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Simulation of Deoxidation and Refining Process Using SimuSage

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- Assumptions to models development
- Dedicated tool for process simulation using SimuSage
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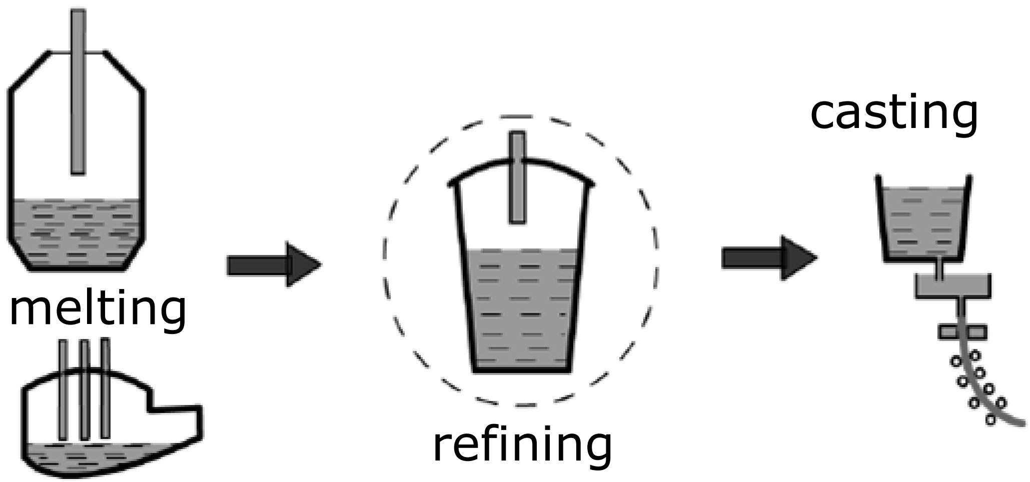
Deoxidation Process Parameters during tapping

Slag	Metal	Additions
□ weight and chemical composition of the converter slag getting into the ladle during tapping □ oxygen activity before the deoxidation process startup □ final chemical composition	□ weight after tapping from the furnace □ start temperature □ start chemical composition □ oxygen activity before and after the deoxidation process	□ weight of the ladle additions (fluxes, alloys addition) put into the ladle during tapping and their chemical composition



Ladle Furnace Process Parameters

Slag	Metal	Additions
□ weight and chemical composition of the slag before refining the refining process startup □ oxygen activity before the refining process startup □ final chemical composition	□ weight after tapping from the furnace □ start and final temperature □ start chemical composition □ oxygen activity before and after the refining process □ intensity and time of argon injection □ chemical composition after argon injection	□weight of the additions put into metal at the ladle furnace post and their chemical composition

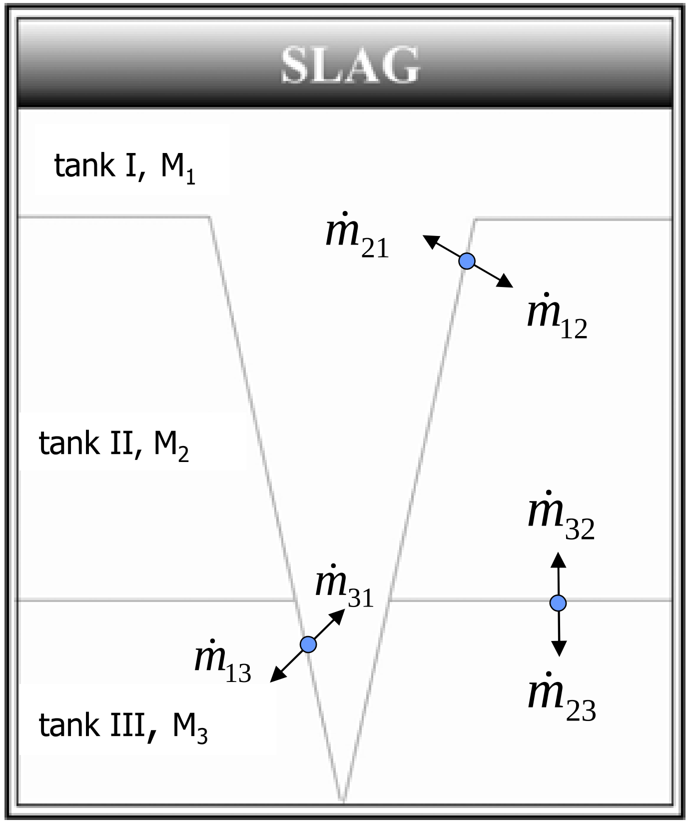
Assumptions to static models development

- Based on thermodynamic model (FactSage calculations)
- The state close to the metal-slag equilibrium is being achieved at the refining final phase
- The process time has no role

Assumptions to the dynamic model development

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

- tank I (M_1) - 25.0% M_{total}
- tank II (M_2) - 52.9% M_{total}
- tank III (M_3) - 22.1% 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).

$$dm_1^i(t) = -\frac{m_1^i(t)}{M_1}\dot{m}_{12}\Delta t + \frac{m_2^i(t)}{M_2}\dot{m}_{21}\Delta t - \frac{m_1^i(t)}{M_1}\dot{m}_{13}\Delta t + \frac{m_3^i(t)}{M_3}\dot{m}_{31}\Delta t$$

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

$$dm_3^i(t) = \frac{m_2^i(t)}{M_2}\dot{m}_{23}\Delta t - \frac{m_3^i(t)}{M_3}\dot{m}_{32}\Delta t + \frac{m_1^i(t)}{M_1}\dot{m}_{13}\Delta t - \frac{m_3^i(t)}{M_3}\dot{m}_{31}\Delta t$$

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 and j reactors, [Mg/min]

t – time, [min]

