Mathematical models, algorithms and software for dynamic simulation of leadle treatment technology

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The original software for dynamic simulation of ladle treatment of steel was developed. Physical and chemical models based on the conservation law of mass and energy, as well as the principles of non equilibrium thermodynamics were used. All the stages of the process (zones) were taken into account in this software. This software takes into consideration input data such as: ladle equipment facilities, initial temperature, slag and metal mass compositions, input time and mass of additives, blowing, electrical and time regimes, thermodynamic database, thermal, physical and chemical databases for additives and inert gas, production database (for statistics). This software allows us to calculate the main characteristics of the ladle treatment such as temperatures and chemical composition of slag and the steel melts. For validation of the software, the results of ladle treatment of real heats of steel and sampling control results were used. This software can be used in online calculations and control of process parameters during ladle treatment, simulation and optimization of ladle treatment technology, teaching and training of steelmaking staff.

KEYWORDS: MATHEMATICAL MODELS – LADLE TREATMENT – NON EQUILIBRIUM THERMODYNAMICS

INTRODUCTION

The production technology of modern steel grades is based on the production of metal with narrow intervals of chemical composition, alloying elements, modifiers, reducing the content of harmful impurities and non-metallic inclusions. Achieving these parameters requires fine-tuning of steelmaking technologies at each stage, taking into account changes in the temperature and composition of the steel melt and slag and the of additives introduction mode. Modern metallurgical technologies of the XXI century provide various methods of ladle processing to control the quality of steels and alloys. All industrial experiments on technology optimization are complex and extensive. The best way is a computational modeling of metallurgical technologies. The modelling of metallurgical processes is a difficult problem that requires the development of physical - chemical models and mathematical algorithms, allowing adequate description of high-temperature processes occurring in open non-equilibrium systems. The most of computer software, that modelling the real metallurgical process are based on approximating and statistical models demanding enormous numbers of experimental data [1-3]. This fact essentially limits possibilities of the software, which aren't capable to sufficiently react to various disturbance and random processes in a wide range of parameters change. Using of computational models that adequately simulate the processes during ladle treatment of steel allows us to calculate the optimal technology for the production of a certain steel grades simulates this on a computer without a series of costly industrial experiments, develop new technologies for steel production and identify new factors that affect product quality.

The aim of this study was to develop of mathematical models, algorithms and software for dynamic simulation of steel treatment technology in ladle furnace (LF).

METHODS AND MODELS

Software for dynamic simulation of ladle treatment technology was based on the physical and chemical models and thermodynamics models [4-5]. The target of this software was modelling and on-line control of steel temperature and chemical composition of slag and steel melt during steelmaking processes (ladle-furnace). Physical and chemical models based on mass and energy conservation law and principals of non-equilibrium thermodynamics were used. All process stages (zo-

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nes) were taken into account in this software. It was assumed that the metallurgical systems do not reach equilibrium and are in non equilibrium steady states. In accordance with the L. Onsager, it was proposed that the reaction rate is proportional to the gradient of the chemical potential according the formulae:

$$V_i = -SLgrad\mu_i \quad [1]$$

where
Vi – reaction speed of i -component, mol/s;
S- interaction surface, m2;
L- Onsager's coefficient, mol2/(J·s·m);
gradμi- gradient of the chemical potential of i component, J/(mol·m).
All components in the interaction zone in the slag-metal system are equal to the turbulent mass transfer conditions.
Therefore it was assumed that the surface area of interaction, Onsager coefficients, temperature and boundary layer thickness - δ are the same for all reactions. If the coefficient ß is:

$$\beta^* = SL\frac{1}{\delta} \quad [2]$$

Than reaction speed of i –component is:

$$V_i = \beta^* RT \ln\frac{K_r}{K_e} \quad [3]$$

Where Ke and Kr are equilibrium and real reaction constants. To calculate the reaction rates of interactions between components of slag-metal system was developed by an iterative algorithm. Model defines a direction of chemical reactions for metal-slag system witch presented as a matrix of k reactions and takes into consideration mass and energy balance equations. All interaction zones are described by deterministic rather than statistical dependencies, models are stable over a wide range of variables and it is stable even after changes of technology. This software takes into consideration input data such as: temperature, slag and metal mass and compositions, input time and mass of additives, blowing, electrical and time regimes. Additional data which is to be used in calculations are ladle equipment facilities (ladle geometry, transformer parameters, electrode consumption, number of lances, type of refractory materials), thermodynamic database, thermal, physical and chemical databases for additives and inert gas, production database (for statistics). It was demonstrated that software is stable even after changes in technological scheme.

