



**AGH UNIVERSITY OF SCIENCE
AND TECHNOLOGY**

Simulation of Deoxidation and Refining Process Using SimuSage

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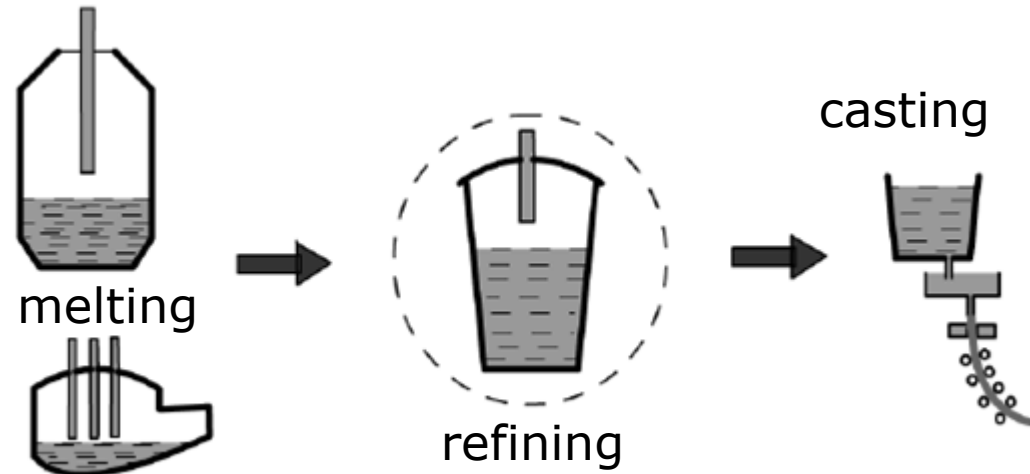


Contents

- Main Process Parameters
- Assumptions to models development
- Dedicated tool for process simulation using SimuSage
- Conclusions

Deoxidation Process Parameters during tapping

Slag	Metal	Additions
<ul style="list-style-type: none"> □ weight and chemical composition of the converter slag getting into the ladle during tapping □ oxygen activity before the deoxidation process startup □ final chemical composition 	<ul style="list-style-type: none"> □ weight after tapping from the furnace □ start temperature □ start chemical composition □ oxygen activity before and after the deoxidation process 	<ul style="list-style-type: none"> □ 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
<ul style="list-style-type: none"> □ weight and chemical composition of the slag before refining the refining process startup □ oxygen activity before the refining process startup □ final chemical composition 	<ul style="list-style-type: none"> □ 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 	<ul style="list-style-type: none"> □ weight of the additions put into metal at the ladle furnace post and their chemical composition



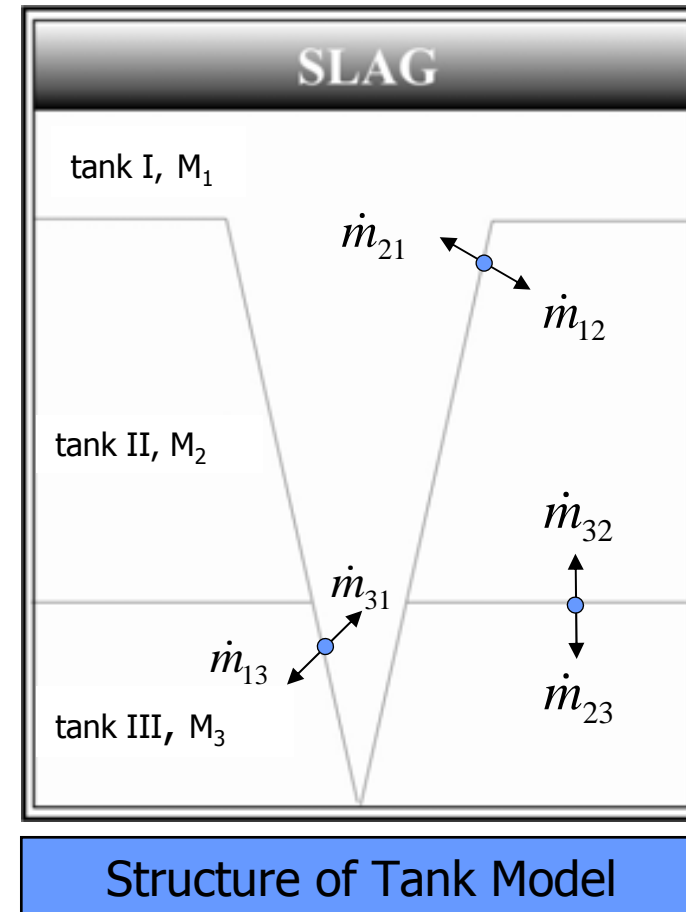
Assumptions to static models development

