Modification of inclusion composition in steel during secondary metallurgical ladle treatment

A comprehensive process simulation model

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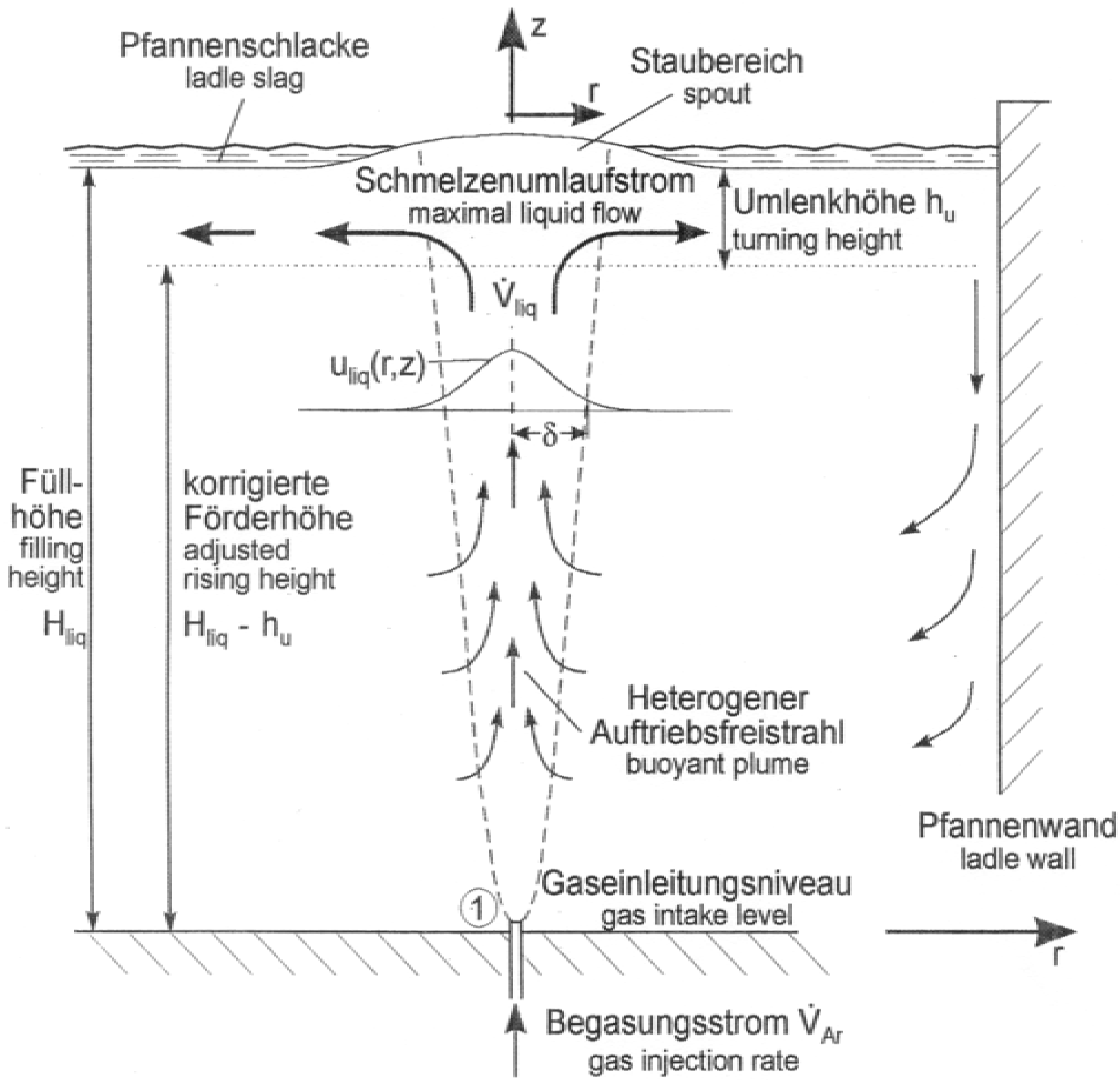
Contents

Tasks in the ladle metallurgy:

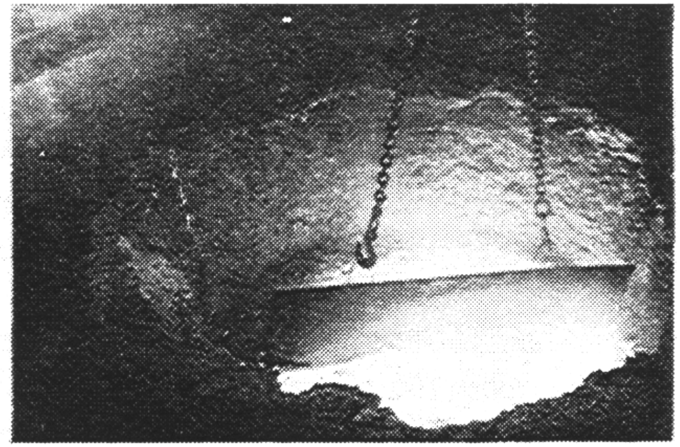
•adjustment of chemical comp.
•adjustment of temperature
•separation of inclusions
•….

Intention:
to develop the robust model predicting the inclusion composition and amount which can be used on line in the process

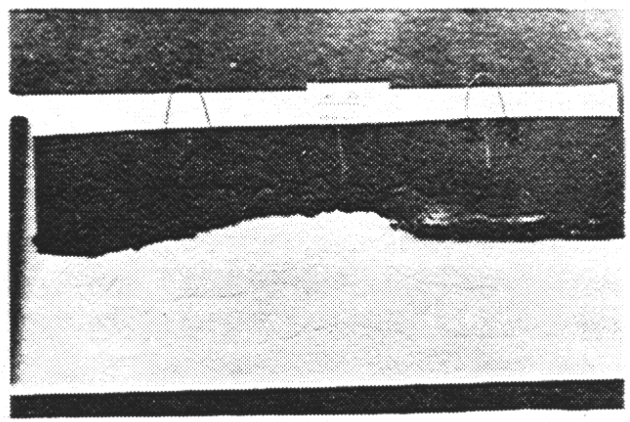
Sketch of the buoyant plume flow pattern



Industrial experiments, 30 t ladle



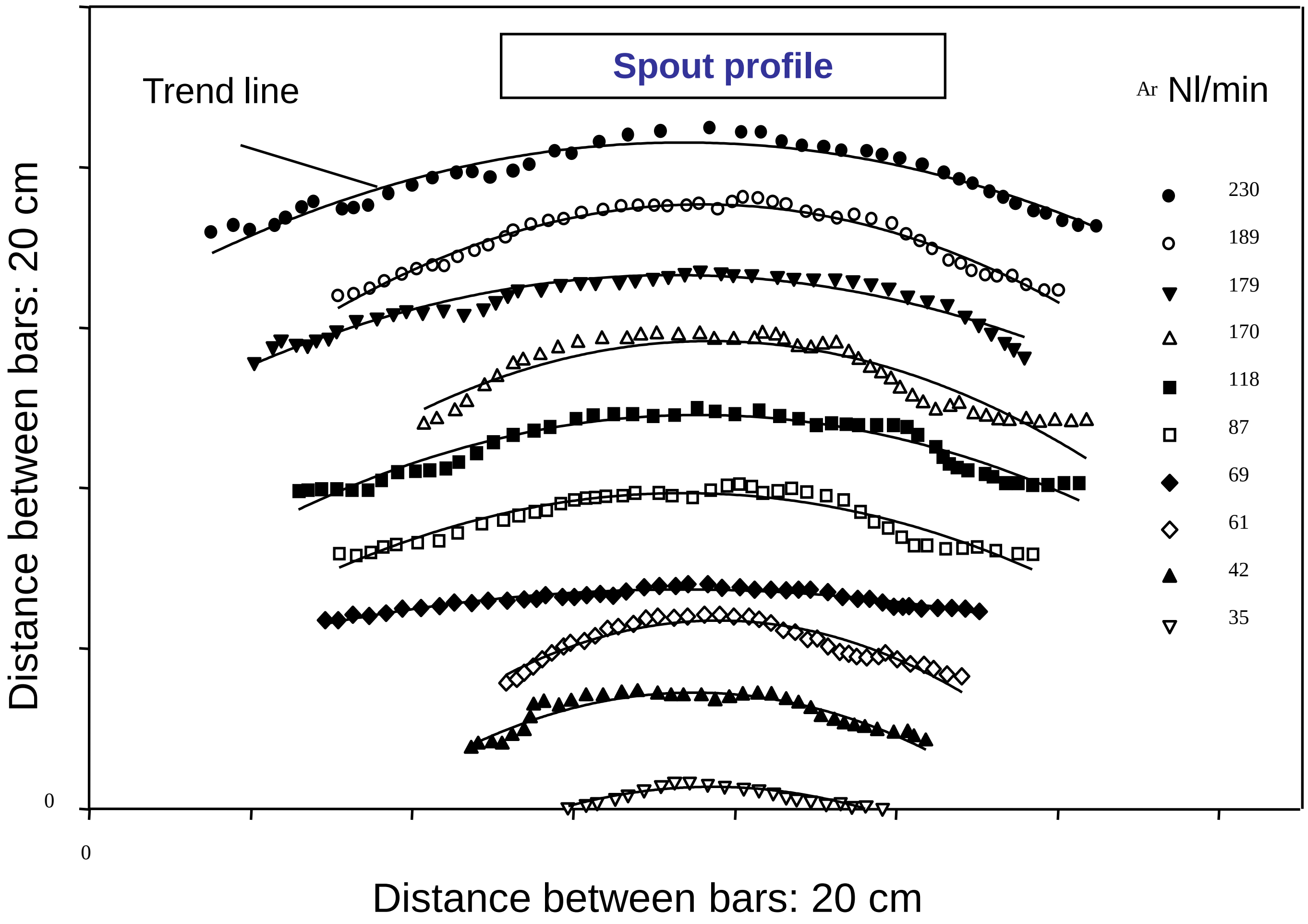
a) spout profile measuring



b) plate after melting procedure

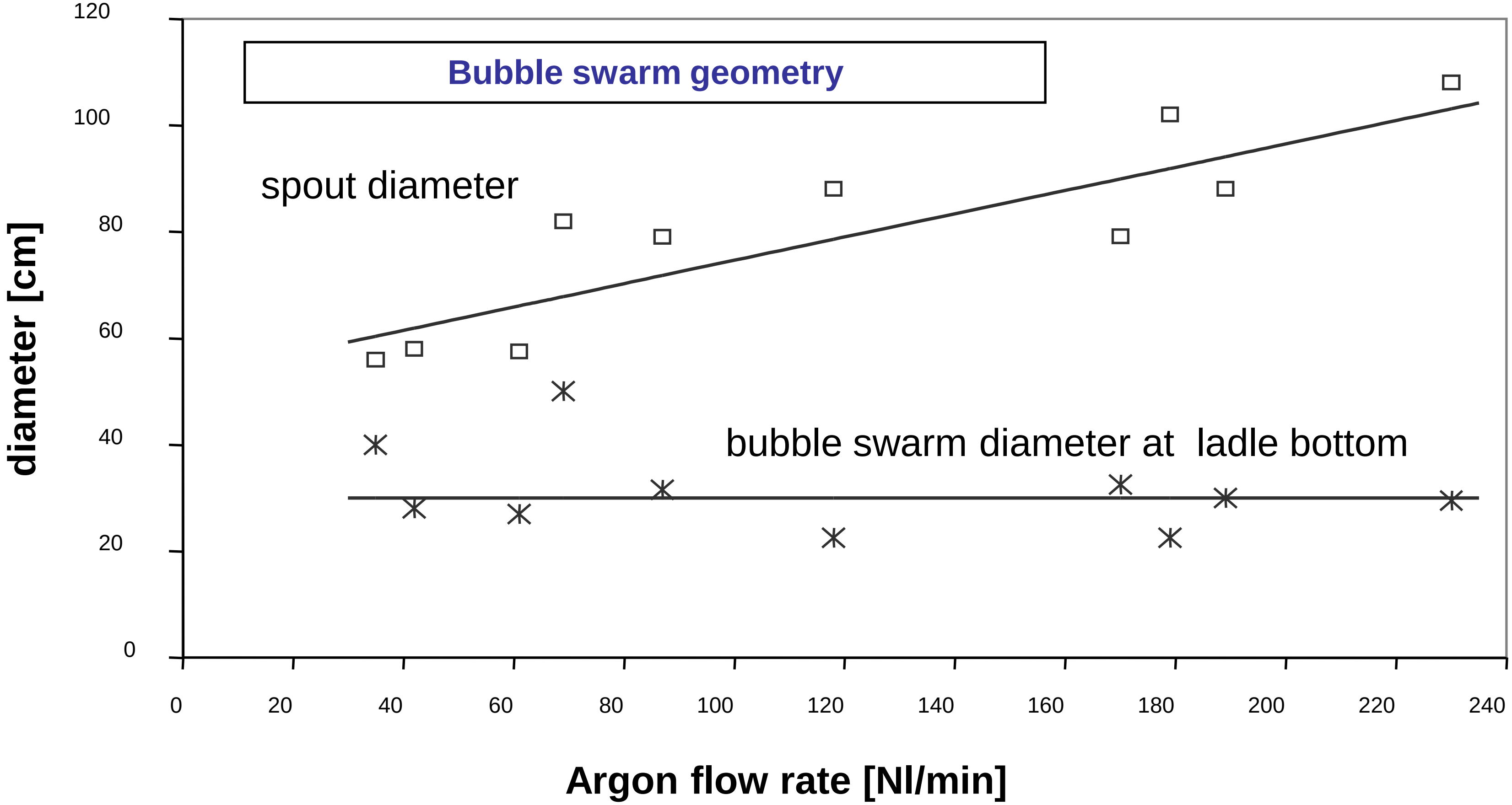
E. Steinmetz, and P.R. Scheller, *Stahl und Eisen,* 1987, no. 9, p. 57-65