Mathematical model consists of the following blocks:
- Calculation the speed of interaction between the components in the slag-metal system;
- Calculating the amount of metal and slag in the interaction zone depending on the power of stirring of the bath;
- Calculation of the mass of metal and slag;
- Calculation of the chemical composition and temperature of the slag and metal bath.

Calculations of energy balance for metal-slag system and in all areas including arc heating and takes into consideration heats of chemical reactions;
Calculations of heat of metal and slag melts, alloying elements and fluxes;
Heat loss calculations through the lining by radiation, for heating the inert gas and the reacting components at the boundary of the slag - metal lining ;
Calculations of nonmetallic inclusions formation and removal.
The Figure 1 represents of the calculating scheme of the Ladle-Furnace software package.

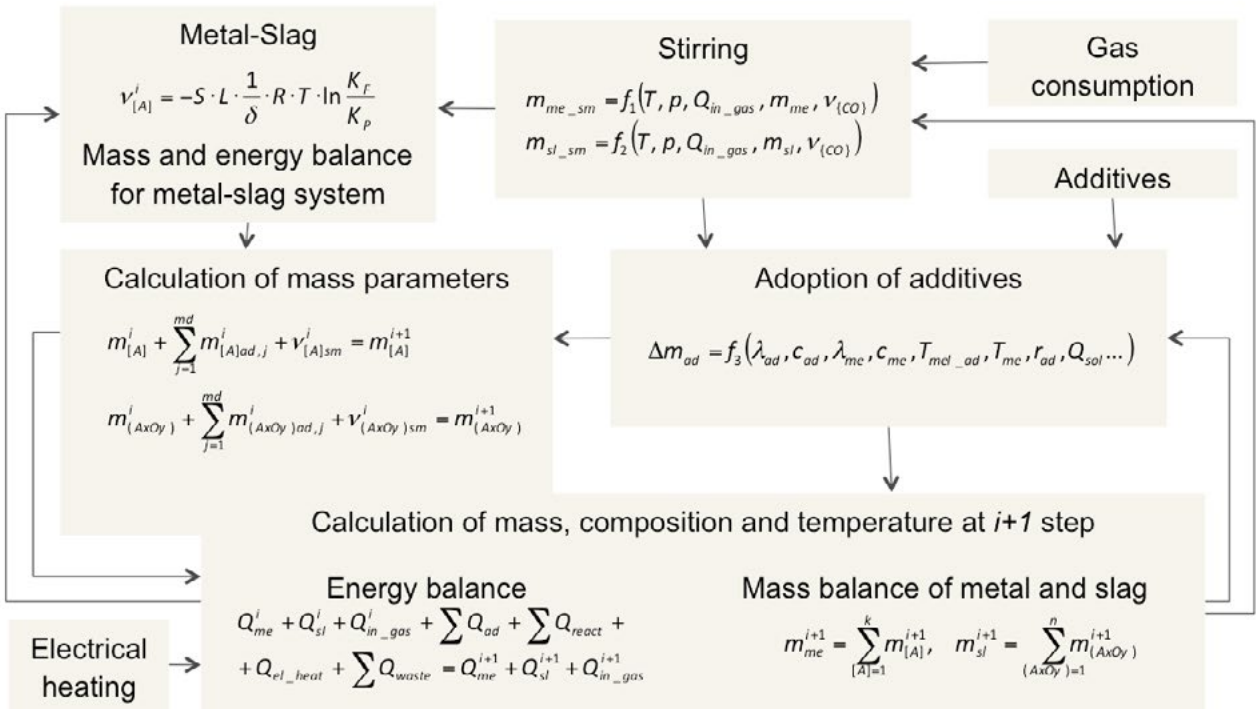
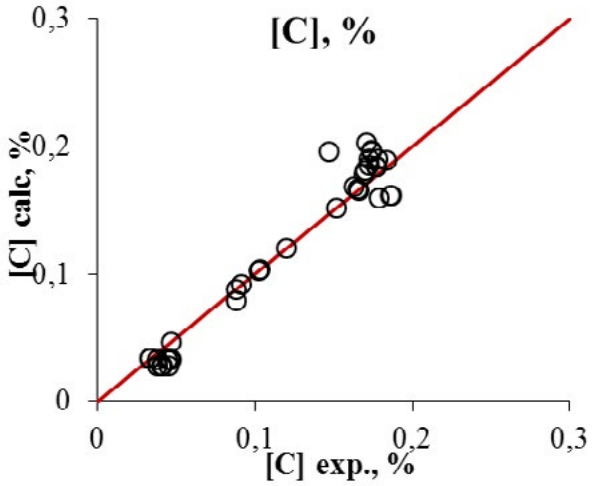
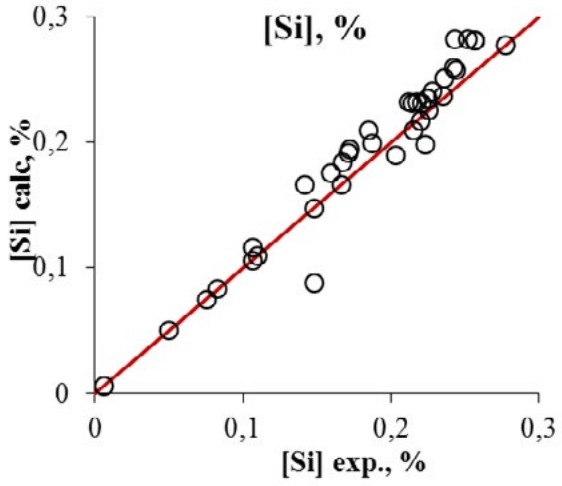


