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Modeling of argon process refining based on equilibrium state analysis of metal bath - slag reactions and tank model theory

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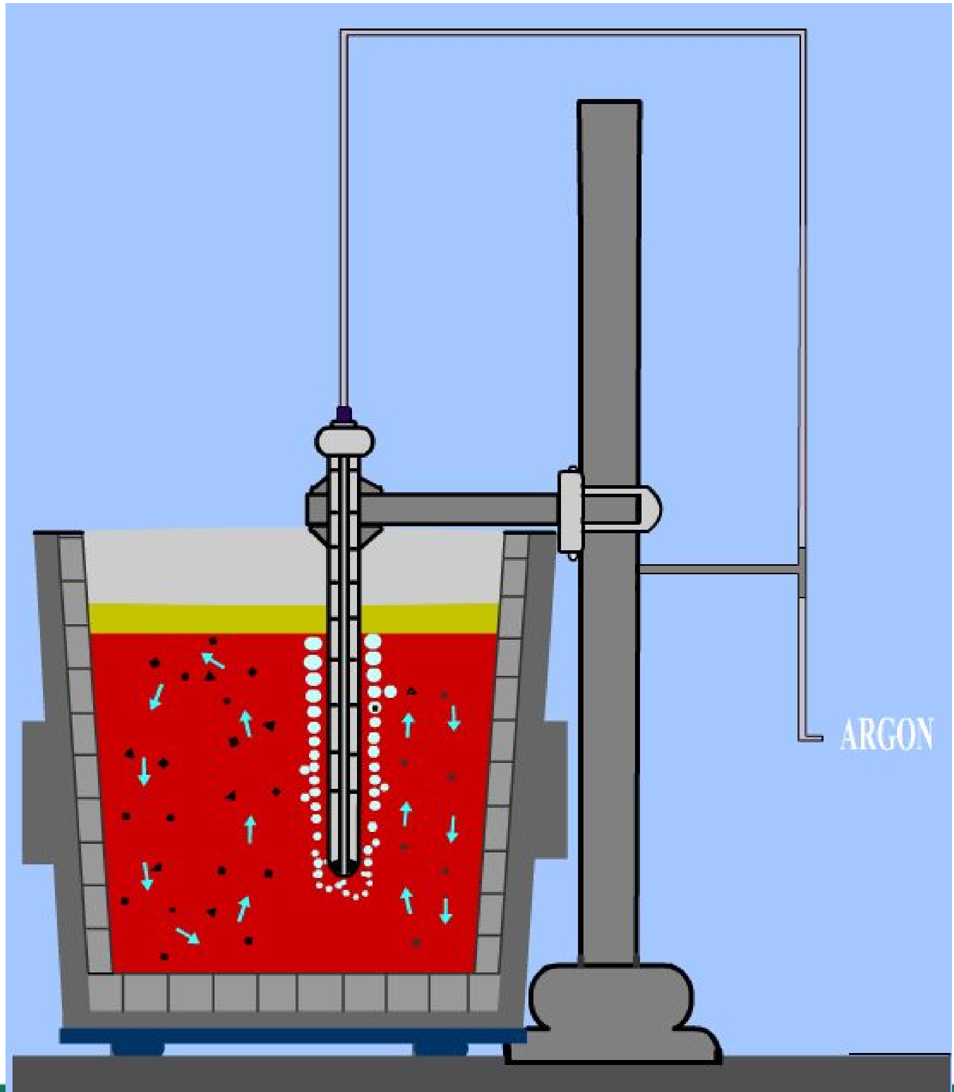
Objective of Argon injection

- homogenize bath composition and temperature,
- remove inclusions in the steel by flotation
- supplement steel composition.

The argon injection process is controlled by a proper selection of operation time, argon flow rate and mass and time of making additions.

