place of work nozzles and next on the side wall of furnace and to zone behind nozzles.

Distribution of flow velocity melt and value of velocity we can evaluate in arbitrary place of bath by oxygen blowing and we can evaluate from detailed image plane cross-sections. Two cross-sections are evaluated, which are intersecting by selected places of furnace (Fig. 3.3, Fig. 3.4). According to evaluated pictures of melt velocity fields in furnace (Fig. 3.5, Fig. 3.6, Fig. 3.7, Fig. 3.8) it is evident that the melt flow velocity in direction of actuating nozzles and along the furnace step by step drop to low values of about 8.0^{-4}m.s^{-1}. In principle the fact that the region of low step by step decreasing speeds except of narrow undersurface thickness of fluid-liquid mixture spreads almost on the whole volume of furnace with exception of region affecting by stream of oxygen from burner and region of oxygen nozzle. That it is noted from Fig. 3.6 showing limitation of maximal velocity v=0.1 m/s. From detail analysis of melt velocity fields in furnace it is evidential, that the melt agitation in the area behind actuating nozzles and first of all in corners and in the surrounding of opposite side wall and also intensity of agitation effect of flowing oxygen from nozzles is very low.

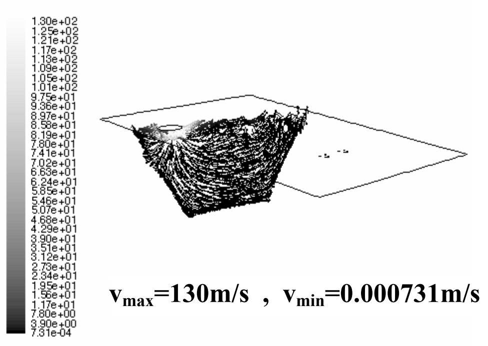


Fig. 3.5 – Velocity field in cross-section 2 – outlet gases velocity from additional turner is v=130m.s^{-1}

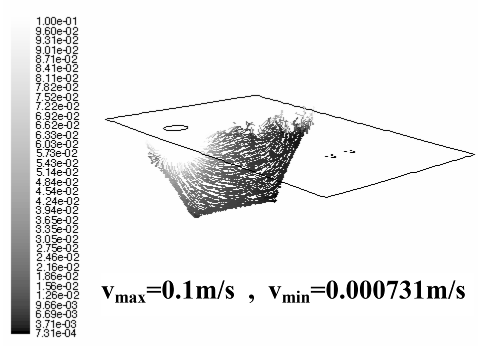


Fig. 3.6 - Velocity field in cross-section 2 – limitation of maximum velocity v=0.1m/s

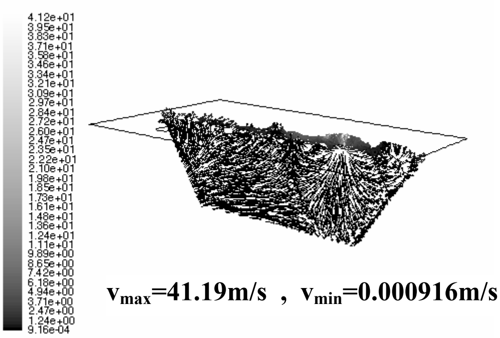


Fig. 3.7 - Velocity field in cross-section 1 – outlet gases velocity from additional turner is v=130m.s^{-1}

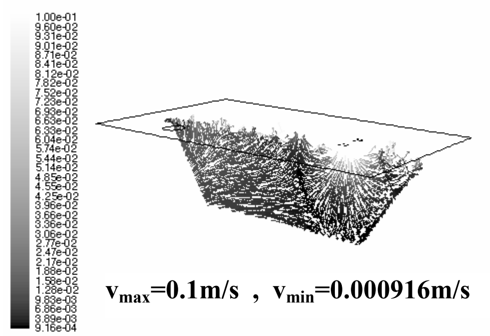


Fig. 3.8 - Velocity field in cross-section 1 – limitation of maximum velocity v=0.1m/s

Base on results evaluation of that variant it is possible to say, that while blowing by this system it happens to expressive reduction of area with low melt velocity in furnace at the expense of velocity increasing in predominant part of furnace volume. According of velocity fields or at combined oxygen supply to the bath by means of nozzle and inbuilt burner the dominant burner effect on increasing of melt agitation (stirring) intensity in furnace is proven.

3.2 Evaluating the variant of pure oxygen blowing on the surface by oxygen nozzle and two additional burners

In the next phase of pure oxygen blowing gets to next change. One oxygen nozzle and two additional burners were used. Position of exits oxygen sources is visible from Fig. 3.2. Boundary conditions are defined in Tab. 2.1.