Fig. 1 – Calculating scheme of the Ladle Furnace software package

RESULTS AND DISCUSSION

For testing of Software and validation of the model, the results of ladle treatment of 25 real heats of steel for pipe line and sampling control results were used. Comparative results of calculated values obtained by the software and results of chemical composition control of metal melt during treatment at the ladle furnace 165 t., presented on the Fig. 2 Fig 3 presented of comparative results of chemical composition control of the samples of molten metal during processing at the 355 tonn ladle furnace. It was shown that Software designed allows us to make dynamic simulation and optimization of ladle treatment technology. It was established that the software to adequately describe the dynamic changes of the basic characteristics of the metal, slag and reaction of system on the process control feedback. It was shown that the software developed for the dynamic simulation of ladle treatment of steel and fractional gas analysis method allows to optimize the secondary treatment technology. This software can be used in online calculations and control of process parameters during ladle treatment, modelling and optimization of ladle treatment technology, teaching and training of steelmaking staff.





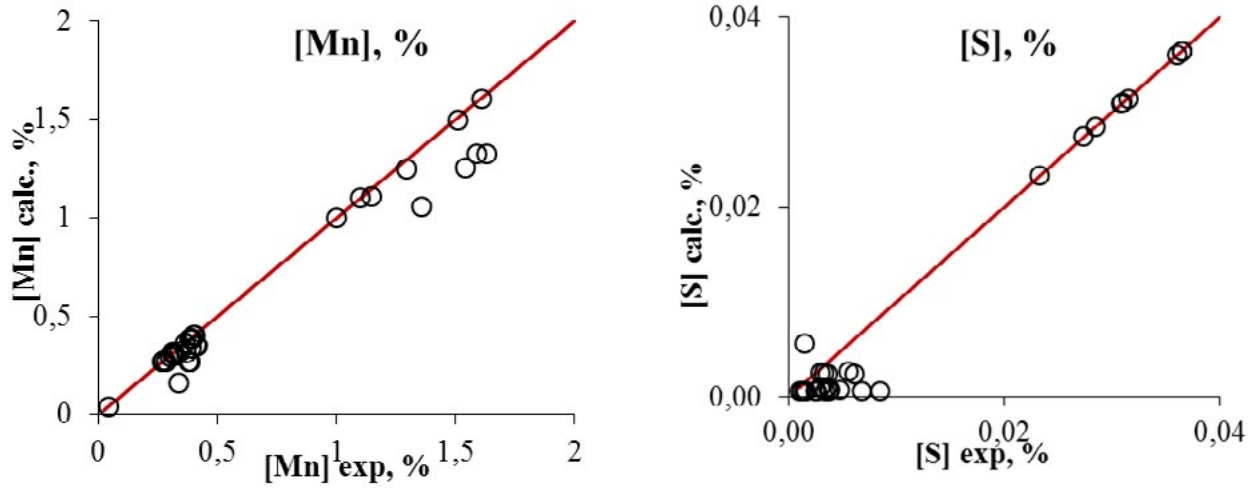


Fig. 2 – Comparative results of calculations by the LF software and obtained results of chemical composition control of metal melt during ladle treatment at the ladle furnace 165 tonn