Spout and bubble swarm geometry in 30t melts

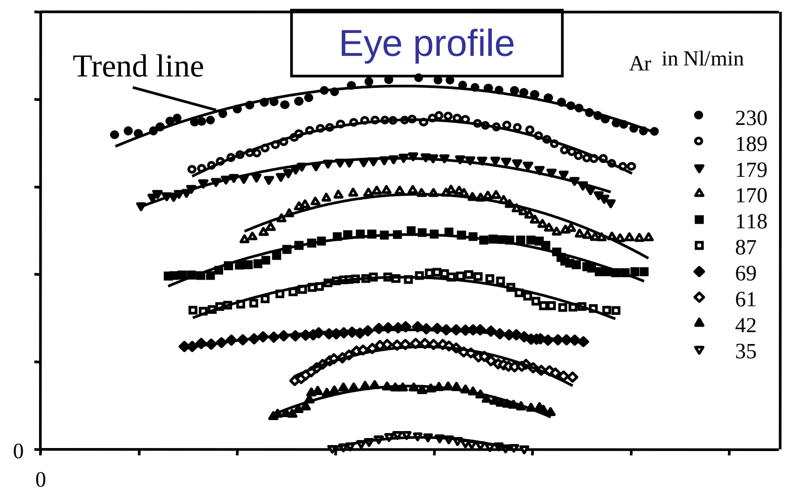


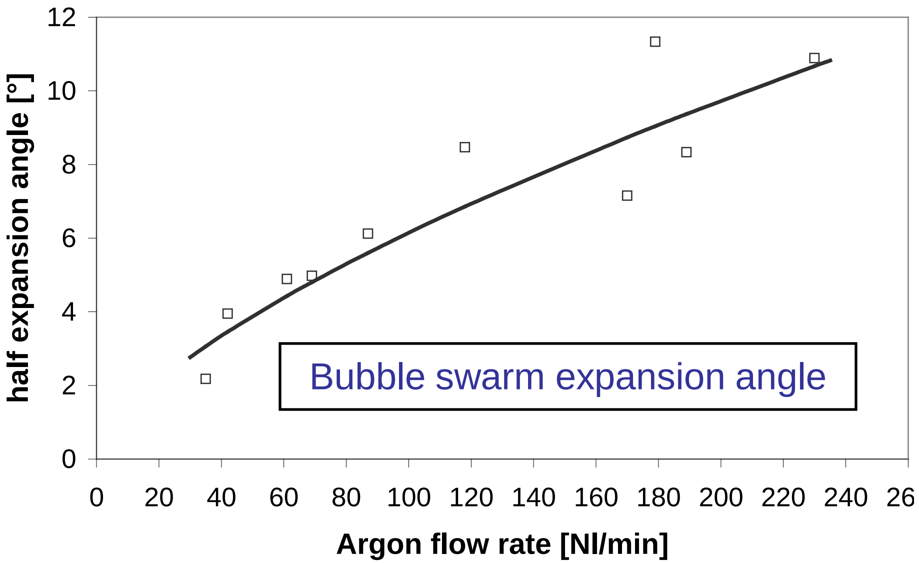
E. Steinmetz, and P.R. Scheller, *Stahl und Eisen,* 1987, no. 9, p.57-65

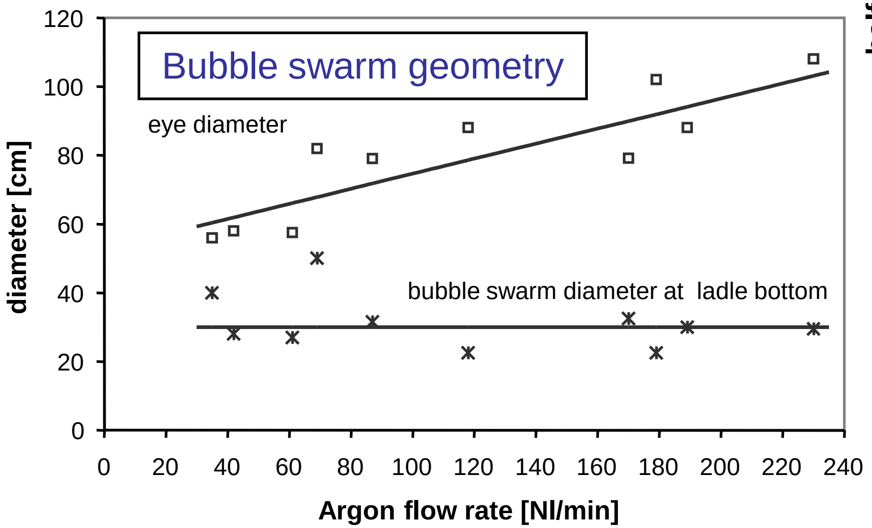
Spout and bubble swarm geometry in 30t melts



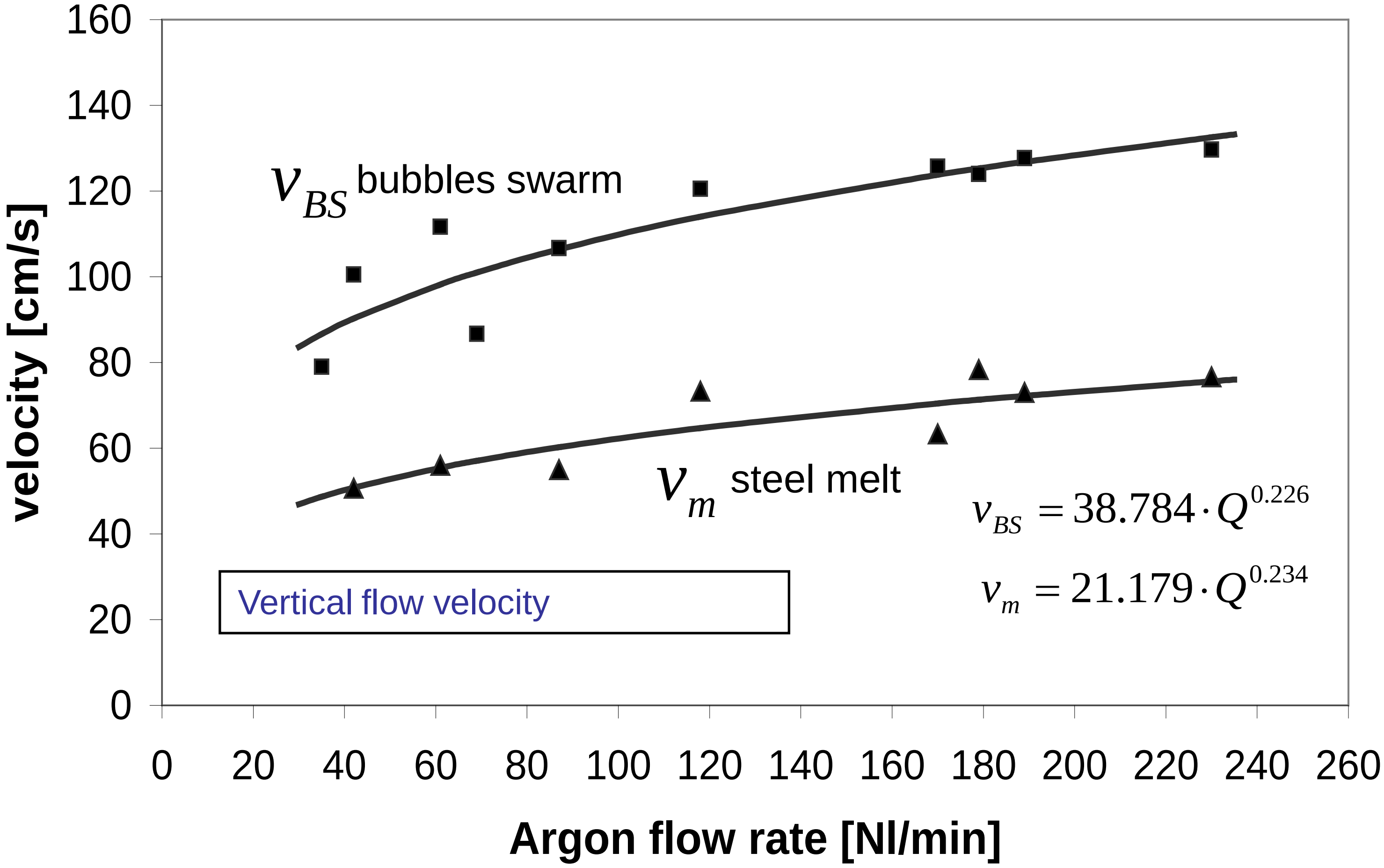
Eye and bubble swarm geometry in 30t melts