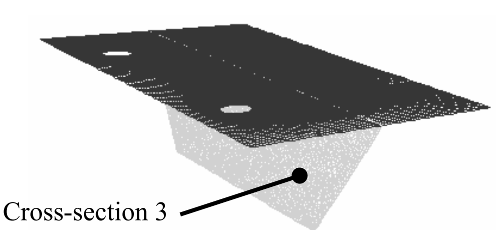


Fig. 3.9 – cross-section 3 through axis of furnace

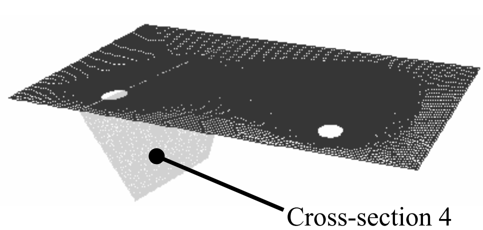
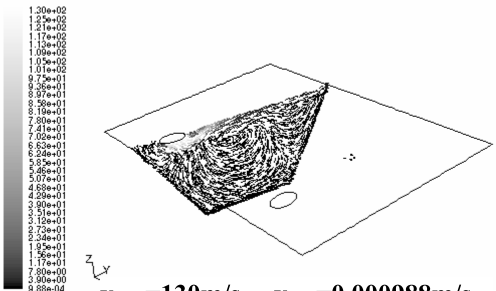


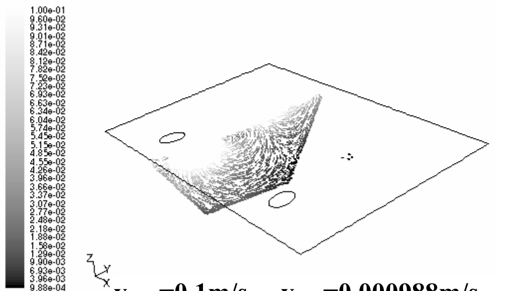
Fig. 3.10 – cross-section 4 through axis of additional burner

Velocity field is evaluated in the two cross-sections for clearness (cross-section through axis of furnace and cross-section through main axis of additional burner, which it is positioned on the opposite side in relation of oxygen nozzle), Fig. 3.9 and Fig. 3.10. For clearness results of velocity field are showed in limited range of velocity (maximum of velocity 0.1 m/s) from reason of better image about momentum of melt in direction to bottom of furnace, Fig. 3.12, Fig. 3.14.



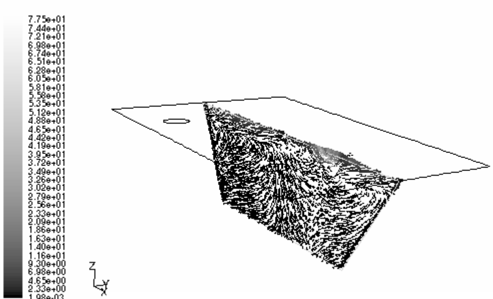
v_{max}=130m/s , v_{min}=0.000988m/s

Fig. 3.11 – Velocity field in cross-section 4 - outlet gases velocity from additional turner is v=130m.s^{-1}



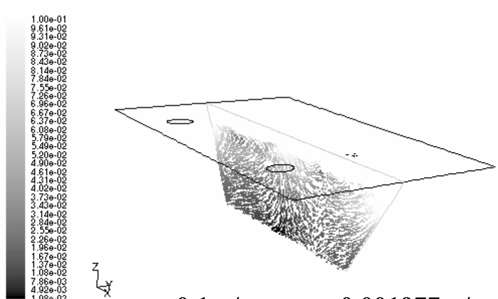
v_{max}=0.1m/s , v_{min}=0.000988m/s

Fig. 3.12 – Velocity field in cross-section 4 – limitation of maximum velocity v=0.1m/s



v_{max}=77.5m/s , v_{min}=0.001977m/s

Fig. 3.13 - – Velocity field in cross-section 3 - outlet gases velocity from additional turner is v=130m.s^{-1}



v_{max}=0.1m/s , v_{min}=0.001977m/s

Fig. 3.14 – Velocity field in cross-section 3 – limitation of maximum velocity v=0.1m/s

CONCLUSION

The objective of mathematical simulation of melt movement in furnace was to considered new methods of oxygen blowing to bath. The corresponding mathematical model of multiphase flow VOF was defined in the first part. Only hydrodynamic conditions in melt during isothermal oxygen blowing without thinking of chemical effect were tested. Tests results documented that higher spectrum of flow velocity distribution in melt it is possible to achieve in variant with using of two additional oxygen fuel burners. From comparing of velocity field in cross-sections through axis of furnace (cross-section 1, cross-section 3) is evident better momentum of liquid in direction to bottom for variant with using of two burners. Maximum of velocity for variant with one burner is v≈0.0007 m/s. While for variant with two burners is v≈0.002 m/s.

Appropriate realization of combined oxygen blowing system on surveyed shape of furnace is complicated problem. Even if the additional oxygen fuel burner will be used in surveyed shape of furnace there will be areas, in which melt motion will more or less stagnate in furnace. The shape change of furnace would considerably intensify melt motion in furnace. From point of view of bath motion intensity it would be preferable to equip the furnace by oval shape of furnace, that would not resist bath motion as it is in case of existing (square) furnace. In case of continuation of existing technology, it will be necessary take a think over technology rationalization and furnace construction (design) for existing operating conditions.

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