- 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}



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]

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

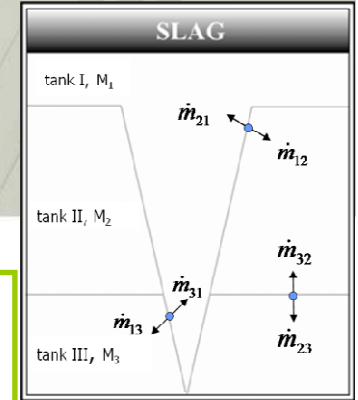
$$m_2^i(t + \Delta t) = m_2^i(t) + dm_2^i(t)$$

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

Structure of hybrid model

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

Mixing model



Input FactSage

Thermodynamic model

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

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

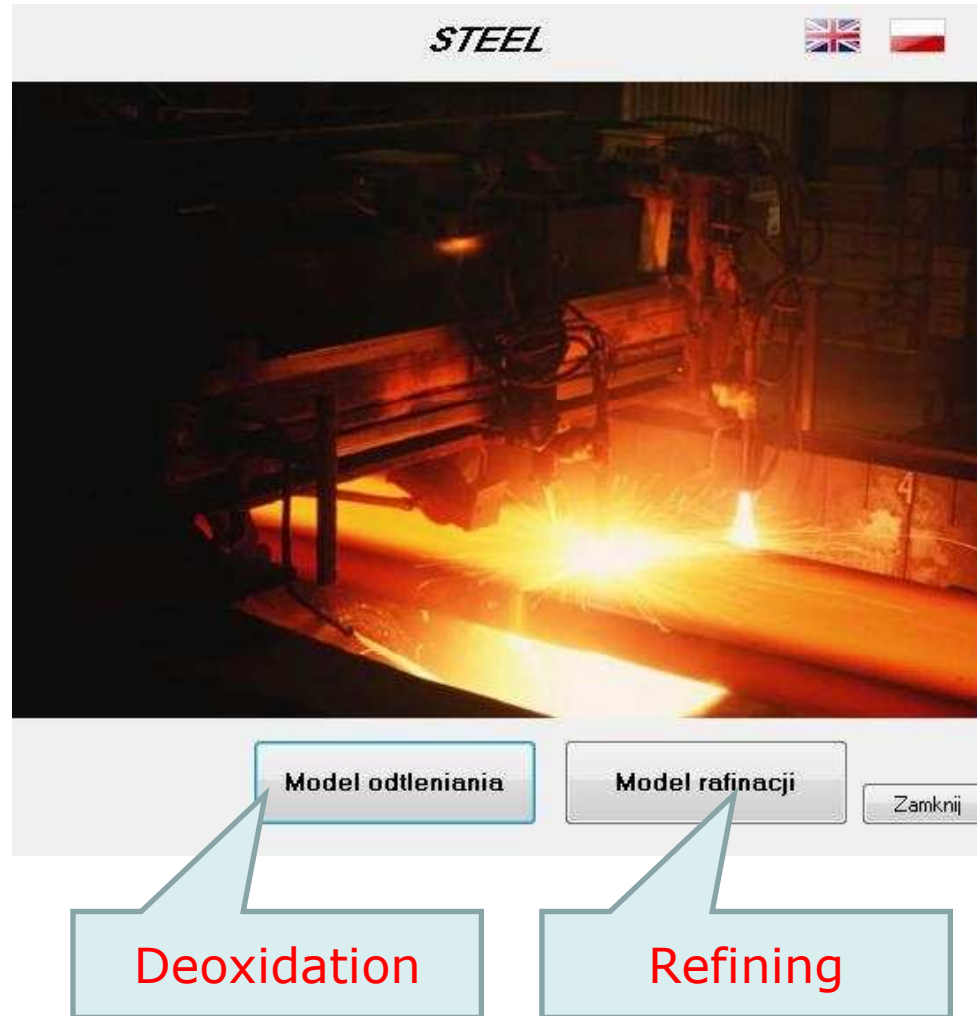
Output FactSage

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

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.