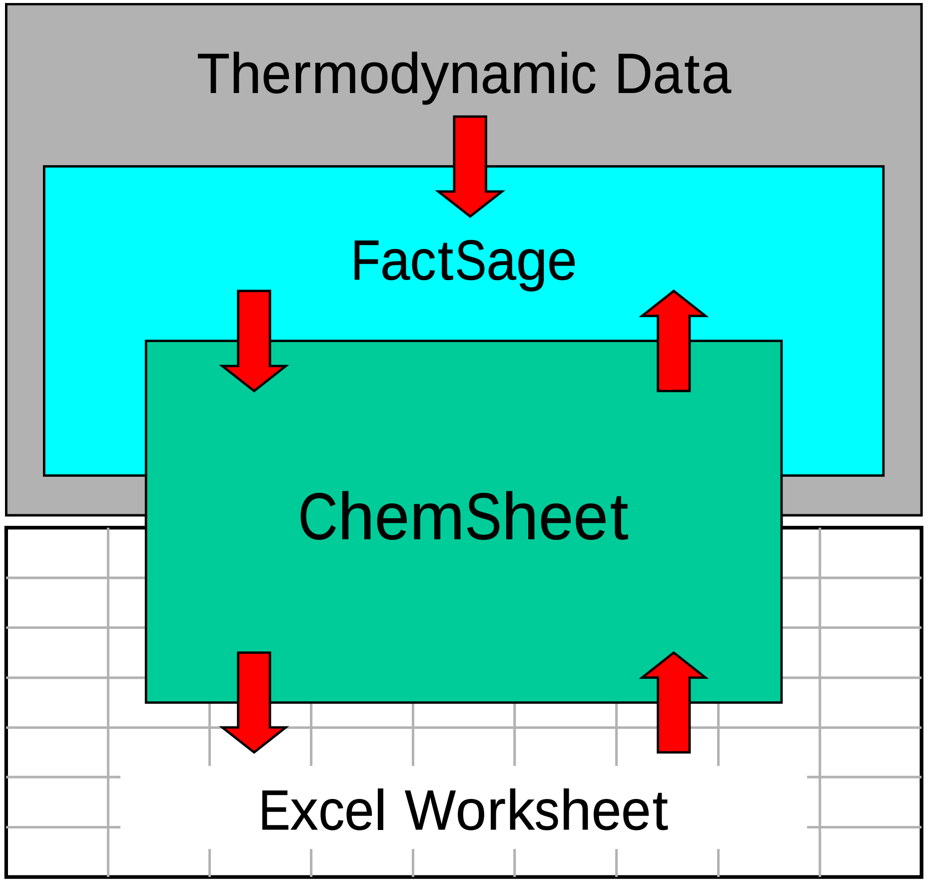
Argon injection process

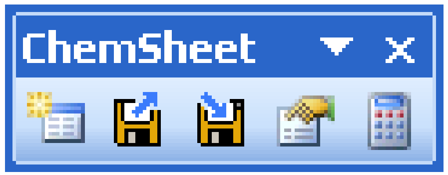


Principle of operation

Tools for computational calculations

FACT - Facility for the Analysis of Chemical Thermodynamics – the database for treating thermodynamic properties and calculations in chemical metallurgy