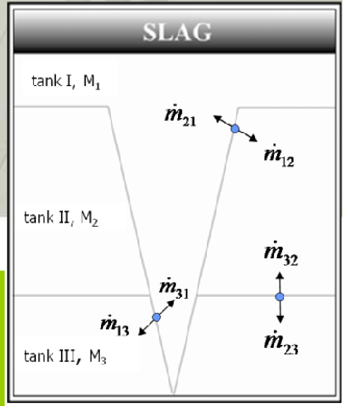
$$m_1^i(t+\Delta t) = m_1^i(t) + dm_1^i(t)$$

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

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

Structure of hybrid model

Mixing model



$$dm_1^i(t) = -\frac{m_1^i(t)}{M_1}\dot{m}_{12}\Delta t + \frac{m_2^i(t)}{M_2}\dot{m}_{21}\Delta t - \frac{m_1^i(t)}{M_1}\dot{m}_{13}\Delta t + \frac{m_3^i(t)}{M_3}\dot{m}_{31}\Delta + \Delta m_1^i(t)_{eq}$$

Thermodynamic model

Input FactSage

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

Output FactSage

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

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

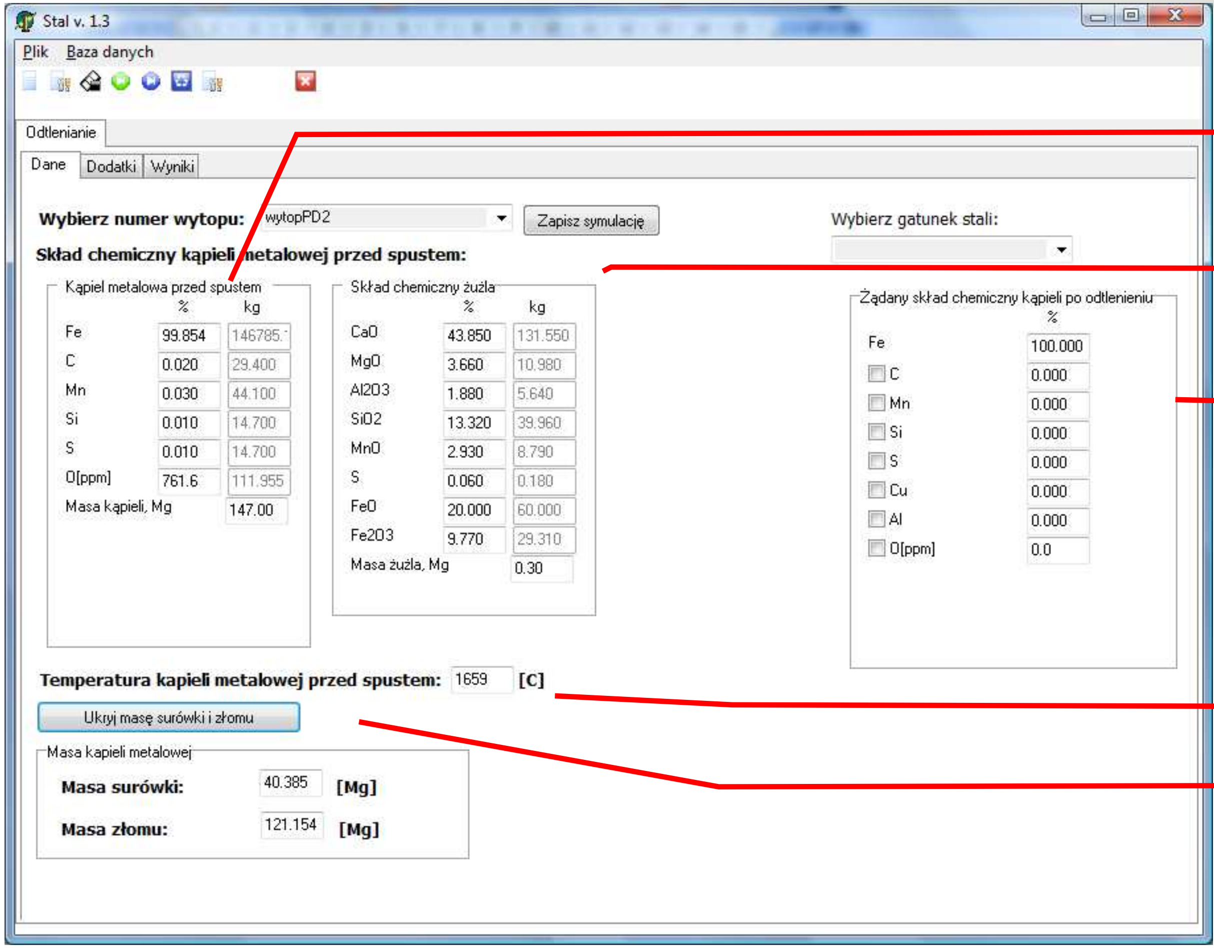
The thicknesses of metal and slag layers which reach the state of mutual equilibrium depends on both the intensity of bath stirring and the calculation time interval value.