Program to simulation processes - main window





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Deoxidation model – input data

Stal v. 1.3

Plik Baza danych

Odtlenianie

Dane Dodatki Wyniki

Wybierz numer wytopu: wytopPD2 Zapisz symulację

Wybierz gatunek stali:

Skład chemiczny kąpieli metalowej przed spustem:

Kąpiel metalowa przed spustem		
	%	kg
Fe	99.854	146785.1
C	0.020	29.400
Mn	0.030	44.100
Si	0.010	14.700
S	0.010	14.700
O(ppm)	761.6	111.955
Masa kąpieli, Mg		147.00

Skład chemiczny żużła		
	%	kg
CaO	43.850	131.550
MgO	3.660	10.980
Al ₂ O ₃	1.880	5.640
SiO ₂	13.320	39.960
MnO	2.930	8.790
S	0.060	0.180
FeO	20.000	60.000
Fe ₂ O ₃	9.770	29.310
Masa żużła, Mg		0.30

Żądany skład chemiczny kąpieli po odtlenieniu

	%
Fe	100.000
<input type="checkbox"/> C	0.000
<input type="checkbox"/> Mn	0.000
<input type="checkbox"/> Si	0.000
<input type="checkbox"/> S	0.000
<input type="checkbox"/> Cu	0.000
<input type="checkbox"/> Al	0.000
<input type="checkbox"/> O(ppm)	0.0

Temperatura kąpieli metalowej przed spustem: 1659 [C]

Ukryj masę surówki i złomu

Masa kąpieli metalowej

Masa surówki: 40.385 [Mg]

Masa złomu: 121.154 [Mg]

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



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Deoxidation model – additions

Stal v. 1.3

Plik Baza danych

Odlenianie

Dane Dodatki Wyniki

Dodatki

Wybierz dodatek: MnSi Dodaj

Masa dodatku [kg]: 100.000

Wprowadzone dodatki:

Usuń

Fe-Mn-Si: 242 kg
Fe-Mn-WC: 1122 kg
Granulki Al: 302 kg
SW2: 100 kg

Uruchom symulację

Uruchom optymalizację

Base of additions

Mass of added
addition

Added additions

Button for starting
simulation

Button for
optimization



Deoxidation model – base of additions, option for optimization

Dodatki

Fe-Mn-WC

Skład procentowy dodatku, %

Fe	15.200	CaO	0.000
Mn	78.300	SiO2	0.000
S	0.009	FeO	0.000
Si	0.070	Fe2O3	0.000
C	6.550	Al2O3	0.000
Al	0.000	TiO2	0.000
Ca	0.000	CaC2	0.000
P	0.190	MgO	0.000
		CaF2	0.000