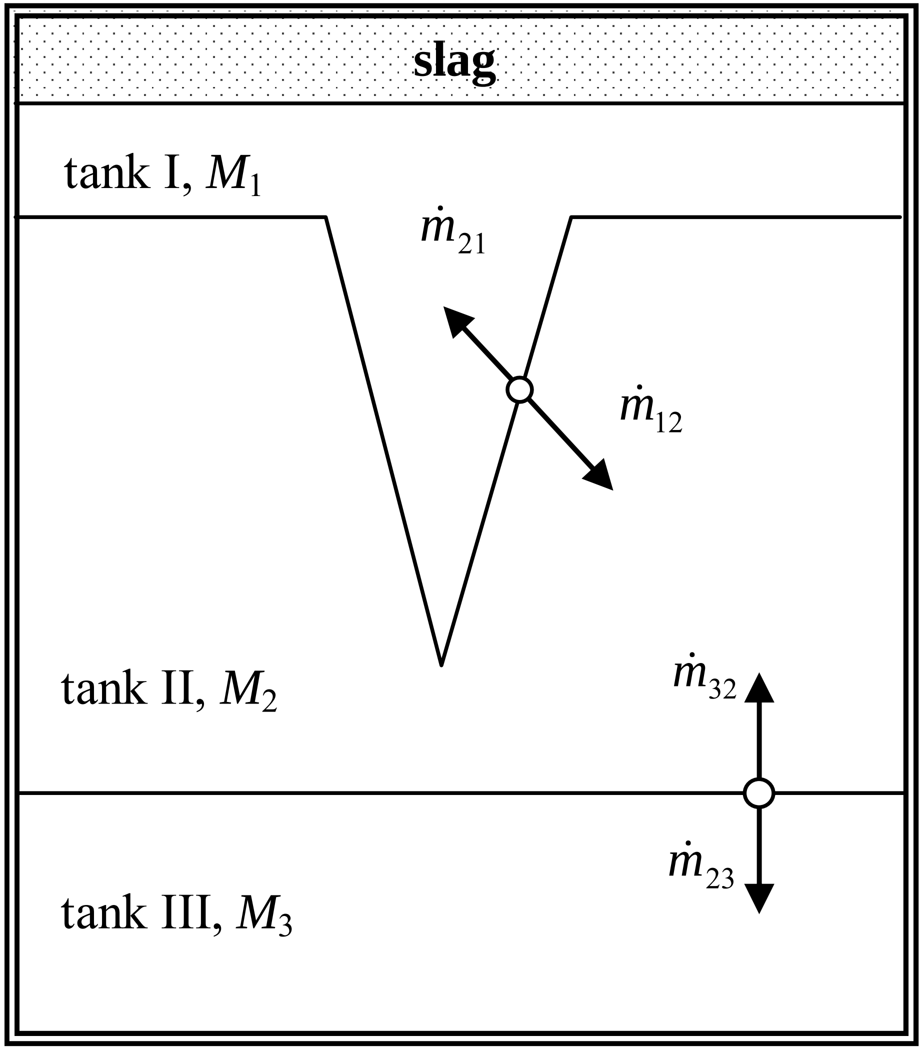




Assumptions to the model development

Division of the ladle volume into tanks in the process of top lance injection of argon into steel

tank I (M_1) - 15% M_{total}
tank II (M_2) - 60% M_{total}
tank III (M_3) - 25% M_{total}



Structure of Tank Model

Arrangement of equations describing mass flow

The mathematical notation of the system of equations describing bath stirring. (Metal-slag interface reactions have not been taken into account in this model yet).

$$dm_1^i(t) = -\frac{m_1^i(t)}{M_1}\dot{m}_{12}\Delta t + \frac{m_2^i(t)}{M_2}\dot{m}_{21}\Delta t$$

$$dm_2^i(t) = \frac{m_1^i(t)}{M_1}\dot{m}_{12}\Delta t - \frac{m_2^i(t)}{M_2}\dot{m}_{21}\Delta t - \frac{m_2^i(t)}{M_2}\dot{m}_{23}\Delta t + \frac{m_3^i(t)}{M_3}\dot{m}_{32}\Delta t$$

$$dm_3^i(t) = \frac{m_2^i(t)}{M_2}\dot{m}_{23}\Delta t - \frac{m_3^i(t)}{M_3}\dot{m}_{32}\Delta t$$

$$m_1^i(t+\Delta t) = m_1^i(t) + dm_1^i(t)$$

$$m_2^i(t+\Delta t) = m_2^i(t) + dm_2^i(t)$$

$$m_3^i(t+\Delta t) = m_3^i(t) + dm_3^i(t)$$

m_i – mass of reactant in i^{th} reactor, [Mg],
M_i – mass of i^{th} elementary reactor, [Mg],
$\dot{m}_{ij}$ – flow rate of metal bath stream between i i j reactors, [Mg/min],
t – time, [min].

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Take account of metal-slag interface reactions

Mixing model

$$dm_1^i(t) = -\frac{m_1^i(t)}{M_1}\dot{m}_{12}\Delta t + \frac{m_2^i(t)}{M_2}\dot{m}_{21}\Delta t + \Delta m_1^i(t)_{eq}$$

Thermodynamic model

Input FactSage

m_{eq} – equilibrium mass of reactant in metal-slag region, [Mg],

$$\Delta m_1(t)_{eq} = m_{eq}(t) - \alpha \cdot m_1(t)$$

Output FactSage

$$\alpha = \frac{\Delta t \cdot \dot{m}_{12}}{M_1} \times 100\%$$

The thicknesses of metal and slag layers which reach the state of mutual equilibrium depends on both the intensity of bath stirring and the calculation time interval value.

Findings

The suggested model has been verified under commercial circumstances in a ladle of 140 Mg.

Cold model research and operational data from industrial units allowed to determine that the mass flow rate for the tested ladle was [kg/min]:

$$\dot{m}_{12} = 6600 \qquad \dot{m}_{23} = 0.4\dot{m}_{12}$$

Credibility of information on mass and chemical composition of the formed ladle slag largely influenced simulation results !!!!!!!