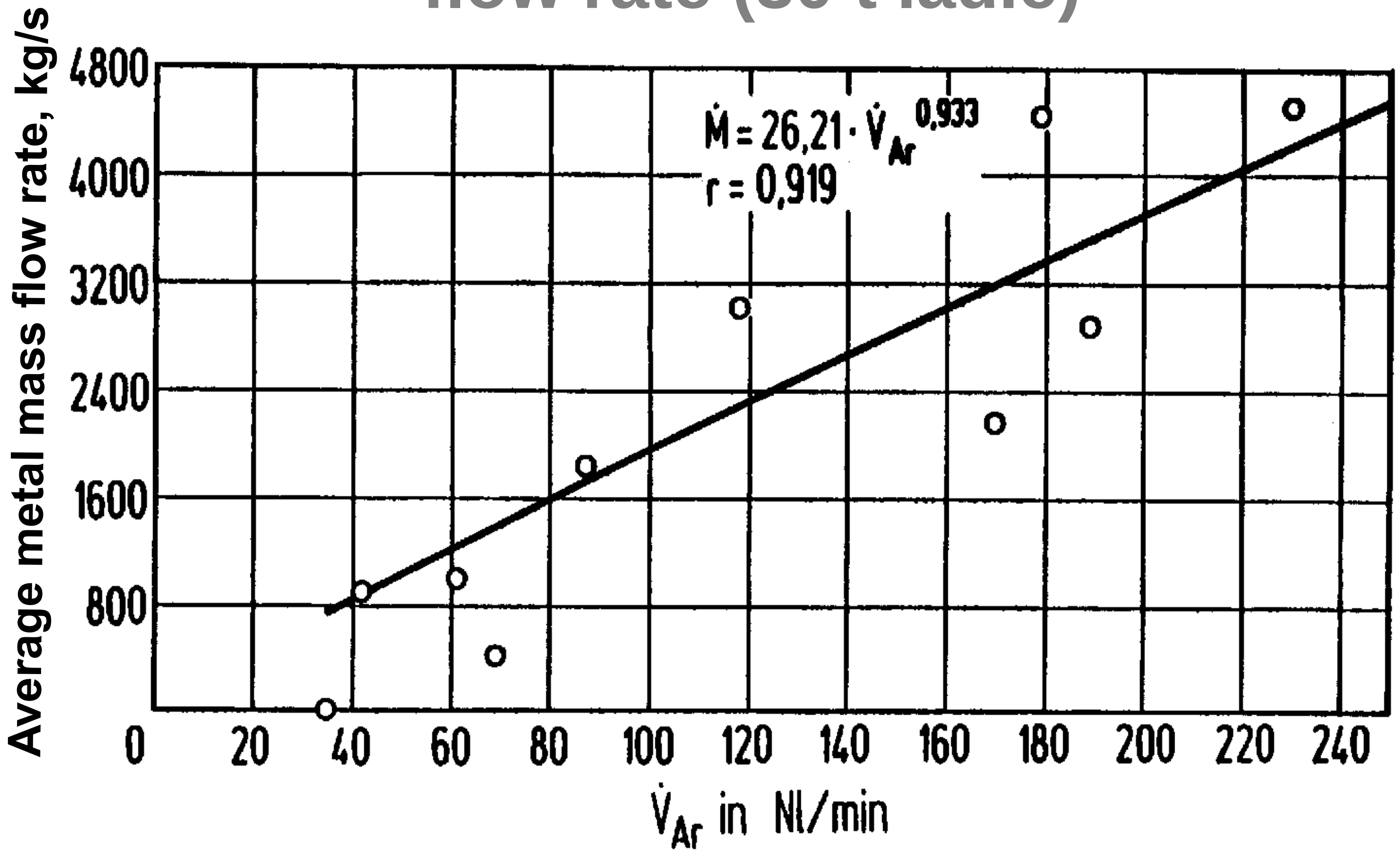




Ascending velocity of bubbles and of steel in the centre of the swarm, 30t melts



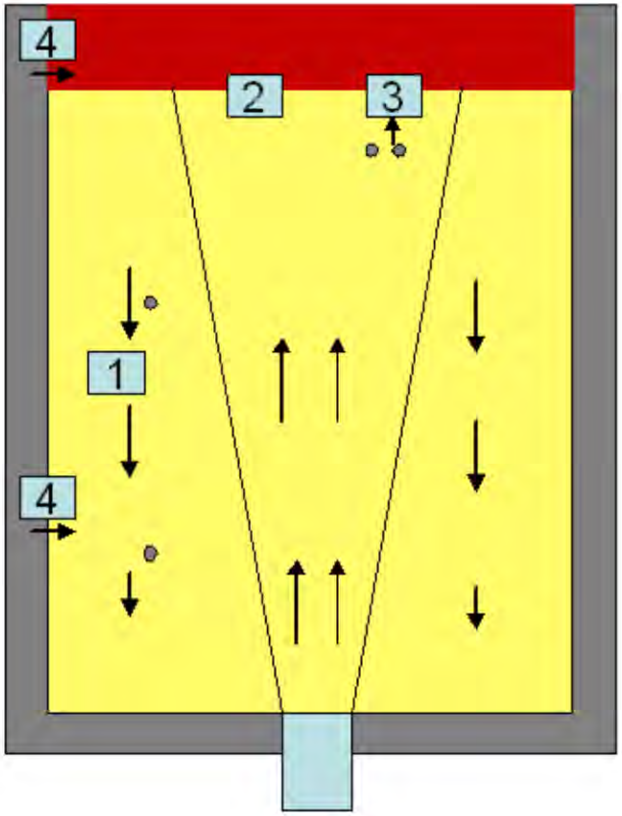
The average metal mass flow rate near the bath surface depending on Ar-gas flow rate (30 t ladle)



E.Steinmetz; P.R.Scheller: (1987)

A comprehensive model for inclusion composition in gas-stirred ladle

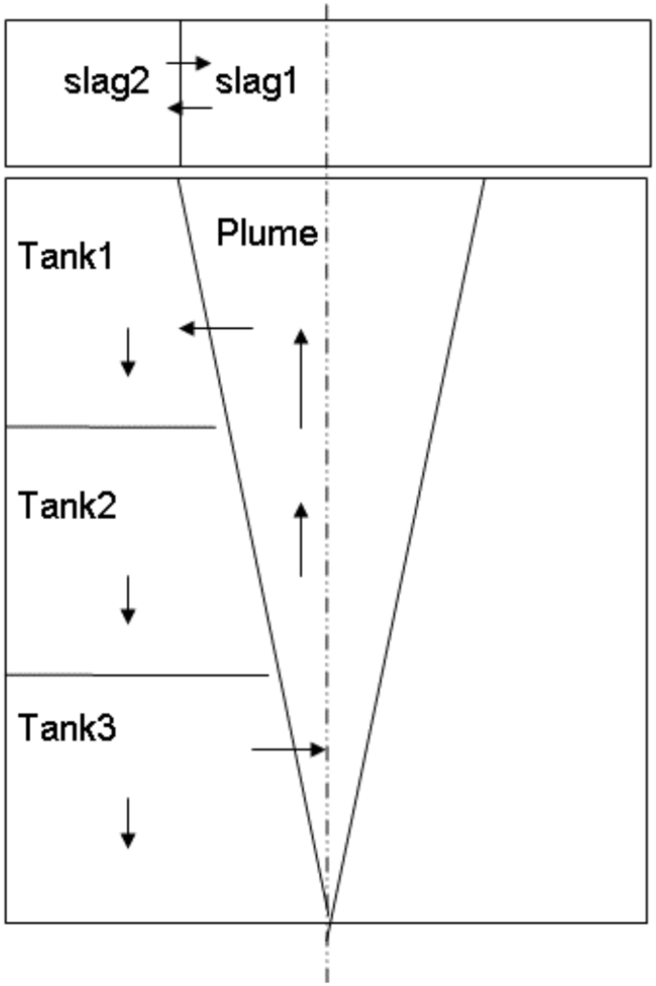
Model Description



Process parameters influencing inclusion evolution in gas stirred ladle:
1: Mixing in the ladle, 2: Slag-Metal reaction; 3: Inclusion separation;
4: Lining interaction with steel and slag

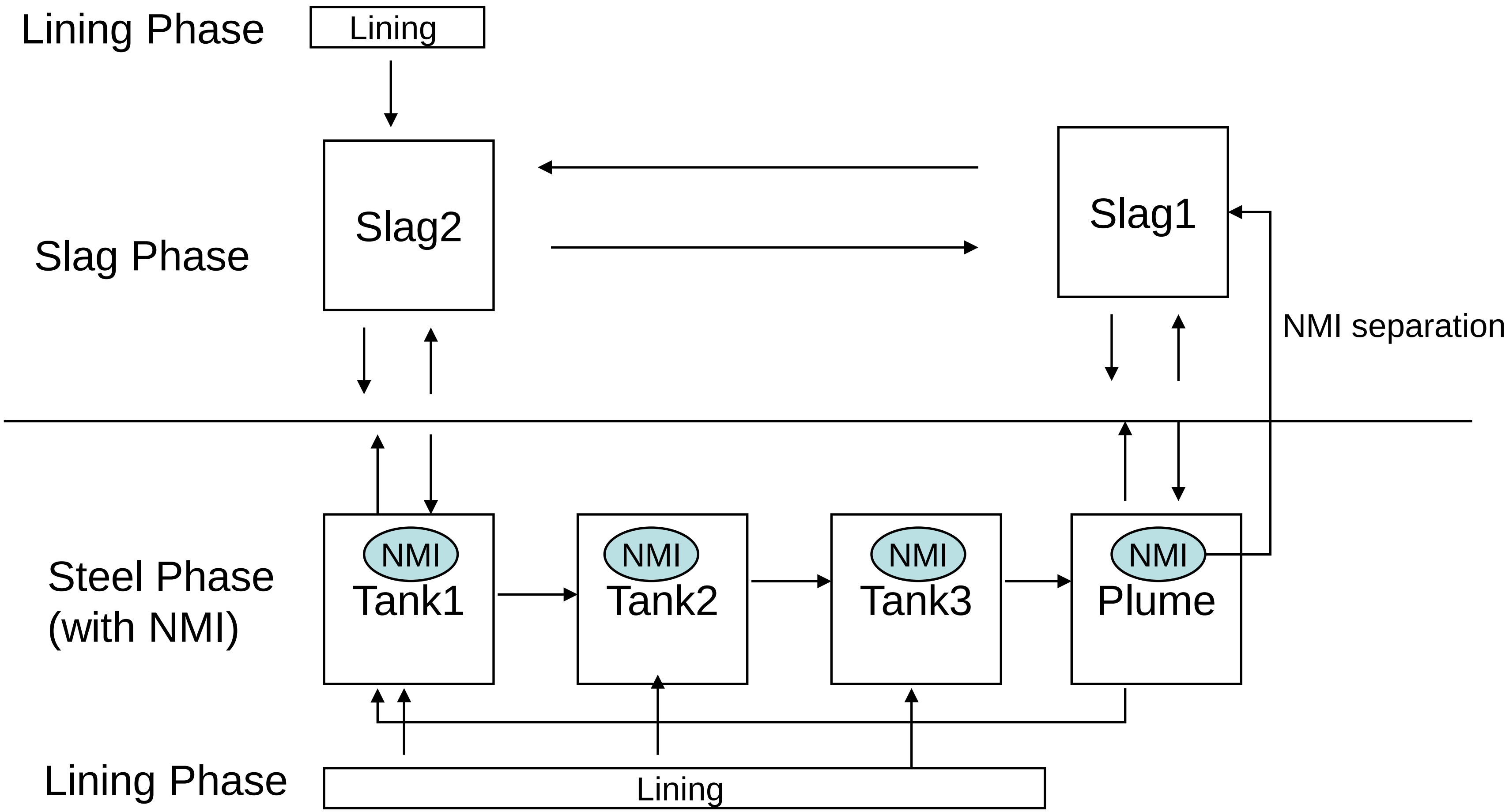
Model Description

Schema of the tanks for calculation of mixing



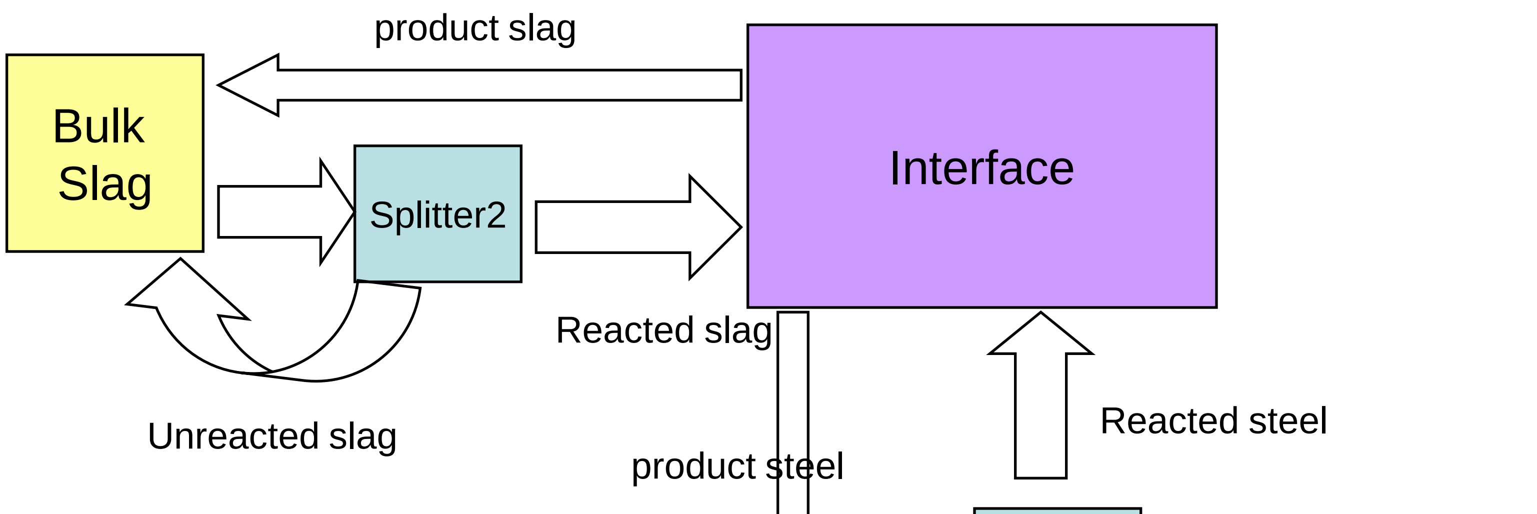
Model Description

Schema of the model



Model Description

Schema for slag-metal reaction



Mass of reacted steel

$$m_{ST} = k_{ST} \rho_{ST} A_{ST-SL} \Delta t$$

Mass of reacted Slag

$$m_{SL} = k_{SL} \rho_{SL} A_{ST-SL} \Delta t$$

Reaction in interface

$$m_{SL} + m_{ST} = m_{SL1} + m_{ST1}$$

Model Description

Model tools

SimuSage™

- SimuSage used as process simulation tool
  - Various basic unit operation components in SimuSage used:

    chemical reactor,

    mixer,

    splitter,

    iterator, …

FactSage™

- FactSage database to acquire thermodynamic data of various phase. (Steel, Slag, Inclusions, Lining refractory)

Local thermodynamic equilbiria

- Thermodynamic equilibrium between steel and inclusions in each tank;
- Thermodynamic equilibrium between slag and steel at the slag-steel interface;
- Thermodynamic equilibrium between steel and dissolved lining material.