Wprowadzony do: Reaktor 3

Opis: Żelazo-mangan

Koszt 1 kg: 4.000

Zmień Usuń

Chemical composition

No. of tank

Description

Cost of 1 kg

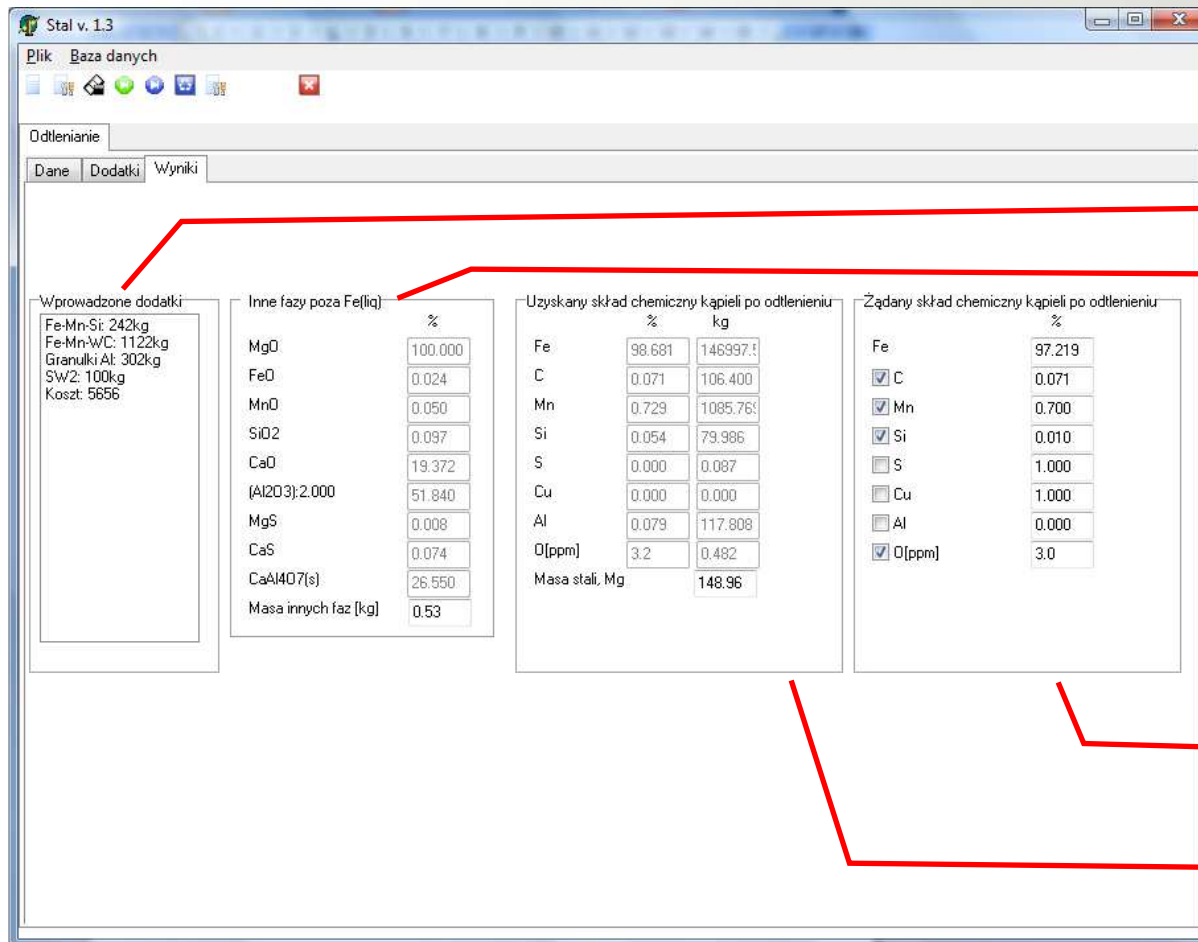
Set a balance between cost of addition and accuracy of chemical composition of steel - optimisation process

Opcje

Waga między loszami dodatków a dokładnością uzyskanego składu kąpieli metalowej po odlenianiu