Comparison of thickness measured and ladle slag mass calculated theoretically in the verification heats

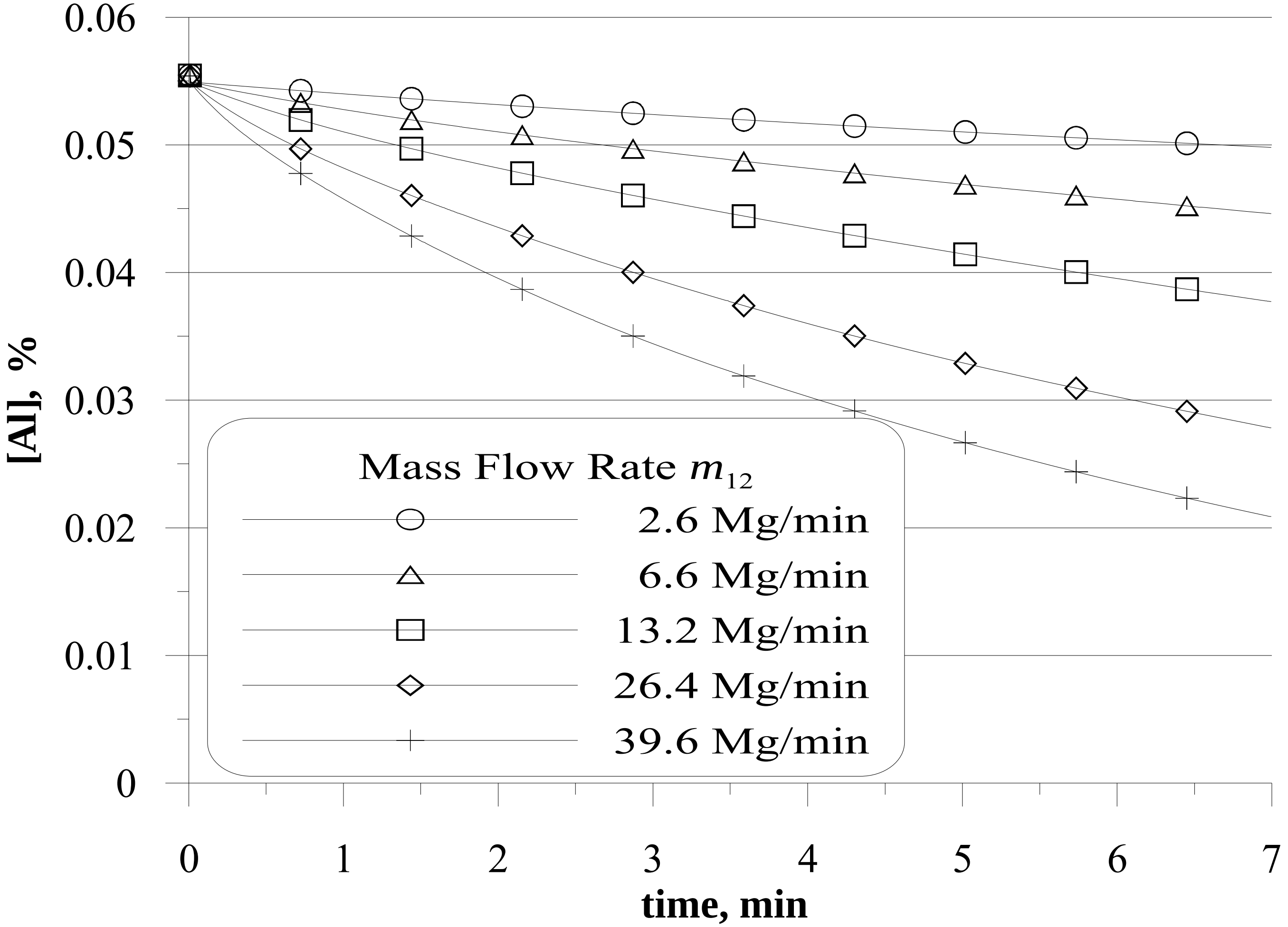
Heat No.	1	2	3	4	5	6	7	8	9	10
Thickness measured, mm	80	250	400	90	200	100	300	370	100	70
Balance calculations, kg	1201	2637	2771	2384	1220	2313	1009	2239	1532	2712