Program to simulation processes - main window

Deoxidation

Refining

Deoxidation model – input data



Chemical composition of metal bath

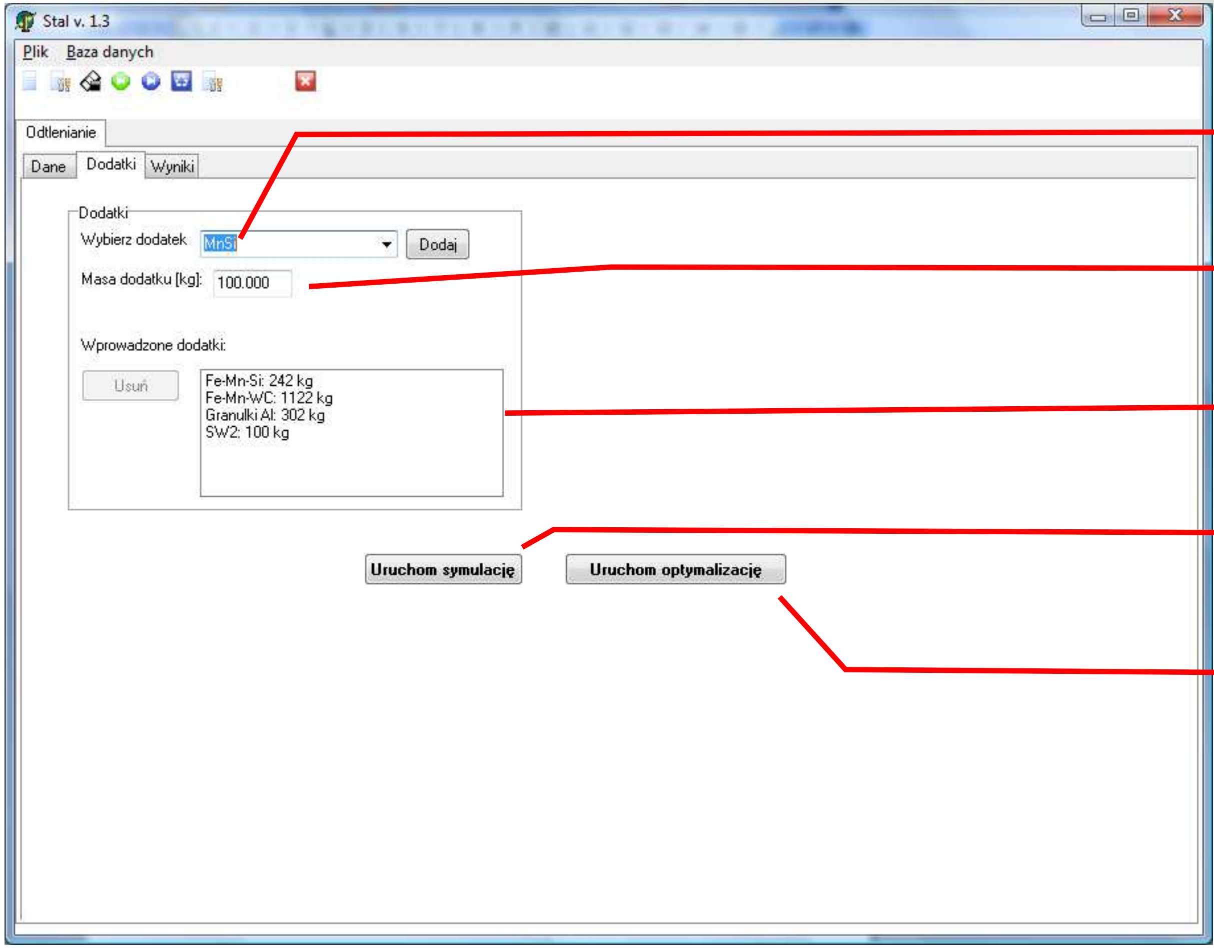
Chemical composition of converter slag

Set chemical composition of metal bath

Metal bath temperature

Tool for calculation of metal bath weight base on hot metal and scrap

Deoxidation model – additions



Base of additions