Koszt stali: 1.000 Gatunek stali

Zapisz



List of used additions

List of non-metallic phases

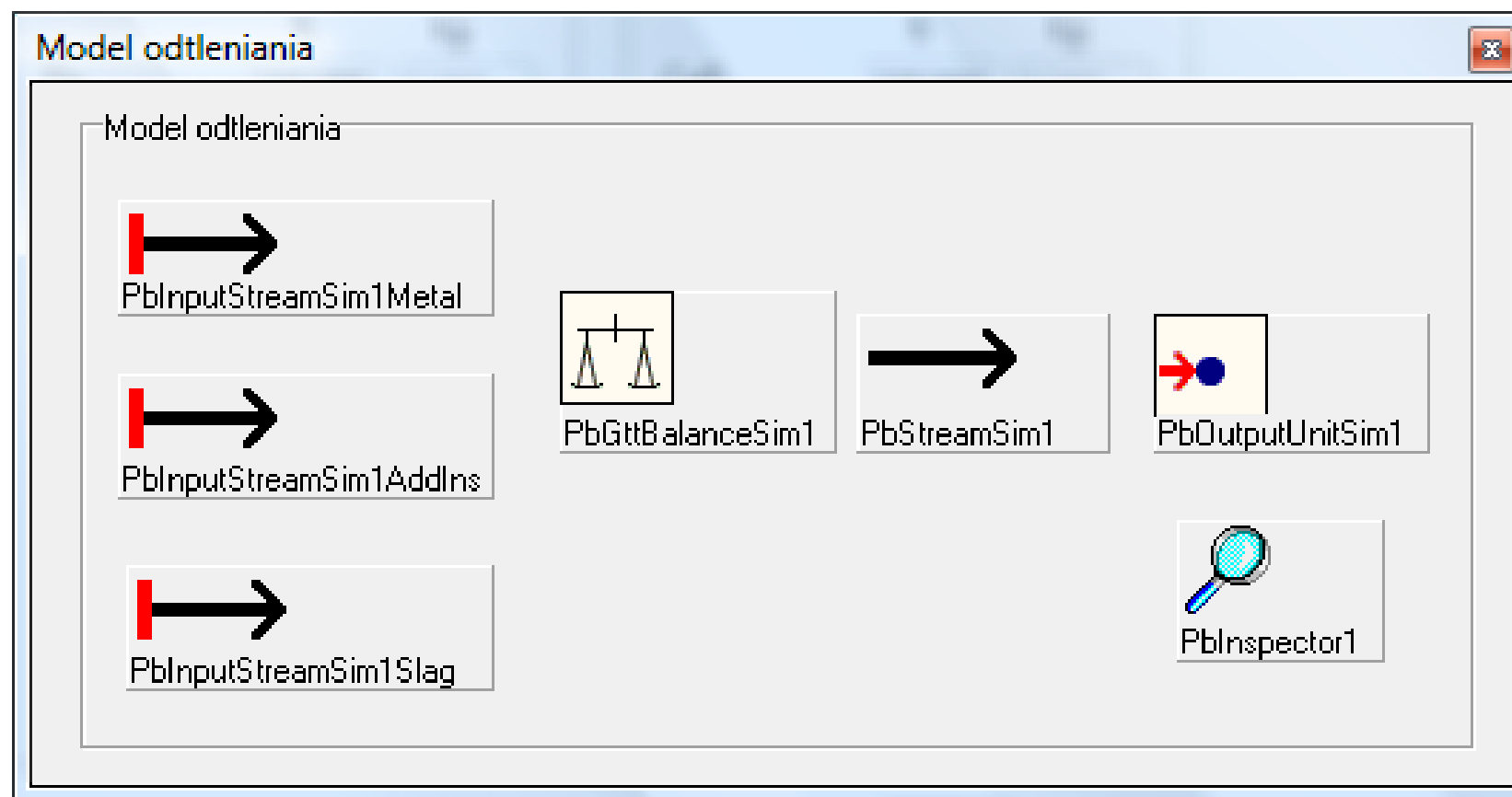
Chemical composition of metal bath from optimisation

Chemical composition of metal bath after deoxidation



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Deoxidation model





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Refining model – input data

Stal v. 1.3

Plik Baza danych

Rafinacja w piecokadzi

Ustawienia składu chemicznego Dodatki Wyniki Model kinetyczny

Wybierz numer wytopu testTK2 Zapisz symulację

Skład chemiczny metalu		
	%	kg
Fe	98.911	137485.7
C	0.150	208.500
Mn	0.690	959.100
Si	0.180	250.200
S	0.064	88.960
Al(met)	0.002	2.780
Al(całk)	0.002	2.780
O(ppm)	34.0	4.726
Masa metalu, Mg		139.00

Skład chemiczny żużła		
	%	kg
CaO	44.500	667.500
MgO	7.500	112.500
Al ₂ O ₃	11.250	168.750
SiO ₂	23.440	351.600
MnO	4.300	64.500
S	0.479	7.185
FeO	5.000	75.000
Fe ₂ O ₃	0.720	10.800
Masa żużła, Mg		1.50

Temperatura początkowa: 1556 [C]

Temperatura końcowa procesu: 1593 [C]

Czas procesu: 37.000 [min]

Chemical composition
of metal bath

Chemical composition
of refining slag

Metal bath
temperature
(start, end)

Time of refining in the
furnace ladle



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Deoxidation model – additions

Stal v. 1.3

Plik Baza danych

Rafinacja w piecokadzi

Ustawienia składu chemicznego Dodatki Wyniki Model kinetyczny

Dodatki

Wybierz dodatek: Granulki Al

Masa dodatku [kg]: 50.000

Początek dozowania [min]: 21.820 Czas dozowania [s]: 1

Wprowadzone dodatki:

FeSi: 80 kg, 21min, przez 40s
Fe-Mn-Si: 30 kg, 20min, przez 20s
Karbonyt: 70 kg, 21.68min, przez 20s
Wapno: 200 kg, 21.77min, przez 60s
Granulki Al: 50 kg, 21.82min, przez 1s