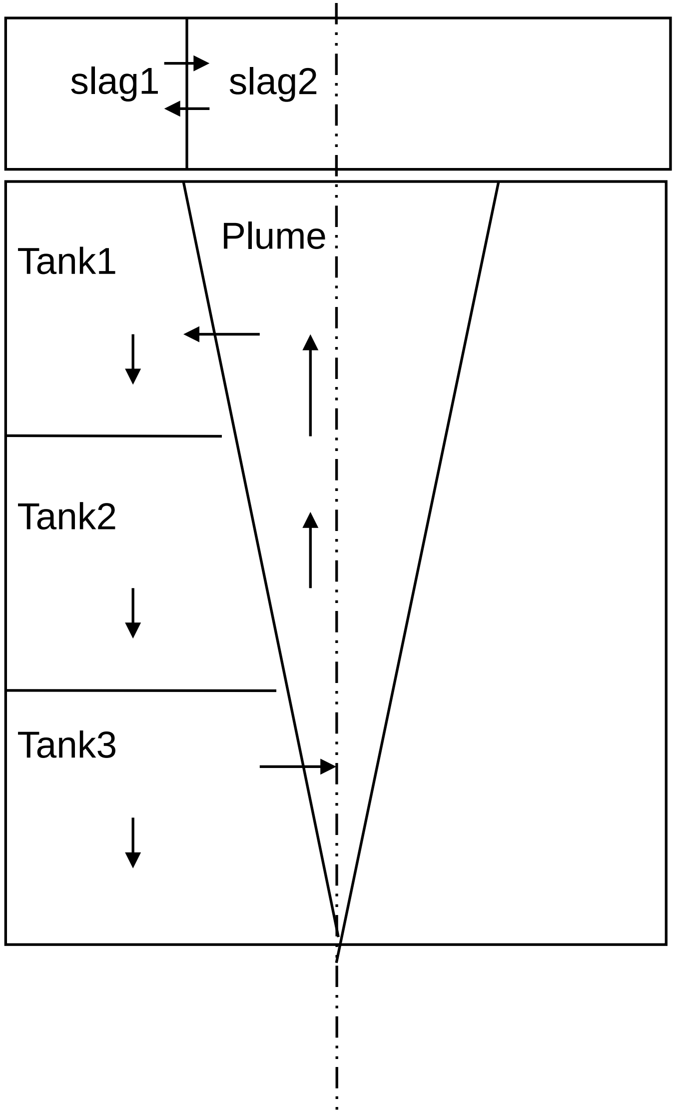
Kinetic parameter

- Based on measurements in the industrial process:

  fluid dynamic, mixing, mass transfer coefficients, lining dissolution, separation of NMI

Model Description

The mixing in gas stirred ladle



- Tank1,2,3 with same height
- Diameter of plume is set as ½ of ladle diameter (larger than real value)
- tracer concentration in tank N at time t:

$$C(N,t)=\frac{C(N,t-\Delta t)(M(N)-r_M\Delta t)+C(N-1,t-\Delta t)(r_M\Delta t)}{M(N)}$$

where

C(N,t) are concentration in tank N at time t,

M(N) is the mass of tank N and

r_M is the mass recirculation rate (obtained from industrial trials).

Model Description

Industrial data for model validation

Steel and slag mass	Steel: 210000Kg, Slag: 2500Kg
Chemical composition of steel before treatment (starting values)	C: 0.11%; Mn:0.90%; Cr: 0.24%; Mo:0.12%; V: 0.007%;Ti: 0.002%
Chemical composition of slag before treatment (starting values)	CaO: 54%; SiO_2: 12%; Al_2O_3 :22%; MgO: 8%. CaF_2: 4%
Deoxidation regime	1) Si 600Kg Al 150Kg. 2) Al 130Kg 3)CaSi treatment:

Model parameters used for calculation

Recirculation rates (industrial data)	2800 kg/s (for medium Ar flow rate)
Mass transfer coefficients	Steel side: K_{ST}=0.002m/s, Slag side: K_{SL}=0.001m/s.
Lining (MgO-C) dissolution rates (industrial data)	For contact with steel: 0.0005kg/(m^2.s) For contact with slag: 0.001kg/(m^2.s)
Bath temperature (derived from industrial trials)	Decrease with time (C.E. Grip, 77th Steelmaking conference proceedings 1994) $T = 1650 - 0.144t/60 - 8.689\sqrt{t/60}$

Model Description

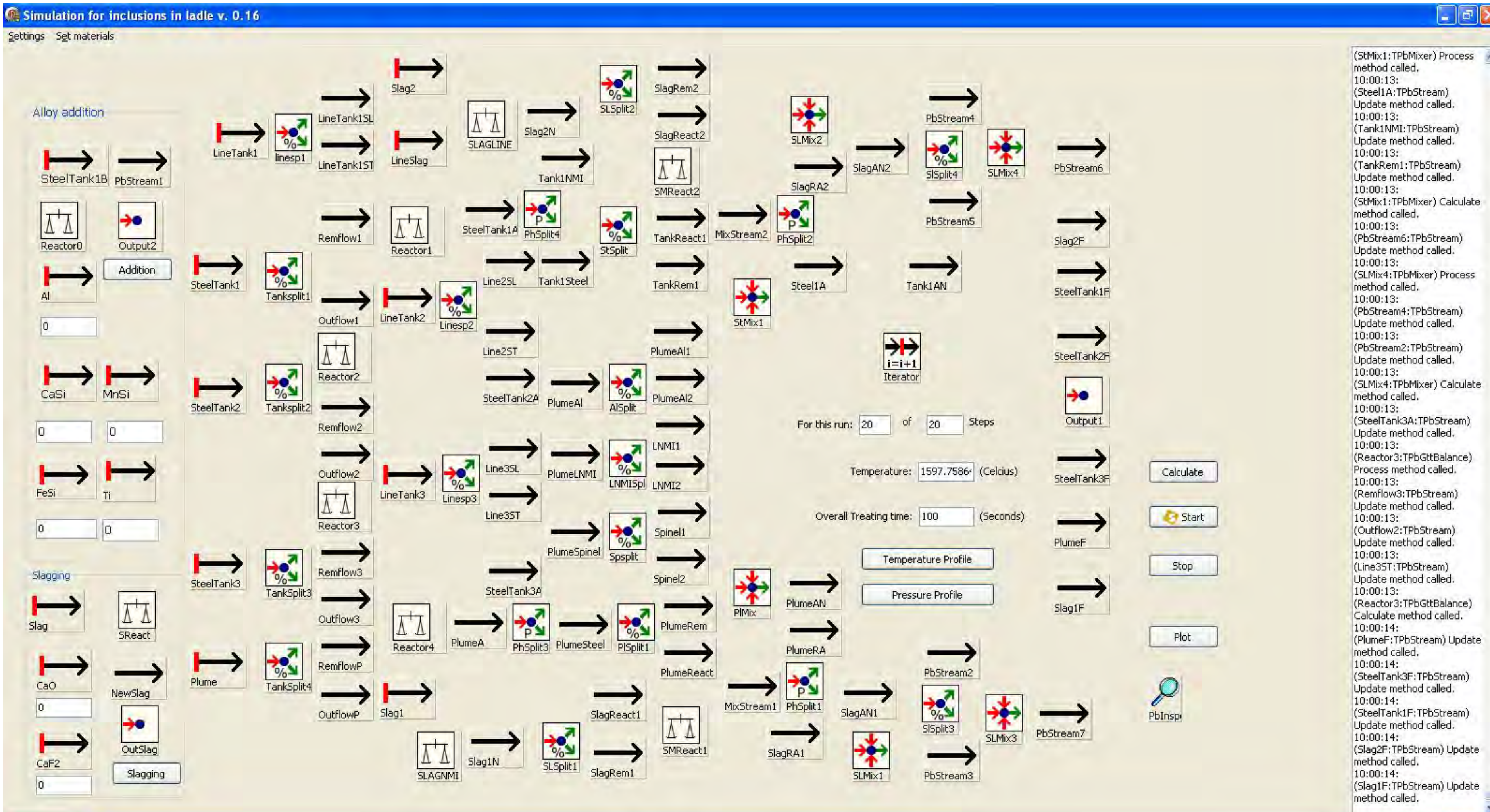
Three steps of simulation were made according to model development:

Model 1: Ladle mixing and slag-metal reaction were taken into account

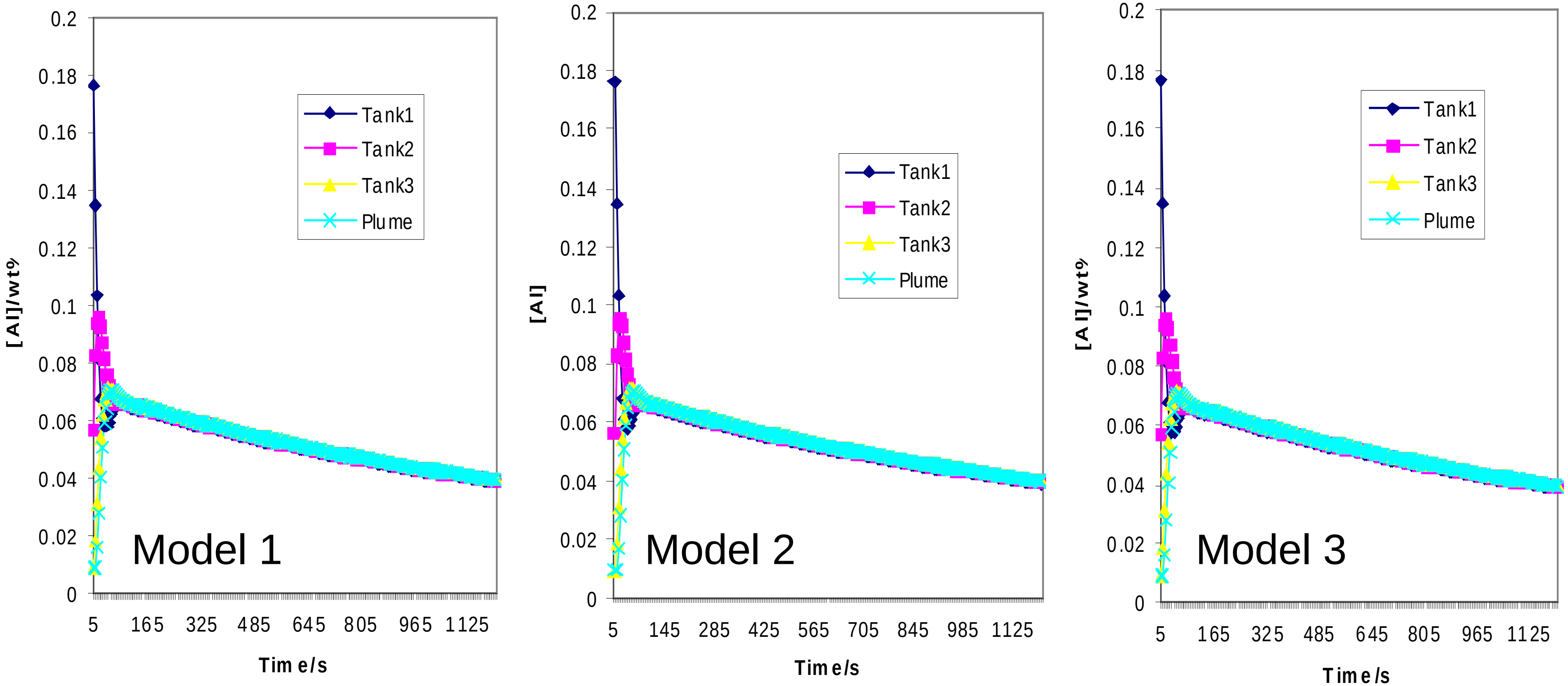
Model 2: Apart from ladle mixing and slag-metal reaction, lining dissolution into steel and into slag was further modeled

Model 3: Apart from ladle mixing, slag-metal reaction and lining dissolution, inclusion separation was also taken in consideration (separation rate depending on nature of inclusions and process development)