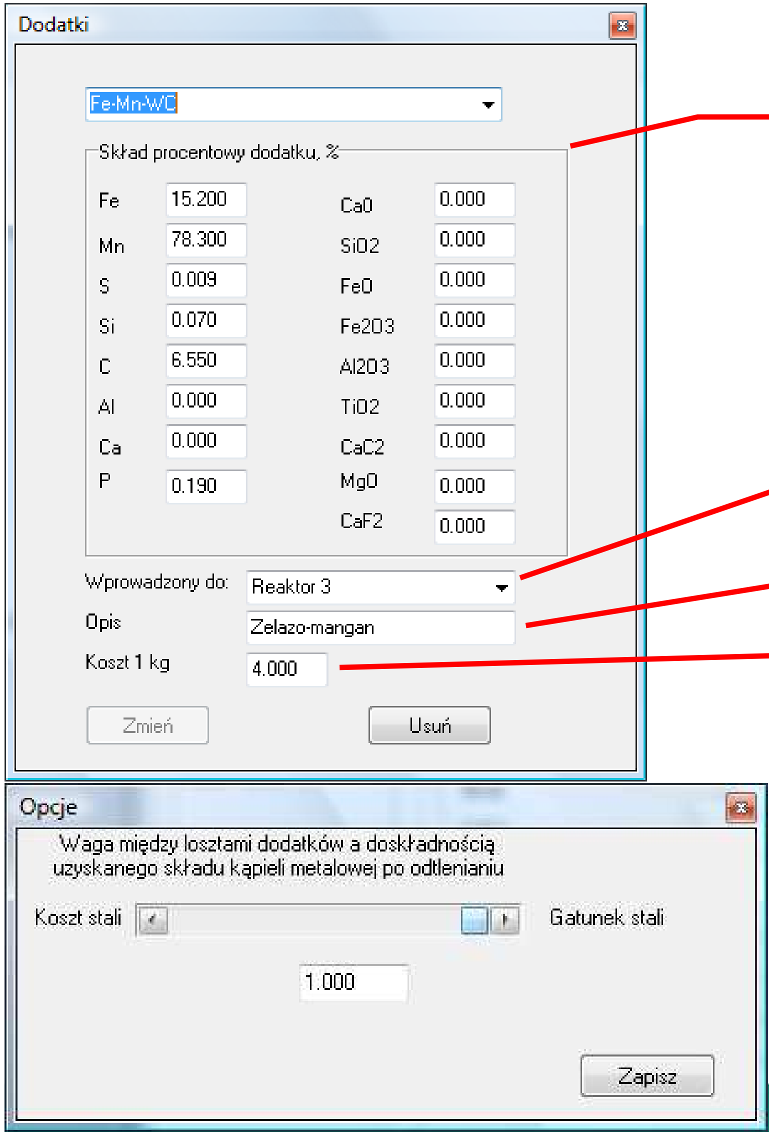
Mass of added addition

Added additions

Button for starting simulation

Button for optimization

Deoxidation model – base of additions, option for optimization



Chemical composition

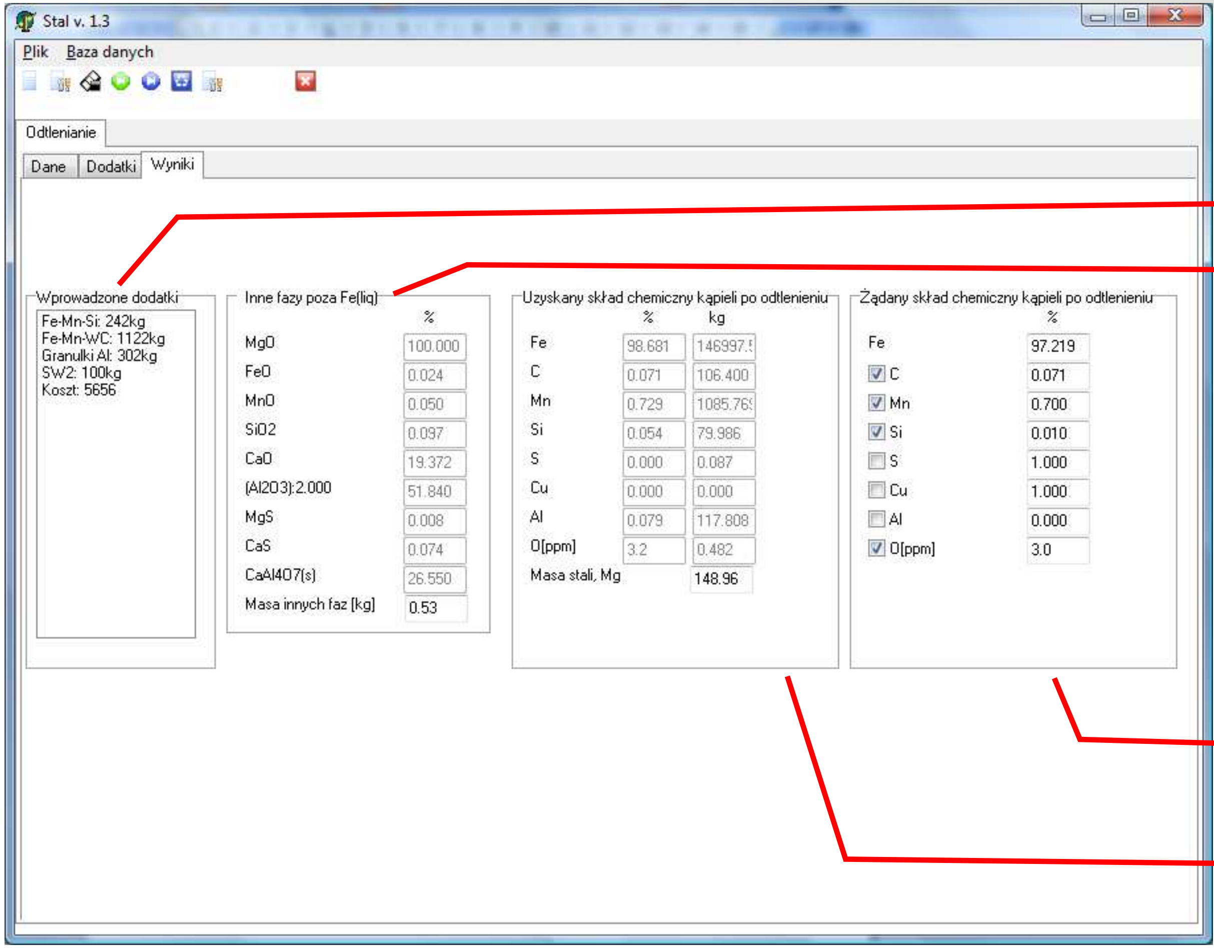
No. of tank

Description

Cost of 1 kg

Set a balance between cost of addition and accuracy of chemical composition of steel - optimisation process