Base of additions

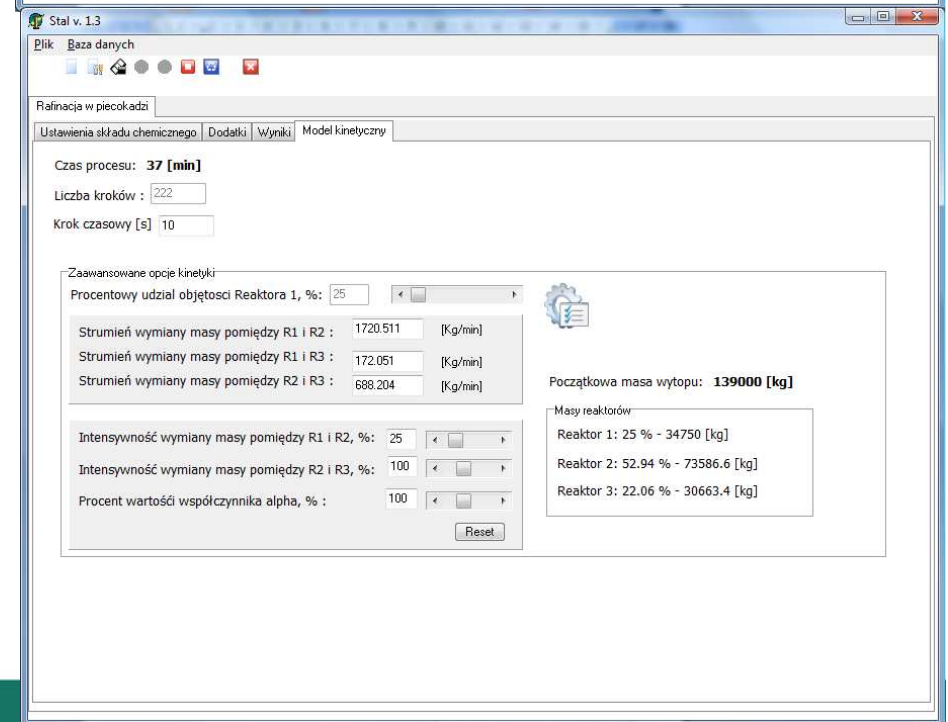
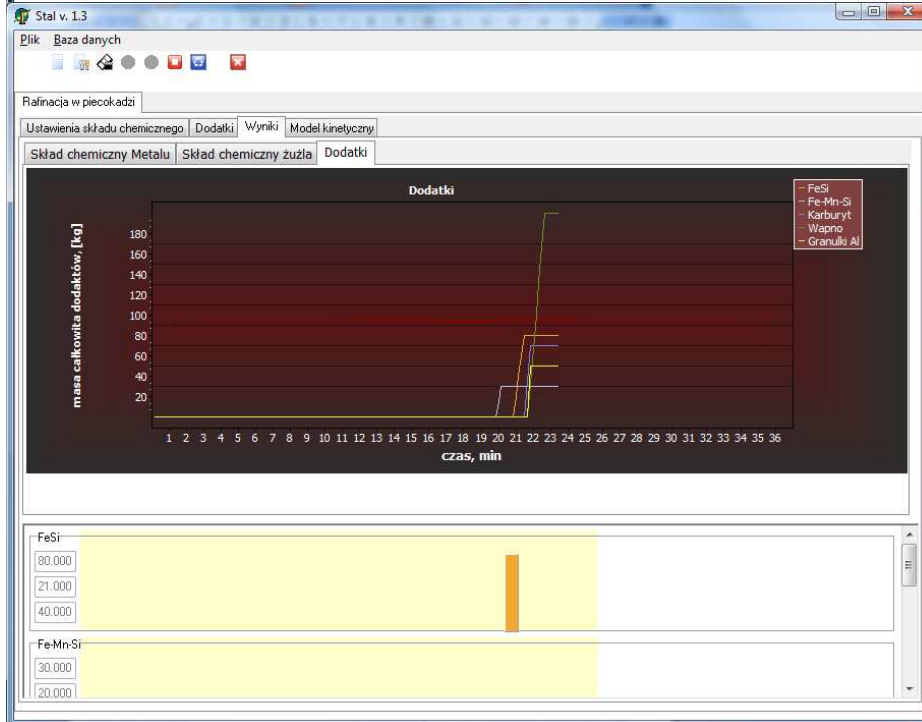