Model Description

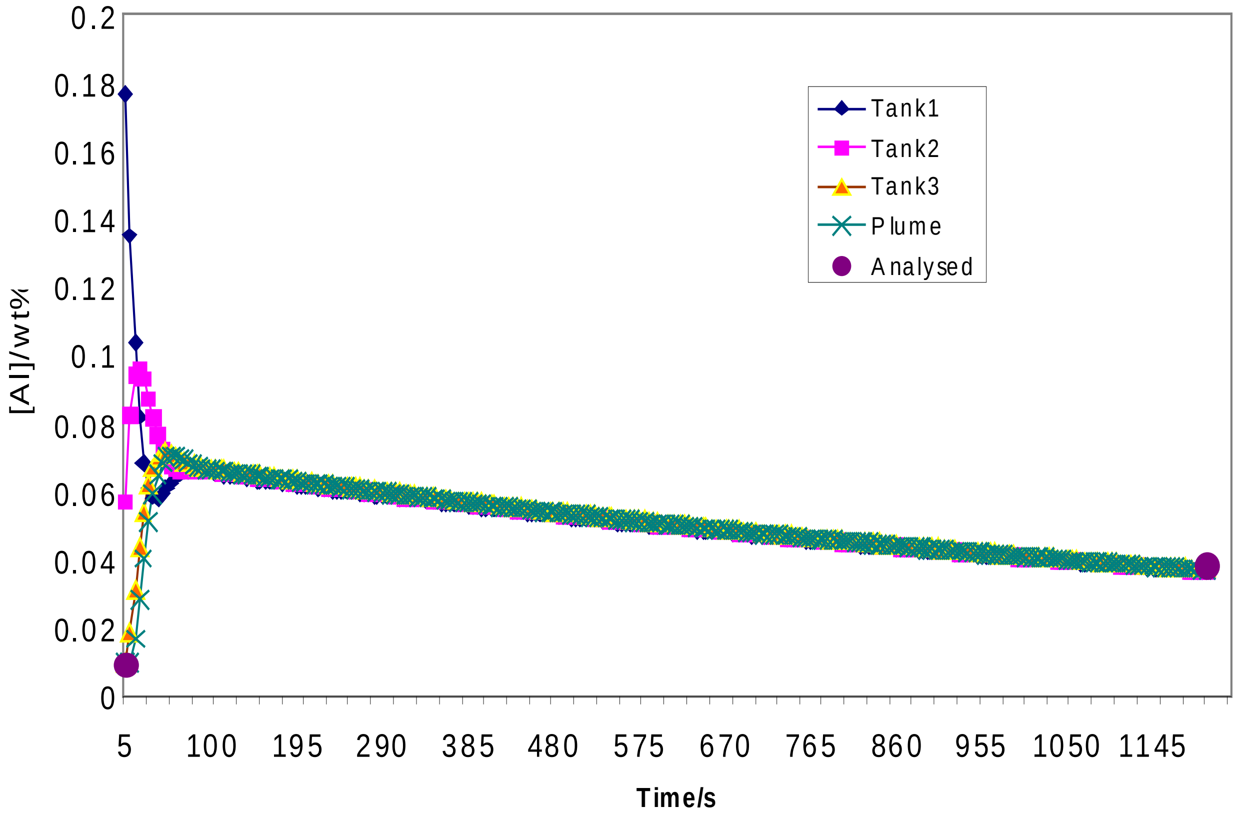


Model Validation



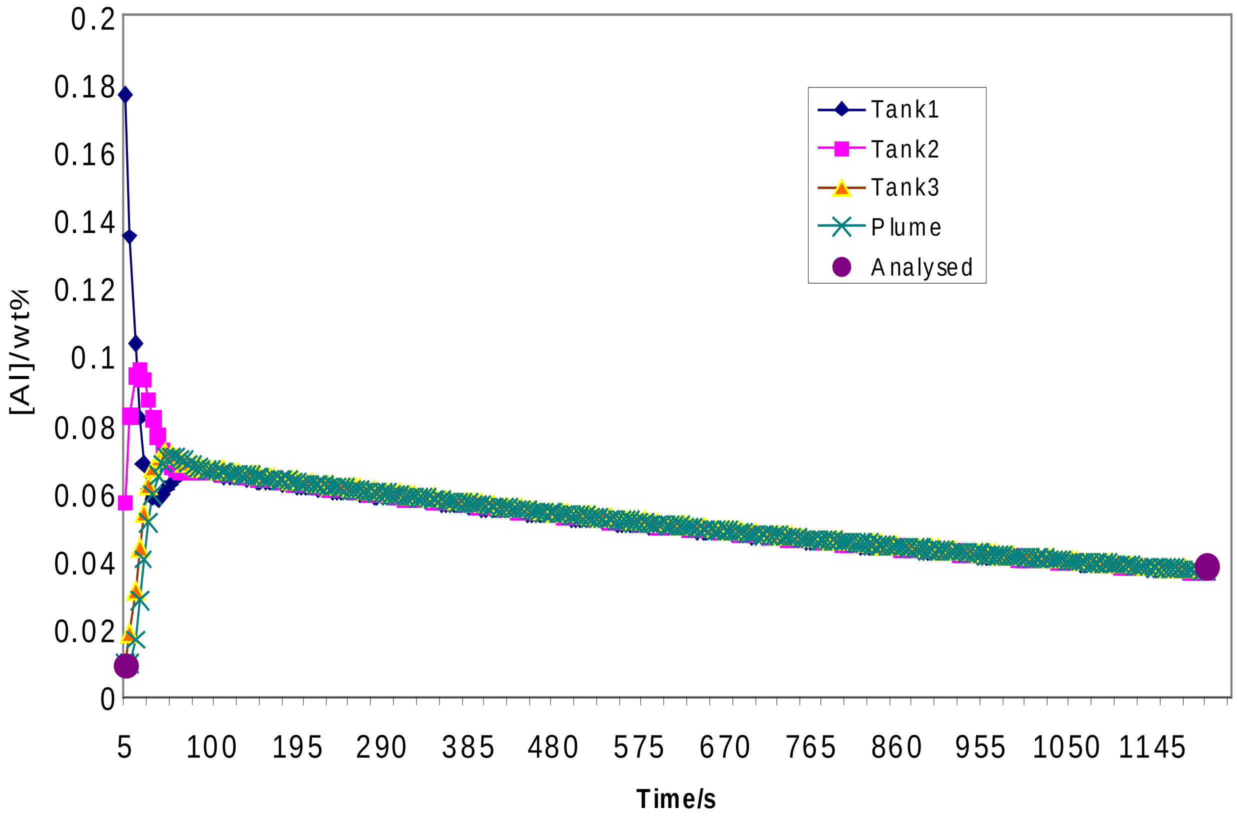
Evolution of aluminum content [Al] in steel during ladle treatment calculated by different models

Model Validation



Comparison between calculated [Al] and industrial analysed [Al] during ladle treatment

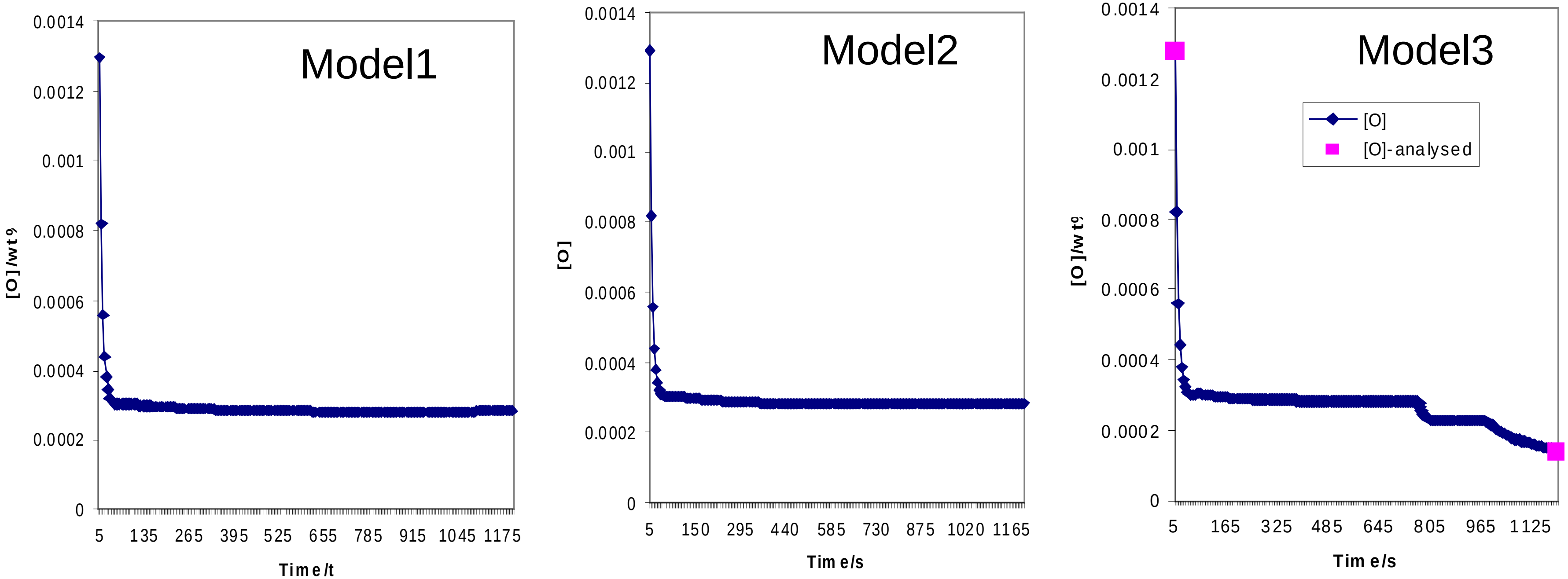
Model Validation



Comparison between calculated [Al] and industrial analysed [Al] during ladle treatment

→ Ladle mixing and slag-metal reaction are dominant factors for [Al] evolution.

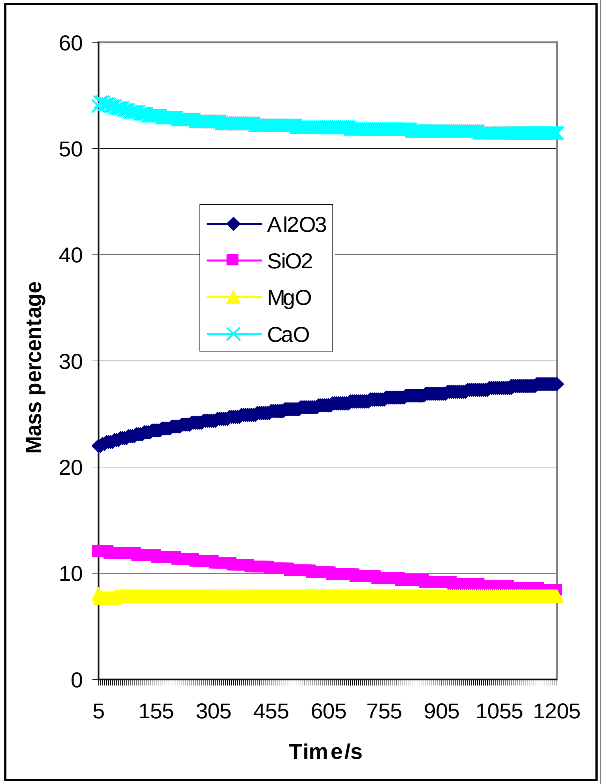
Model Validation



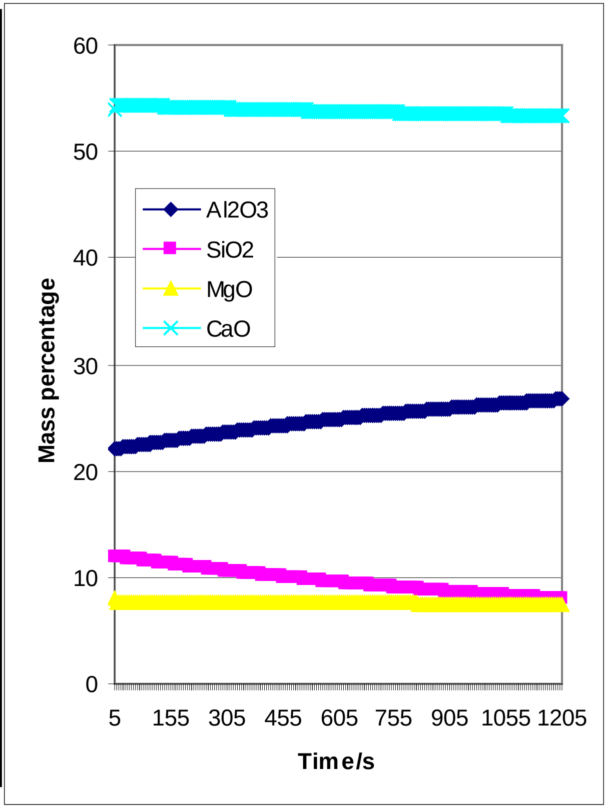
Evolution of oxygen activity a[O] in steel during ladle treatment calculated by different models

Model 3: Agree well with industrial analysed data. The first drop is due to deoxidation of Al. The other drops could be connected with the seperation and modification of inclusion.