Deoxidation model – results



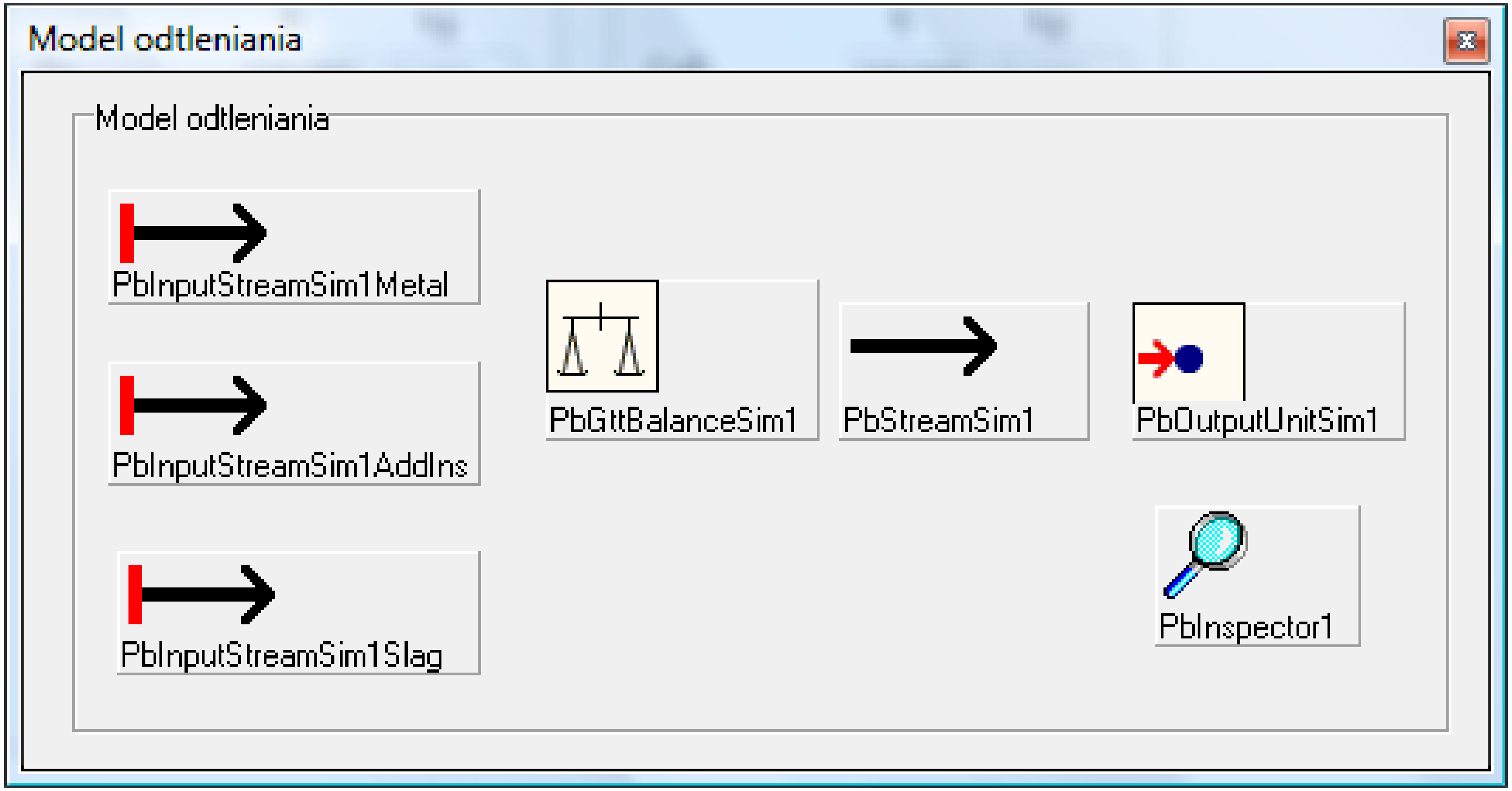
List of used additions

List of non-metallic phases

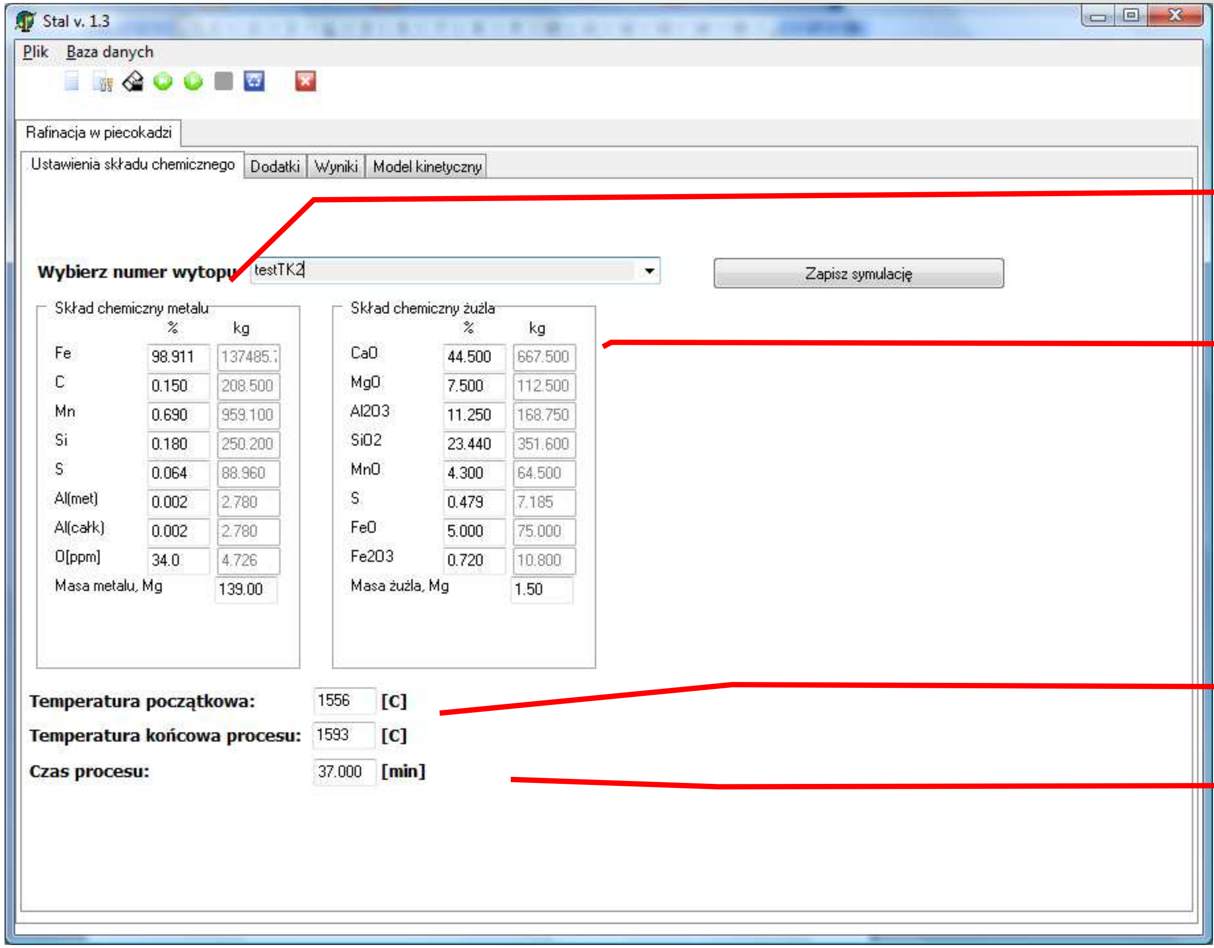
Chemical composition of metal bath from optimisation