The balance method was applied in calculations

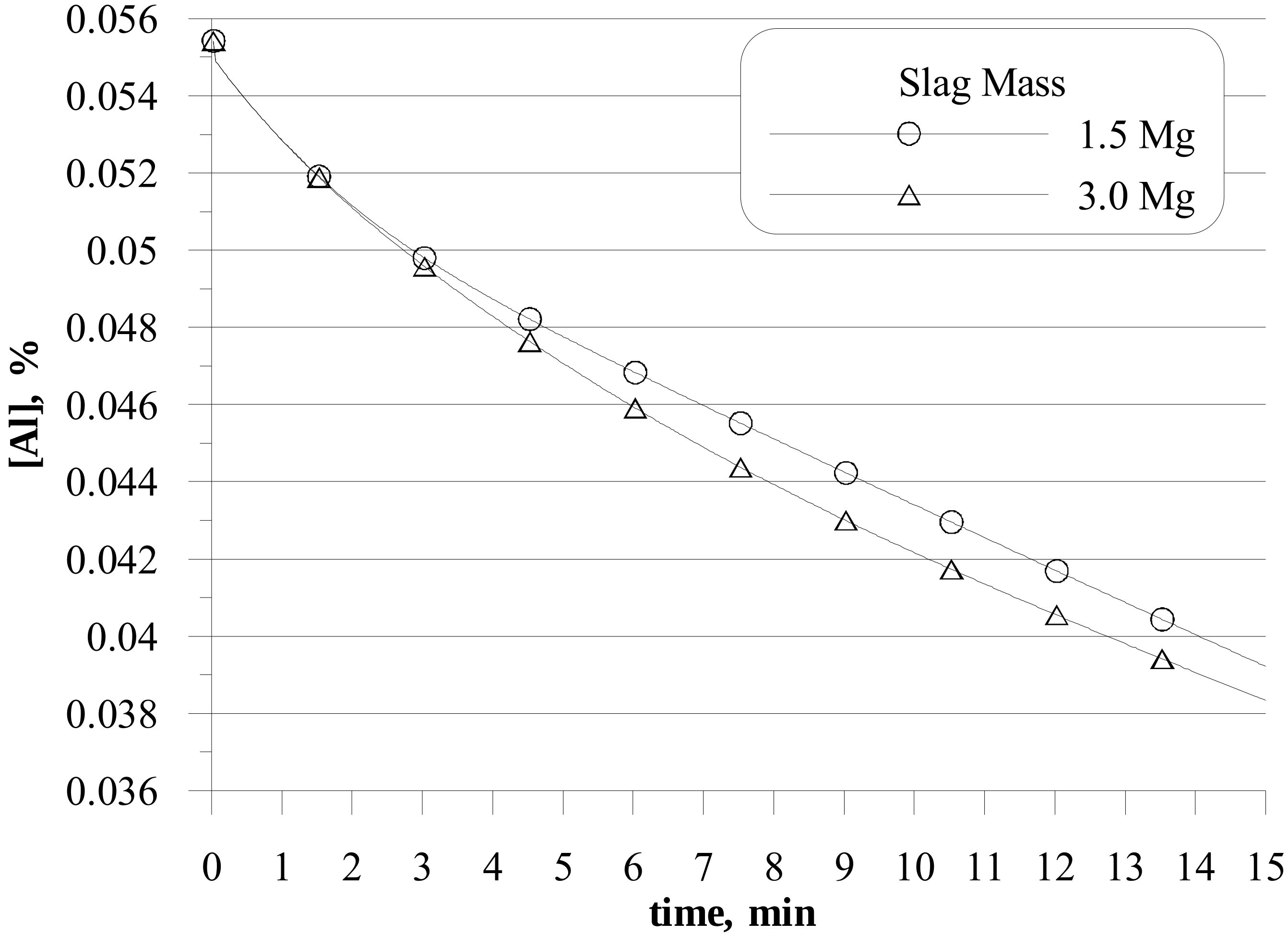
Comparison of the final aluminum content in the metal bath in test heats with model calculation results

Heat No.	1	2	3	4	5	6	7	8	9	10
Chemical analysis, [Al]	0.064	0.051	0.046	0.072	0.042	0.056	0.057	0.050	0.055	0.048
Model calculations, [Al]	0.056	0.042	0.050	0.071	0.059	0.055	0.043	0.054	0.045	0.063