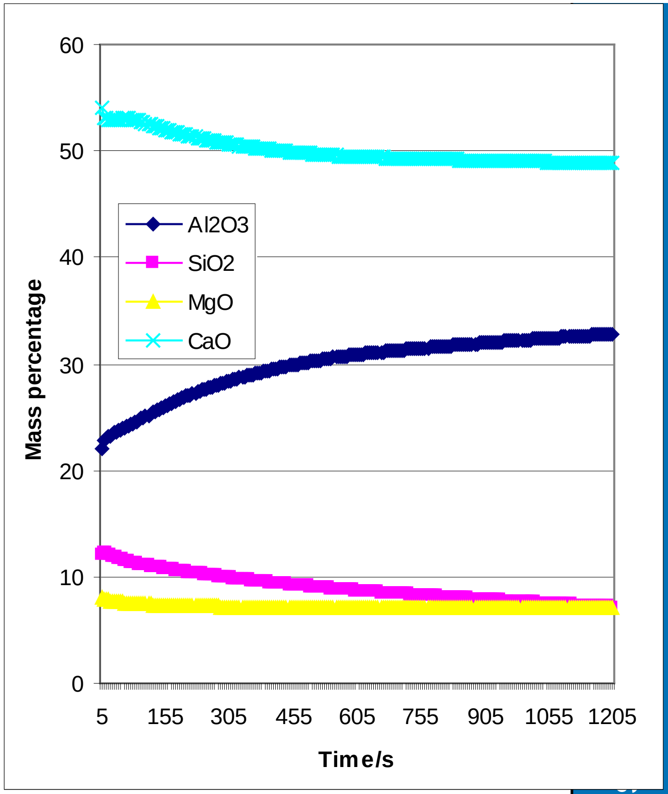
Model Validation



Model 1



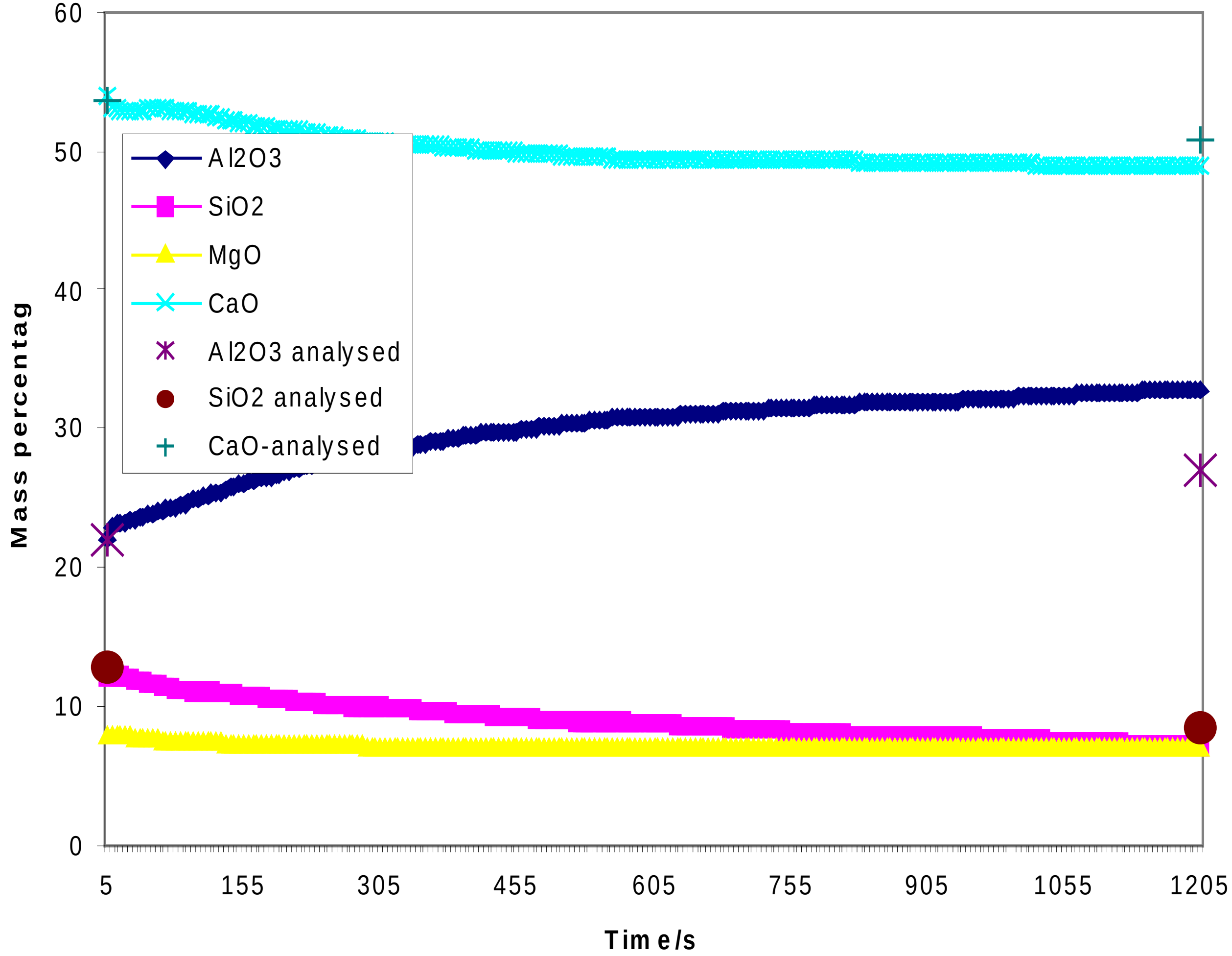
Model 2



Model 3

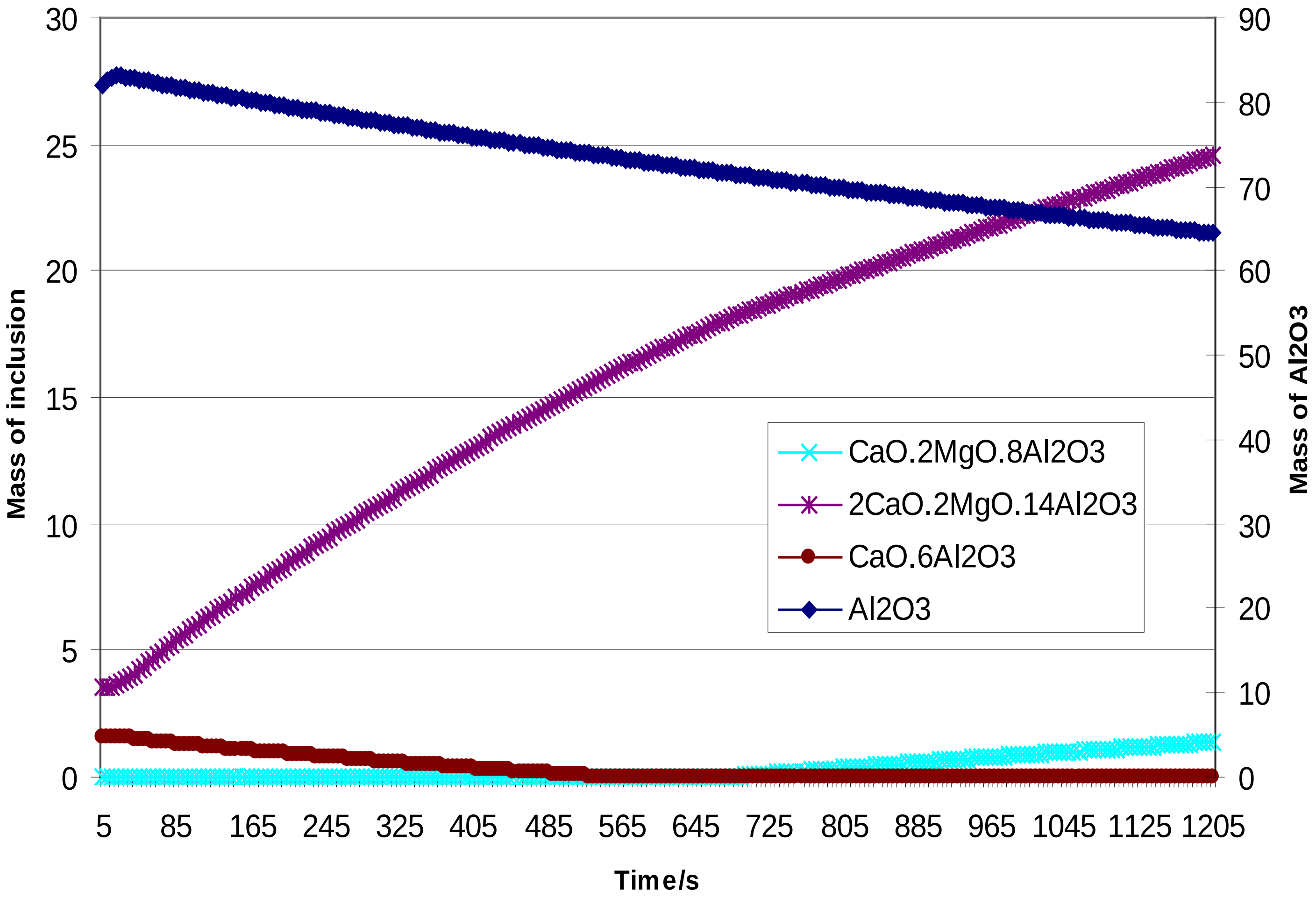
The content of Al_2O_3 by Model 3 increase more than the values by Model 1 and 2 due to the separation of Al_2O_3 into slag

Model Validation



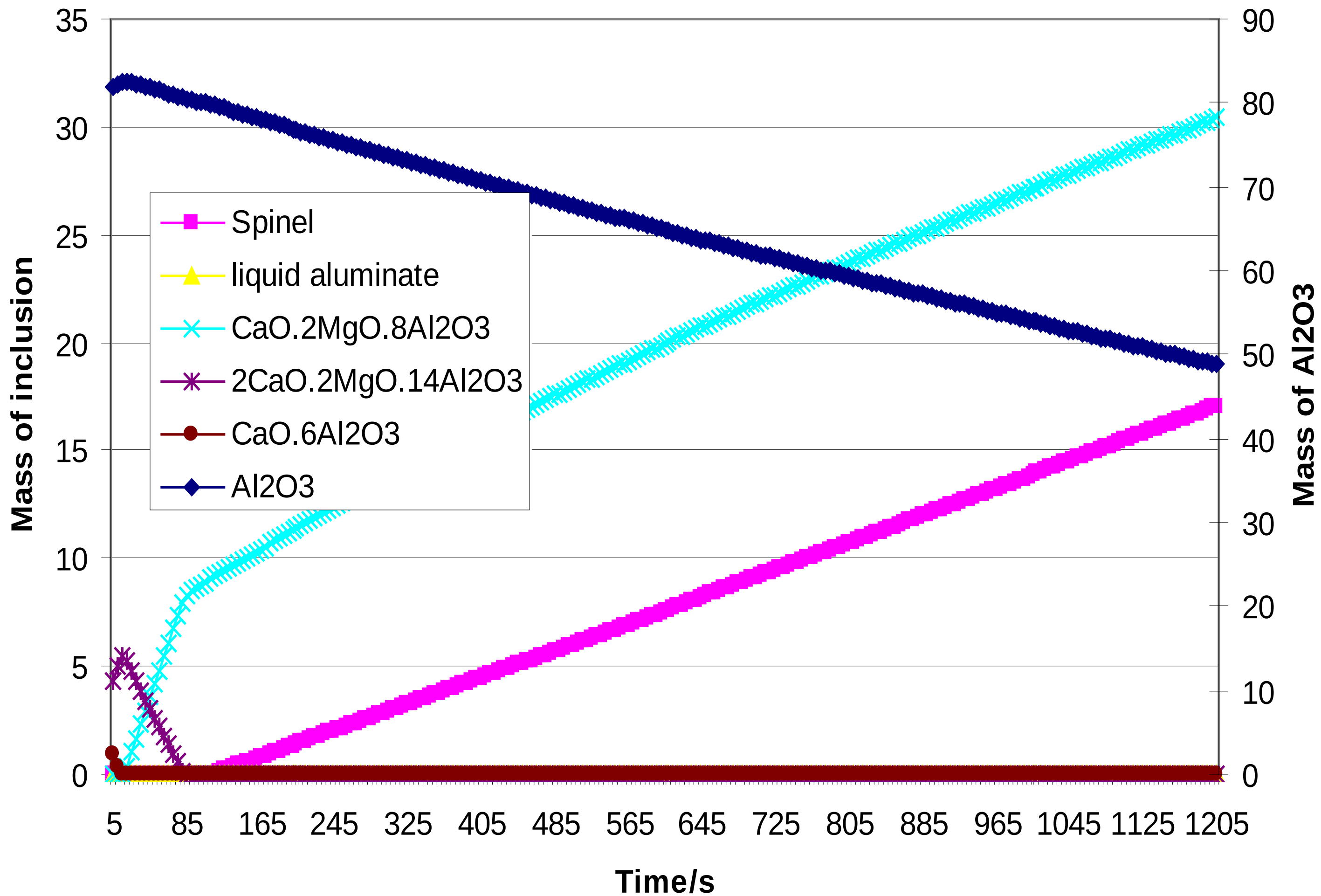
Comparison between calculated chemical composition of slag (Model 3) and industrial analysed compositions during ladle treatment

Model 1: the evolution of inclusion with time (before CaSi treatment)