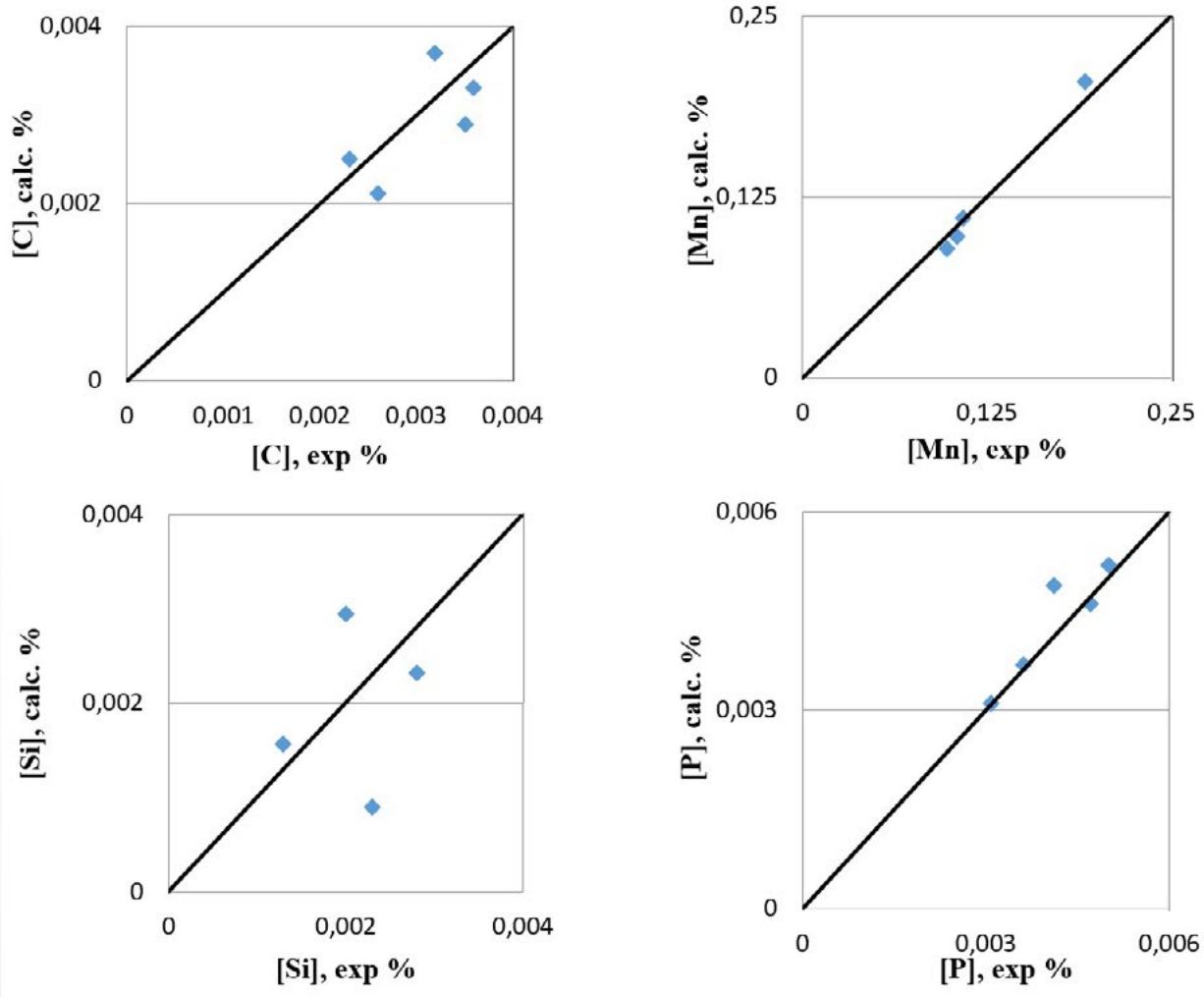


Fig. 3 – Comparative results of calculations by the LF software and obtained results of chemical composition control of metal melt during ladle treatment at the ladle furnace 355 tonn

CONCLUSIONS

The original software for dynamic simulation of ladle treatment of steel was developed. Physical and chemical models based on the conservation law of mass and energy, as well as the principles of non equilibrium thermo-dynamics were used. All the stages of the process (zones) were taken into account in this software. Software for dynamic simulation of ladle treatment technology to increase the steels quality was used in simulating of real in-dustrial hits. It was shown that software designed allows us to provide the dynamic simulation of ladle treatment technology, to optimize one and to lead the process within an optimal way.

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