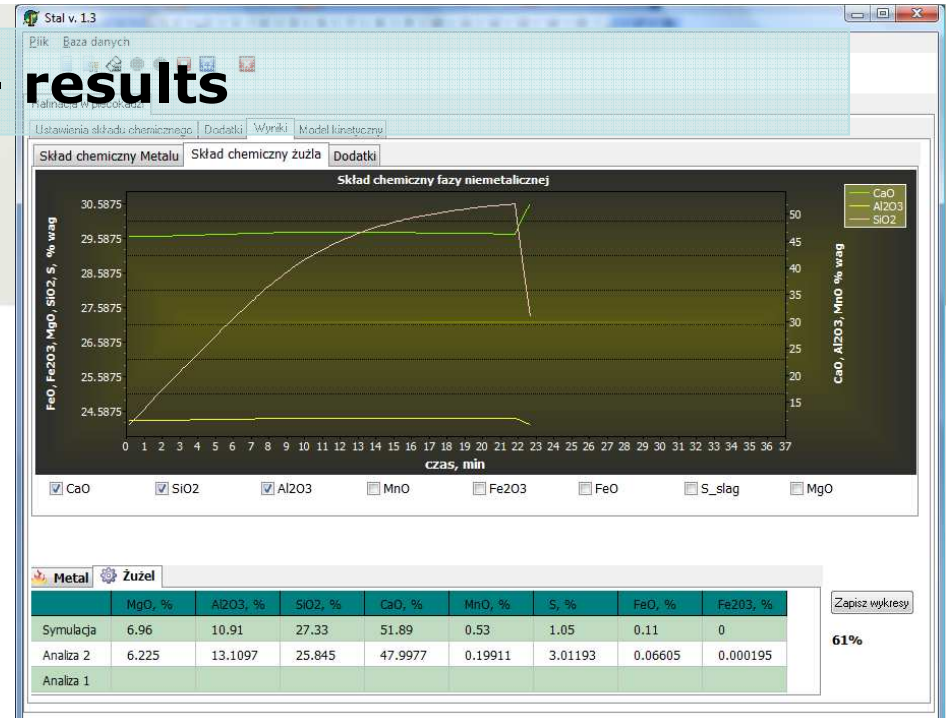
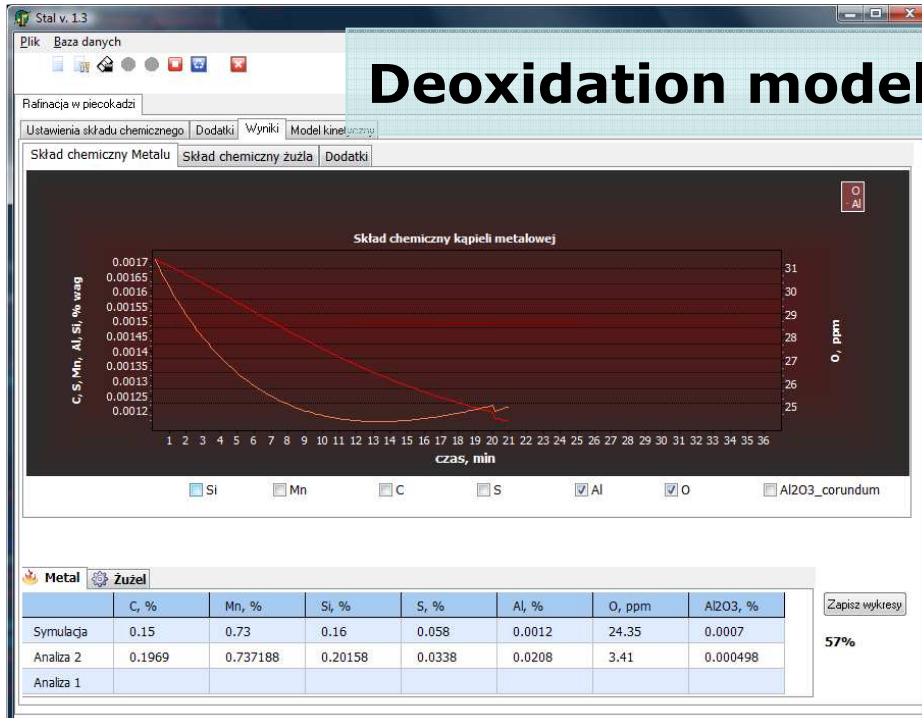
Mass and setup time
of put in an addition