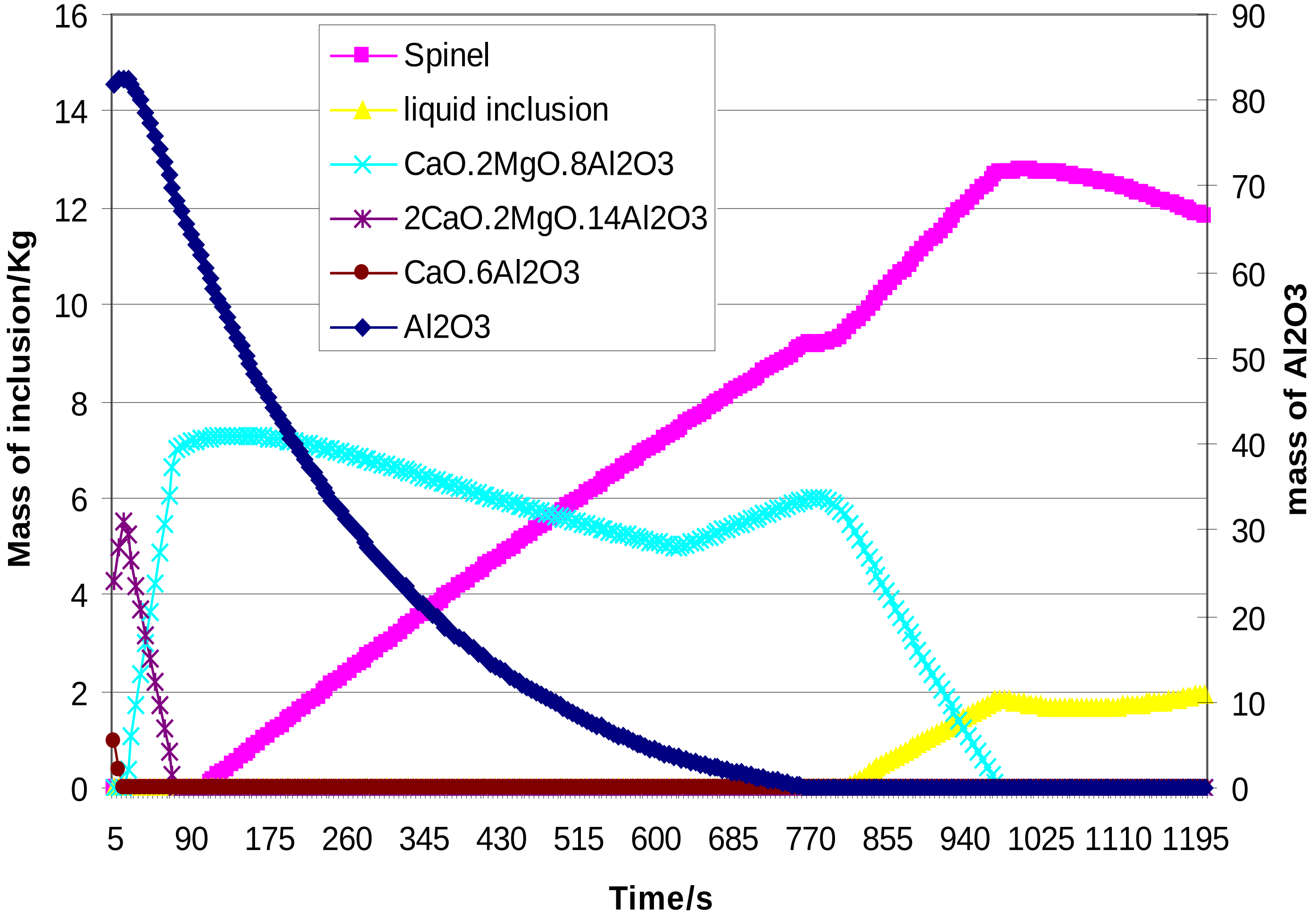
Major inclusions are alumina, $CaO.2MgO.8Al_2O_3$ and $2CaO.2MgO.14Al_2O_3$

Model 2: the evolution of inclusion with time (before CaSi treatment)



Major inclusions are alumina, spinel, $CaO.2MgO.8Al_2O_3$. Final inclusion are alumina, spinel and $CaO.2MgO.8Al_2O_3$

Model 3: the evolution of inclusion with time (before CaSi treatment)



Major inclusions are alumina, spinel, $CaO.2MgO.8Al_2O_3$. Final inclusion are spinel and some liquid aluminate

Model Validation

Inclusions after CaSi treatment:

- Model 1: liquid aluminates, $CaO.2MgO.8Al_2O_3$ and $CaO.2Al_2O_3$
- Model 2: liquid aluminates and $CaO.2MgO.8Al_2O_3$
- Model 3: liquid aluminates and CaS

Process step	Analyzed inclusions	Calculated Inclusions (Model 1)	Calculated Inclusions (Model 2)	Calculated Inclusions (Model 3)
Arrival at ladle treatment station	A C D	A C	A C	A C
Before CaSi treatment	B A C	A C	A B C	B A C
Departure ladle	C E	C	C	E C

A: Alumina; B: Spinel; C: Calcium aluminate; D: Manganese silicate; E: Calcium sulphide

Inclusions are listed by the amount decrease order.

The calculated inclusions by model 3 before and after CaSi treatment are consistent with inclusion found in industrial sample.

Model Validation - conclusion

The best fit with the industrial measurements delivers

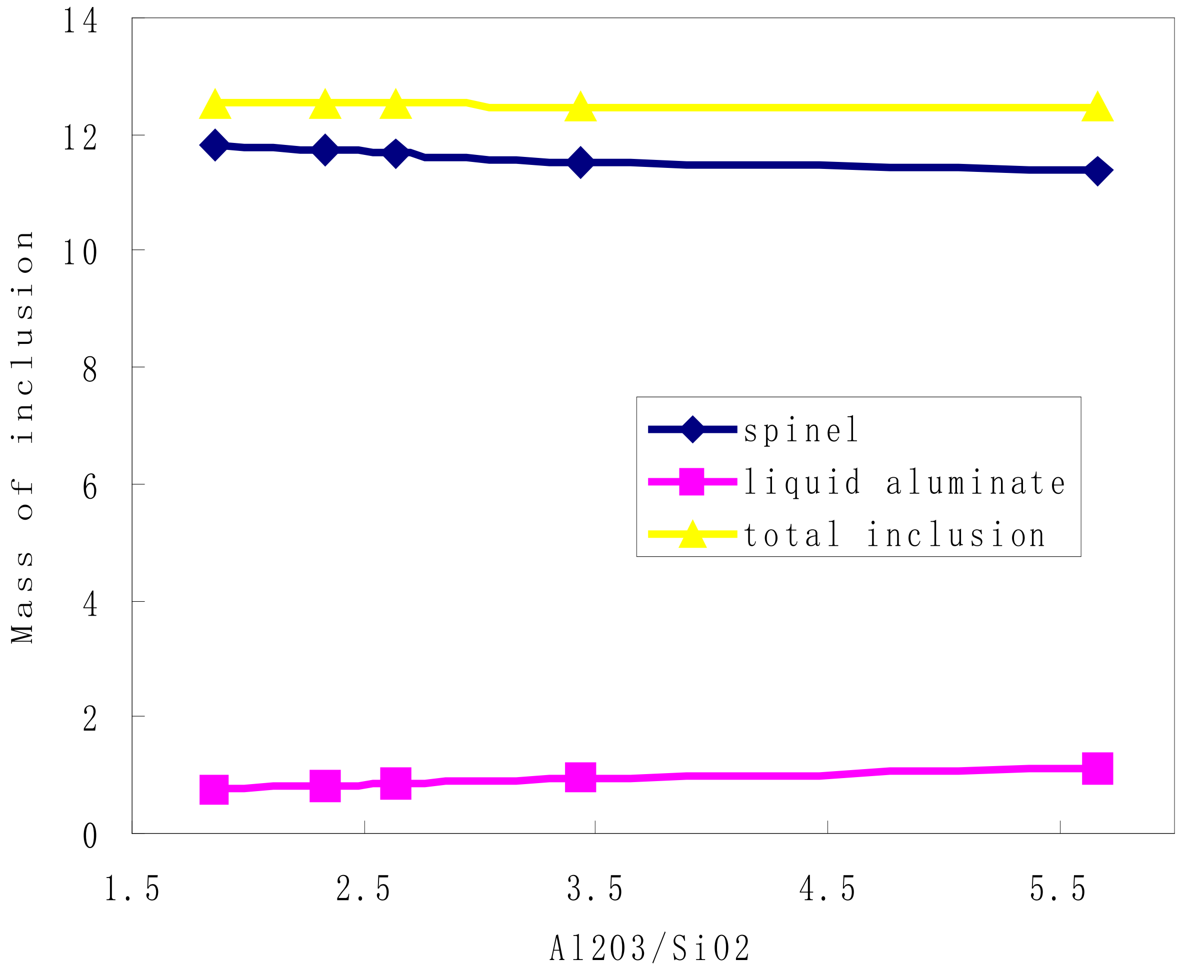
MODEL 3

Further calculations – only using Model 3

-PARAMETER STUDY-

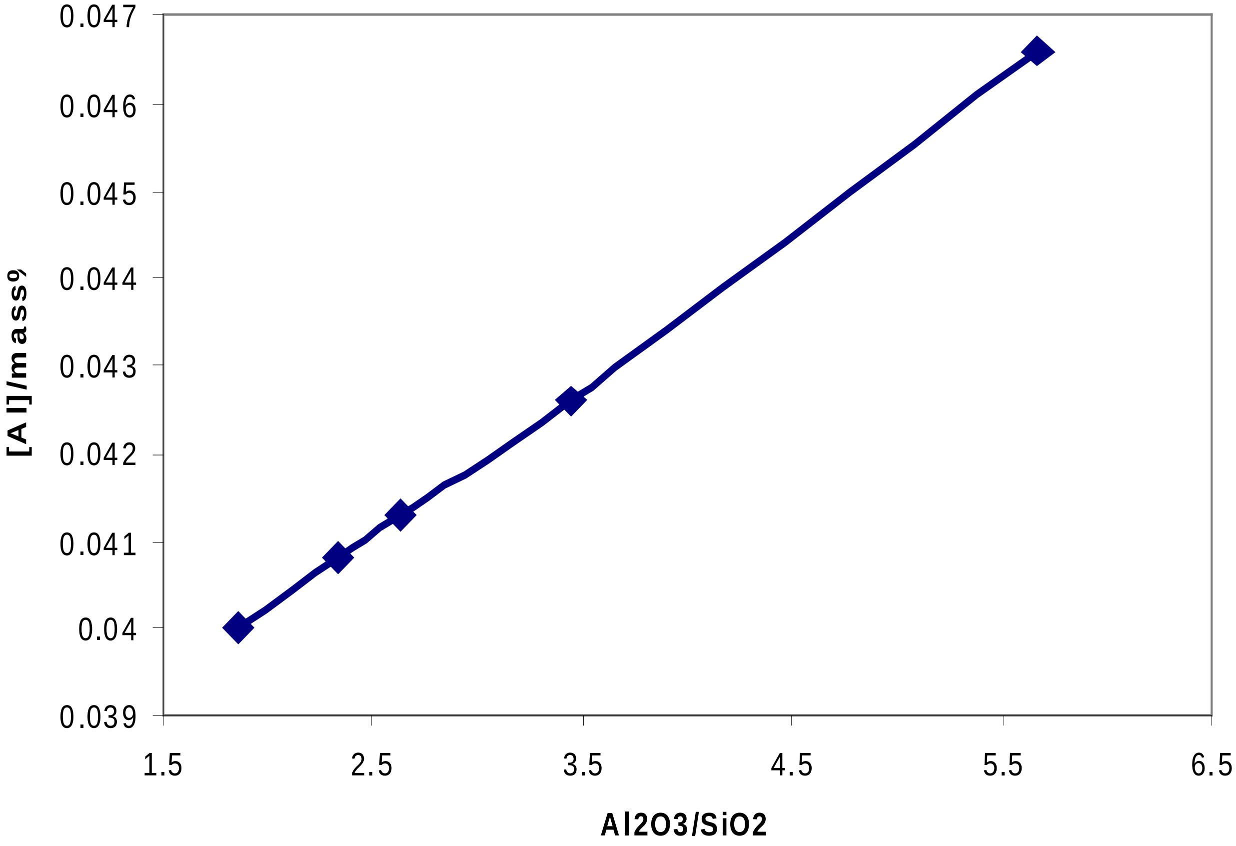
Effect of Slag Composition

Mass of inclusions as functions of Al_2O_3/SiO_2 ratio
(all other industrial and model parameter are unchanged)