Chemical composition of metal bath after deoxidation

Deoxidation model



Refining model – input data



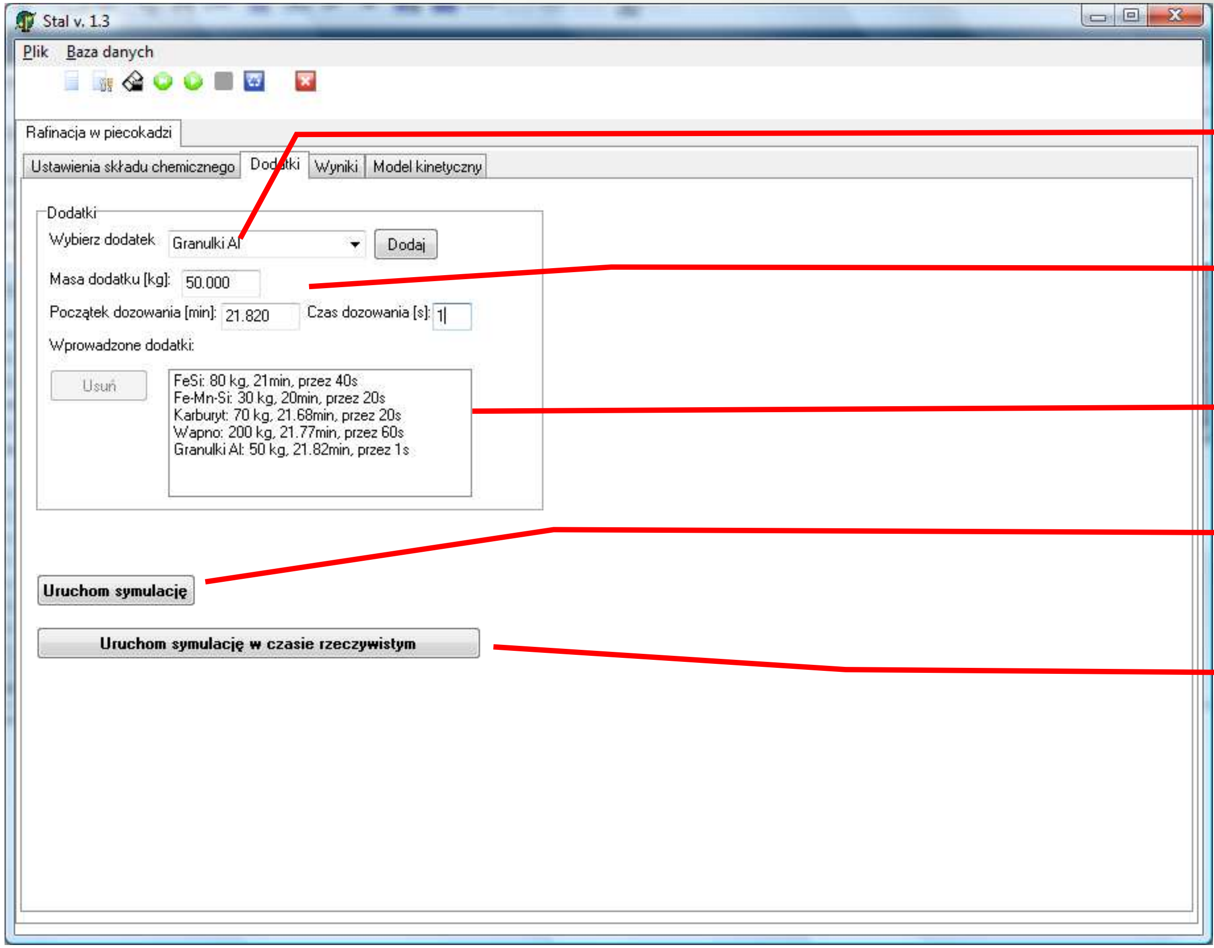
Chemical composition of metal bath

Chemical composition of refining slag

Metal bath temperature (start, end)

Time of refining in the furnace ladle

Deoxidation model – additions



Base of additions

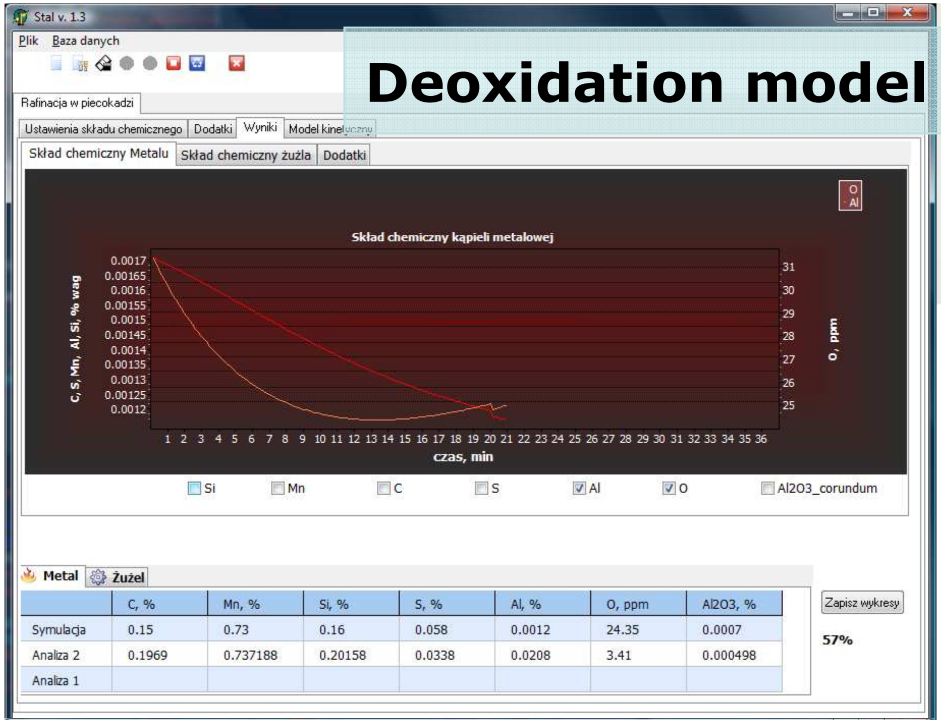
Mass and setup time of put in an addition