Added additions

Button for starting
simulation

Button for simulation
in real time

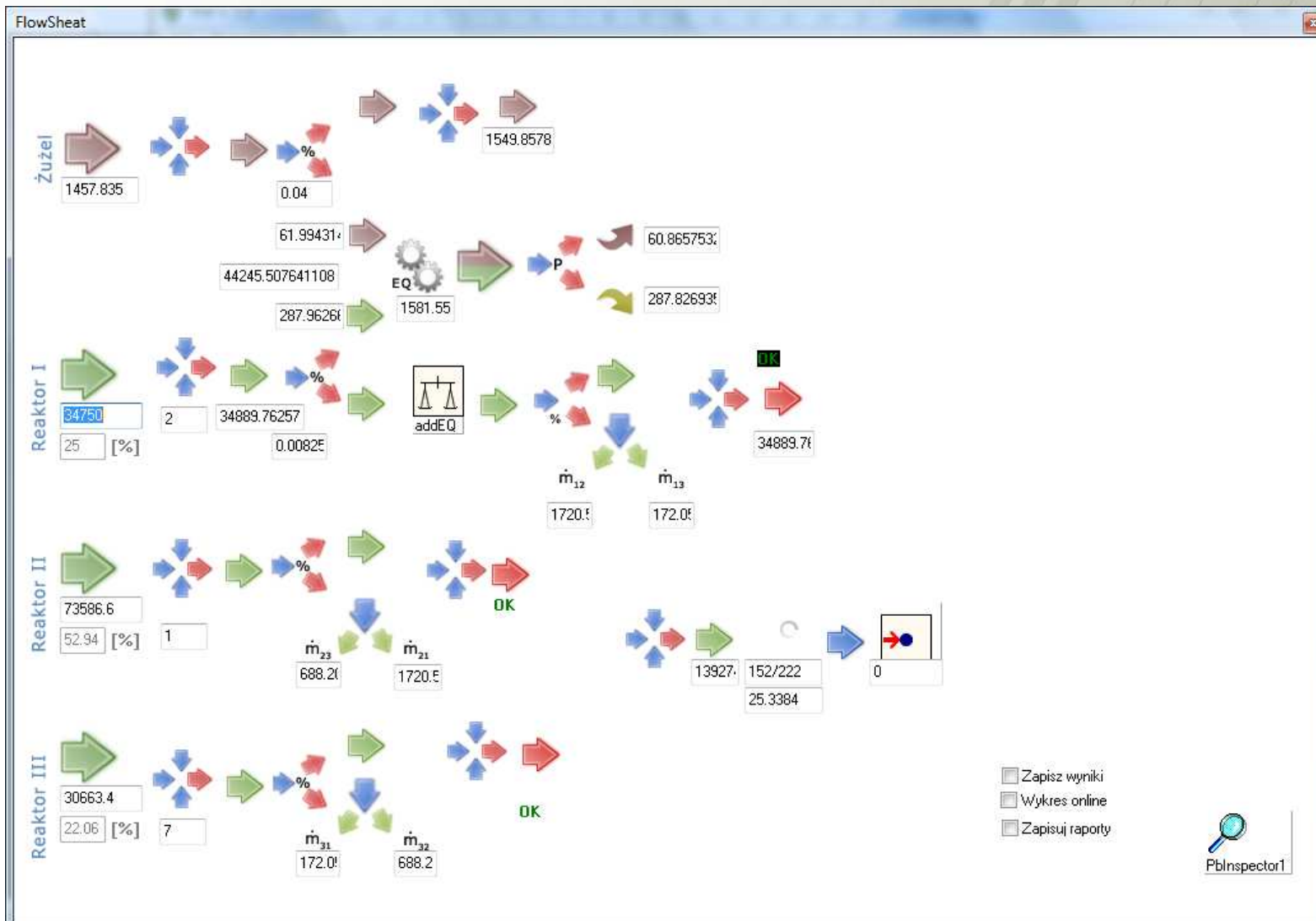
Deoxidation model – results





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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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