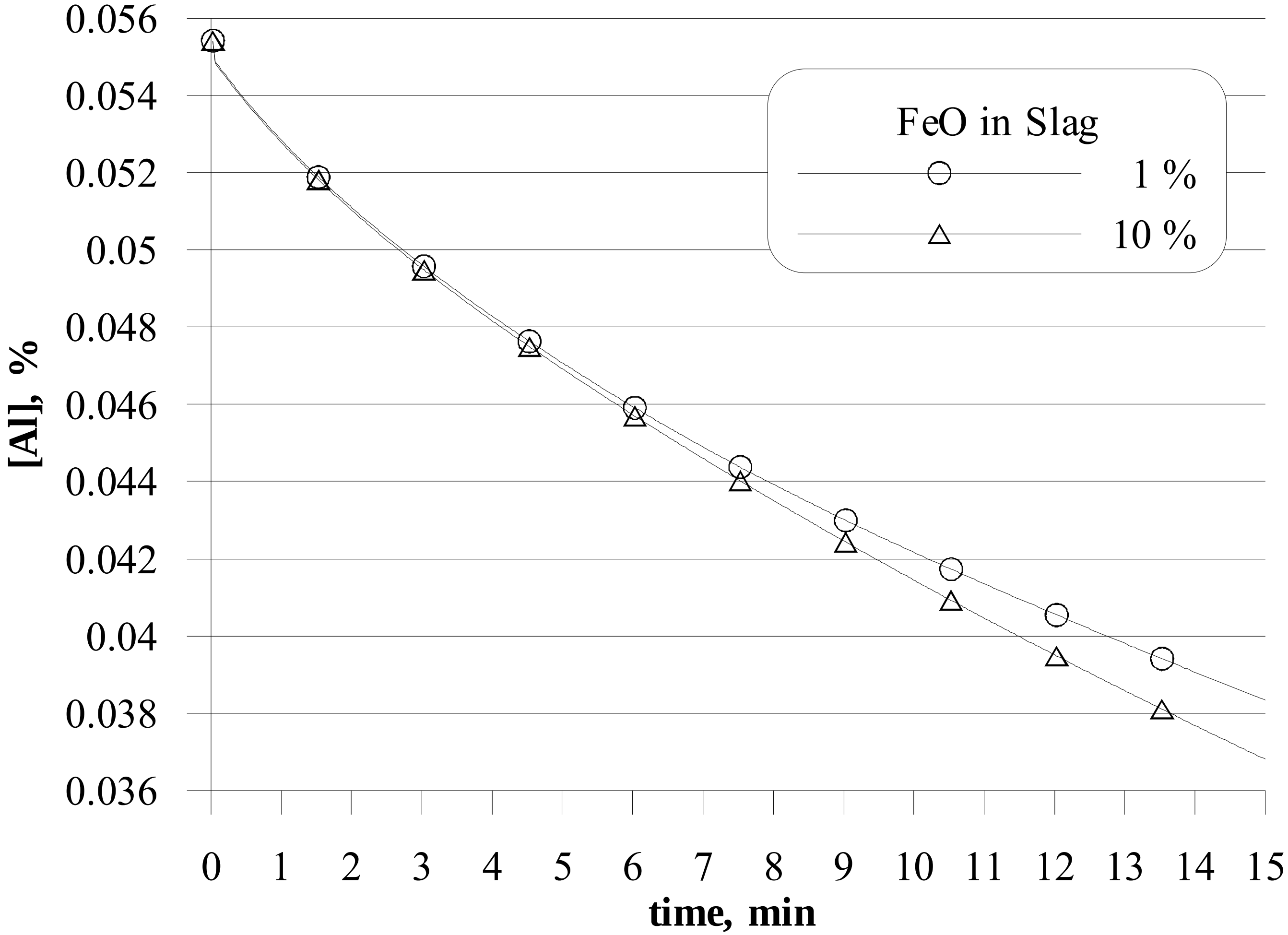
Effect of argon flow rate on the course of changes in aluminum content in the metal bath



Effect of ladle slag mass on the course of changes in aluminum content in the metal bath



Effect of initial content of ferrous oxides on the course of changes in aluminum content in the metal bath



Conclusion

- The most important factor influencing the time of getting to the state of equilibrium by the system is the argon injection flow rate.
- Both increase in the initial FeO content in the slag and increase in the ladle slag mass cause increase in the time of getting to the state of equilibrium by the system. It causes problems with obtaining the state of stable equilibrium of the system at the end of the argon injection process.
- The model calculation time is shorter than the process time and therefore it is possible to use it both for on-line control as well as to argon injection process selection planning.

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Thank You

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