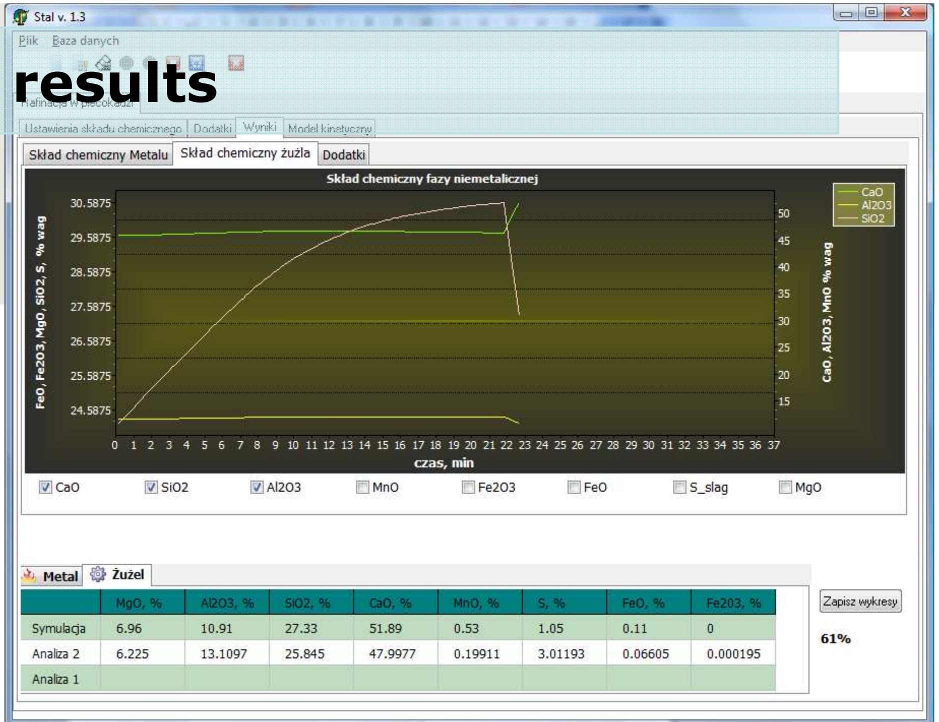
Added additions

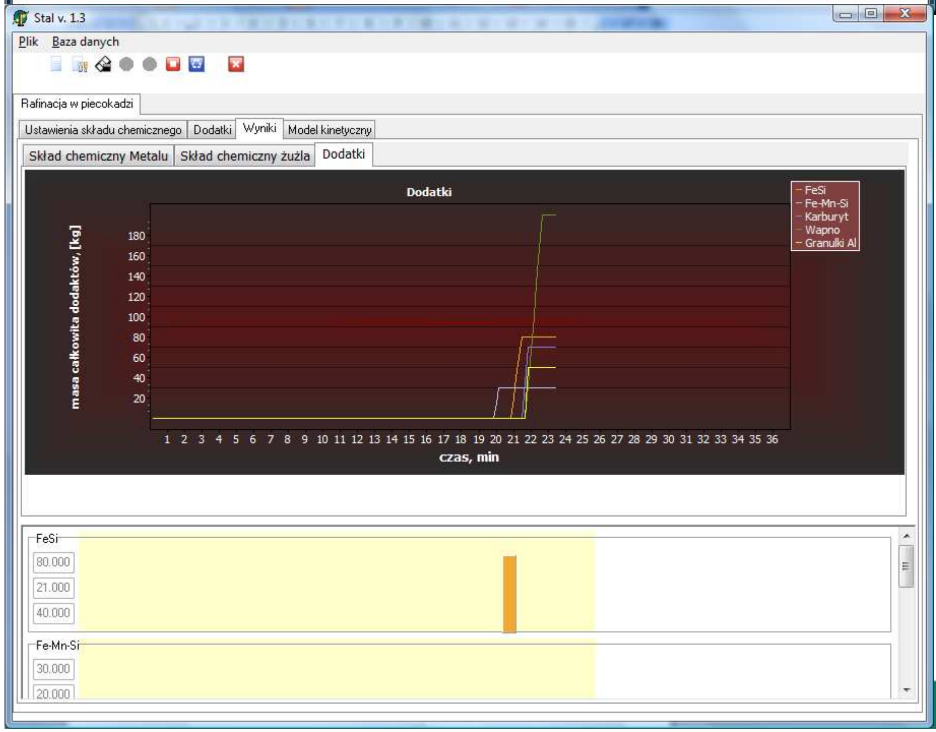
Button for starting simulation

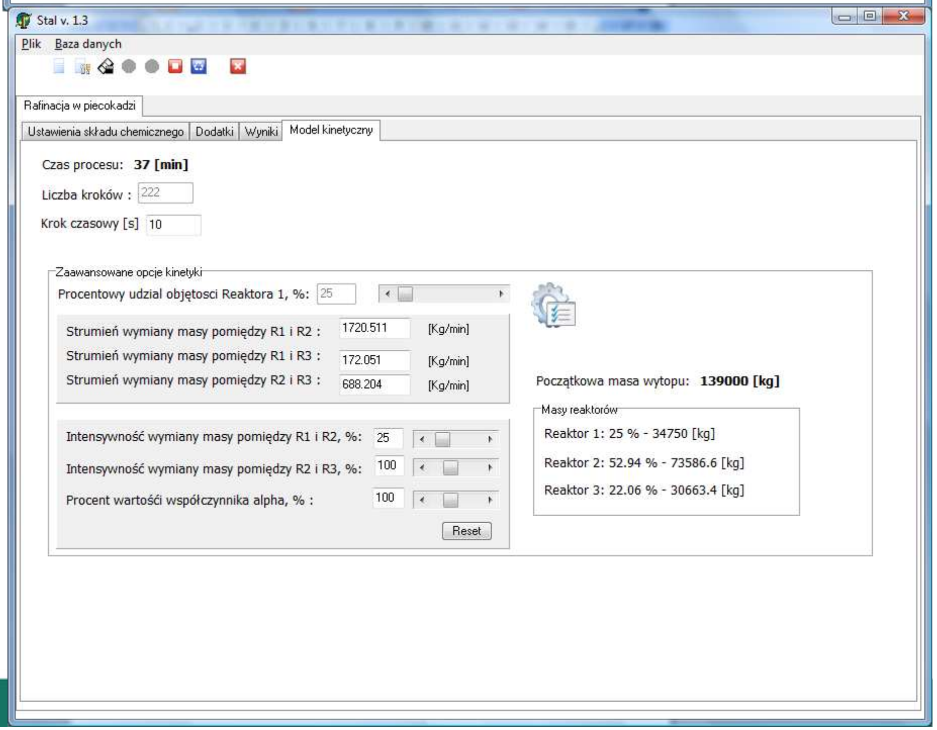
Button for simulation in real time

Deoxidation model – results

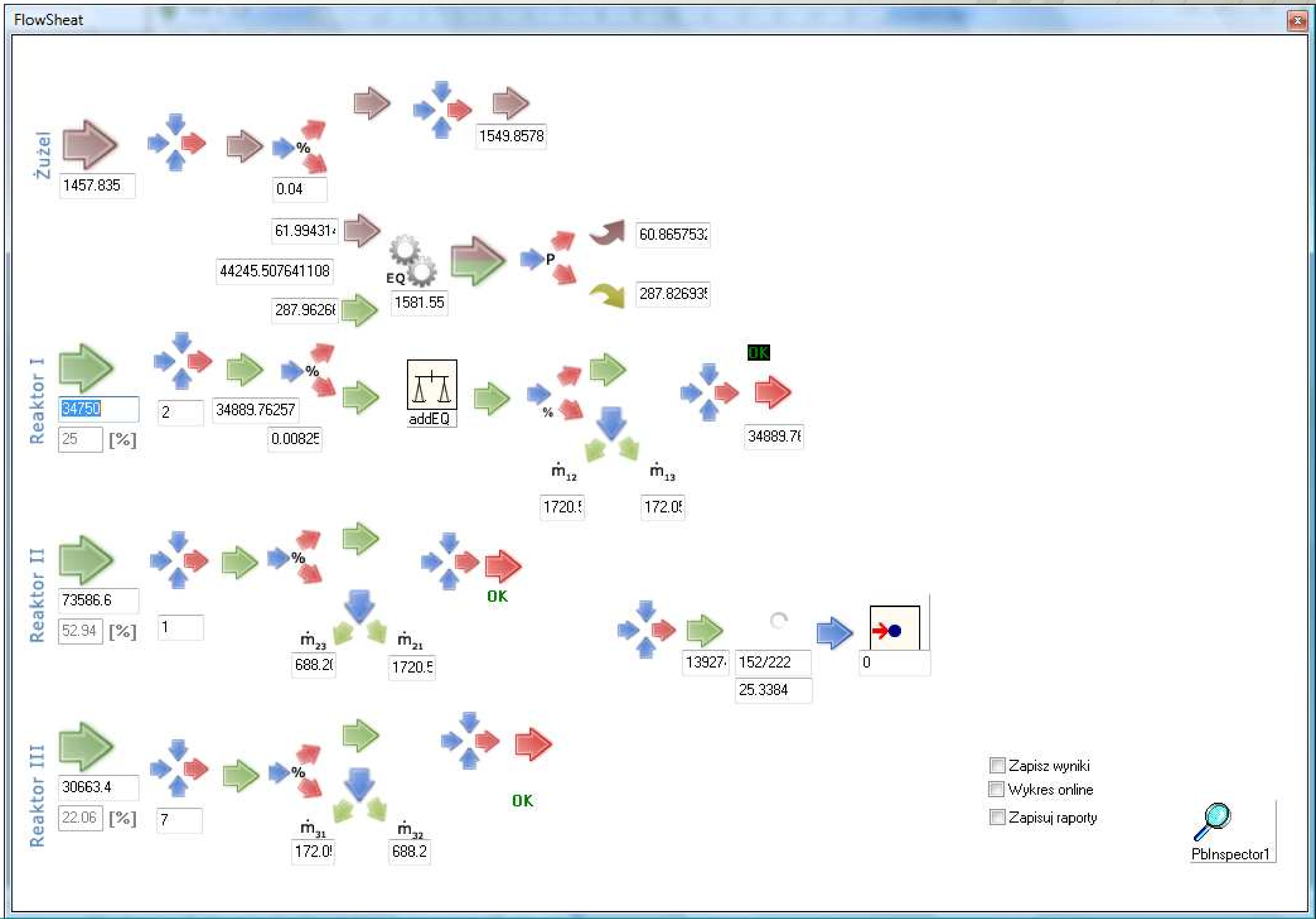








Refining model



Conclusion

- For refining in the ladle it is purposeful to create a static model in order to determine precisely the weight of the alloy additions.
- Proposed model allows to determine the equilibrium state in very complicated metal-slag configurations.
- Complementing the static model with the dynamic one enables it to monitor the dynamics in change of metal and slag chemical compositions, and consequently to prepare better the metal bath for a continuous caster.
- The model calculation time is shorter than the process time and therefore it is possible to use it for on-line control.

Thank You

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