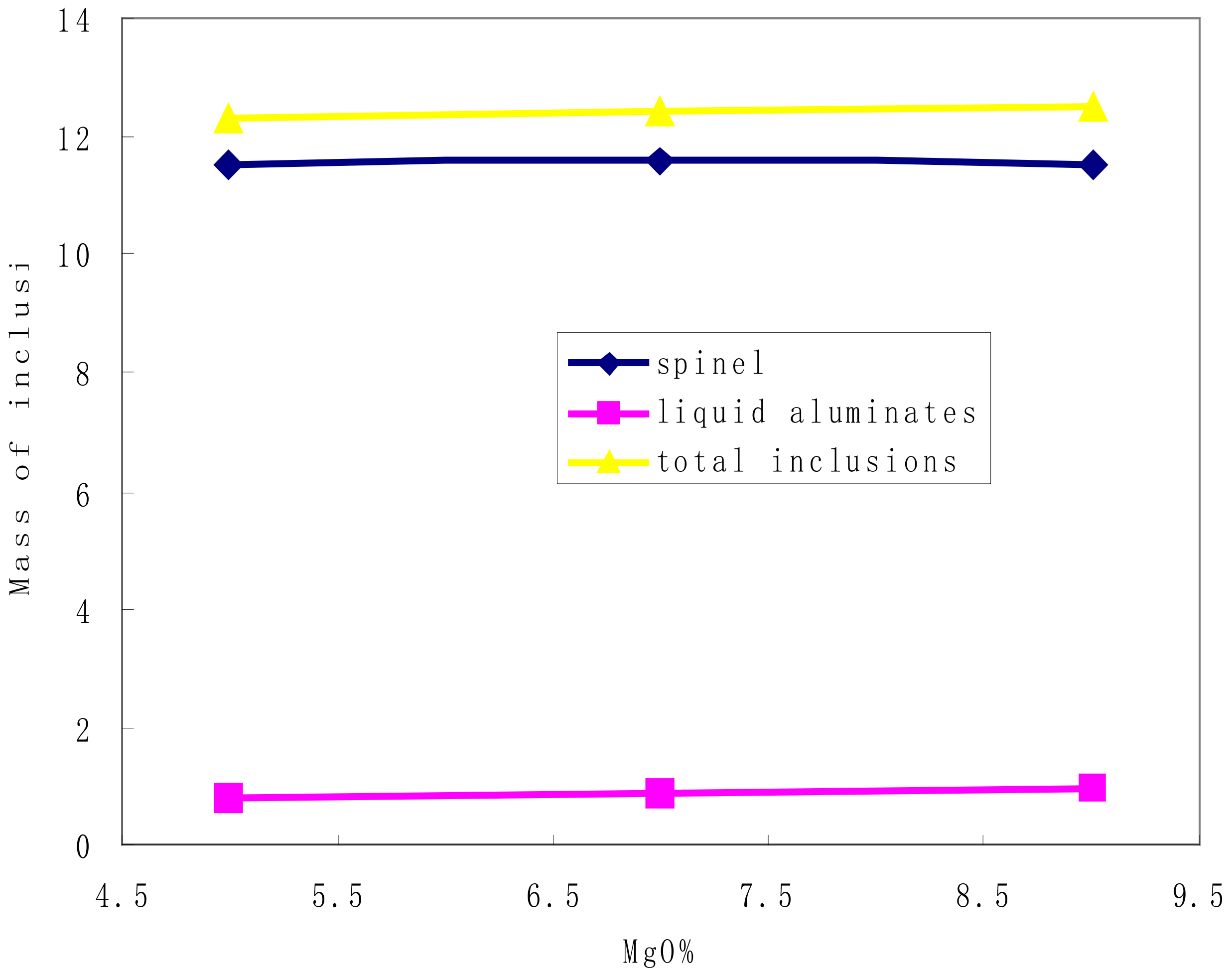
Effect of Slag Composition

Aluminum concentration in steel as a function of Al_2O_3/SiO_2 ratio in slag
(all other industrial and model parameter are unchanged)



Effect of Slag Composition

Mass of inclusions as functions of MgO% in slag
(all other industrial and model parameter are unchanged)



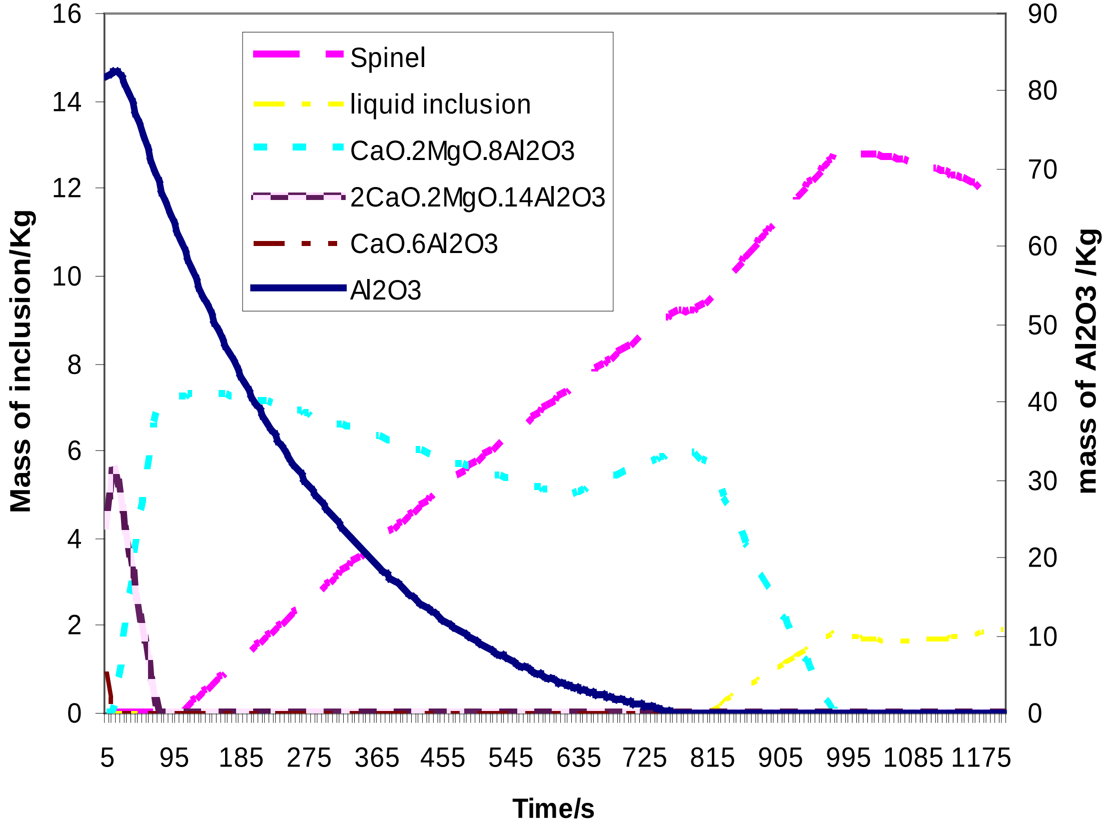
Effect of Lining Material

Composition of ladle lining refractory used in the model calculation

Refractory type	Al_2O_3	Dolomite	MgO-C
Composition (wt%)	Al_2O_3: 92% MgO:8%	CaO:60% MgO:40%	MgO:95% C: 5%

Effect of Lining Material

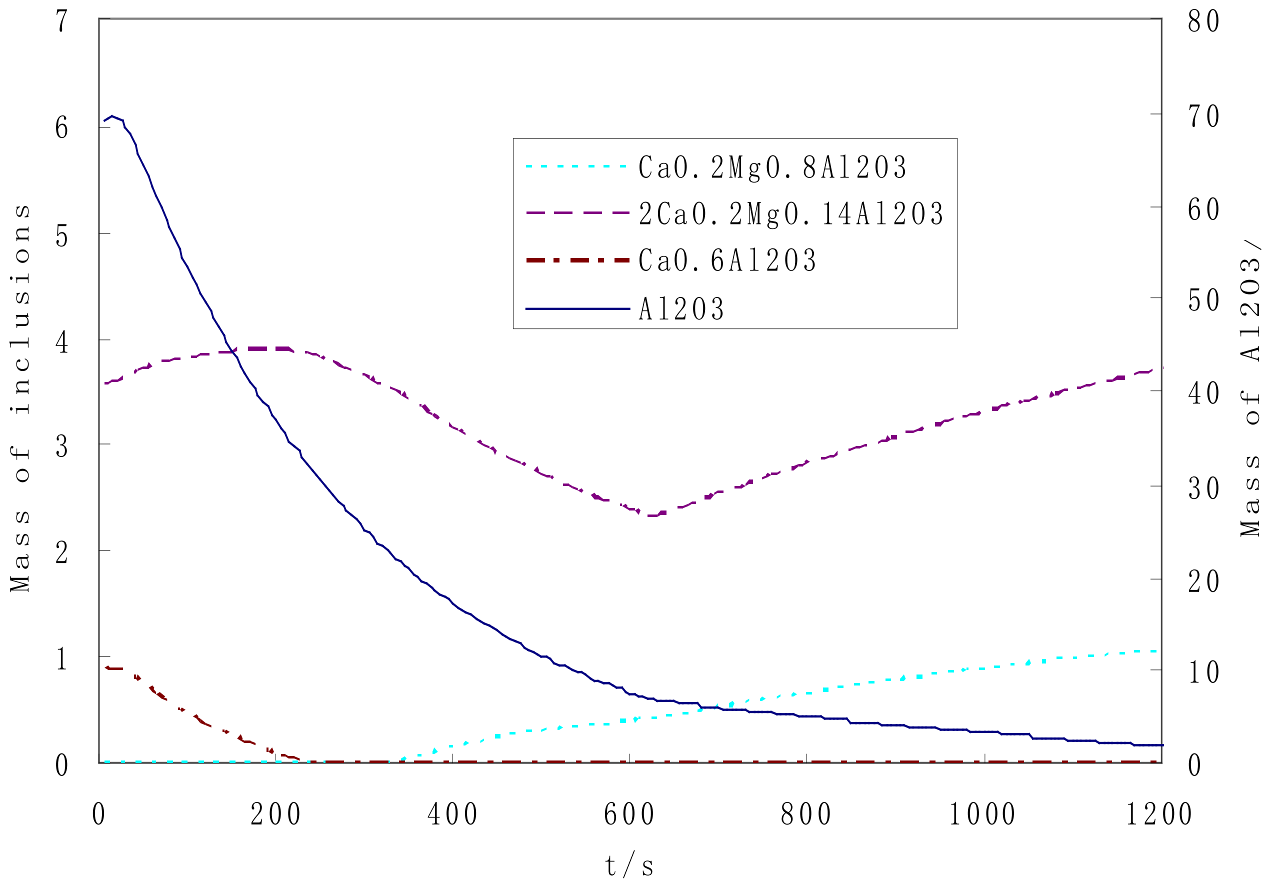
Inclusion evolution in ladle with **MgO-C lining**



→ **final inclusions:** Mg-Al spinels and liquid inclusions

Effect of Lining Material

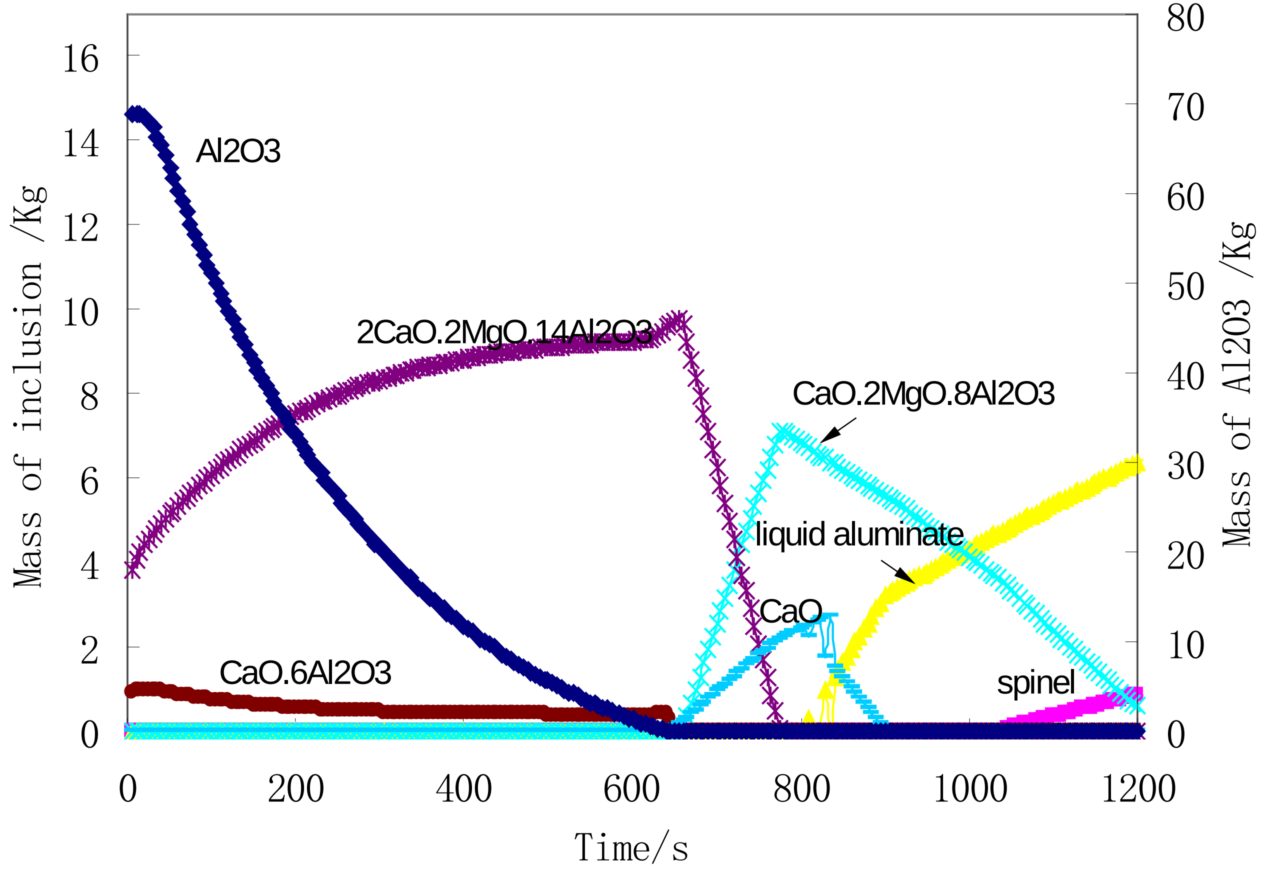
Inclusion evolution in ladle with **Al_2O_3 lining**



→ **final inclusions:** alumina reach inclusions and solid alumina; compared to MgO-C lining: no Mg-Al spinels

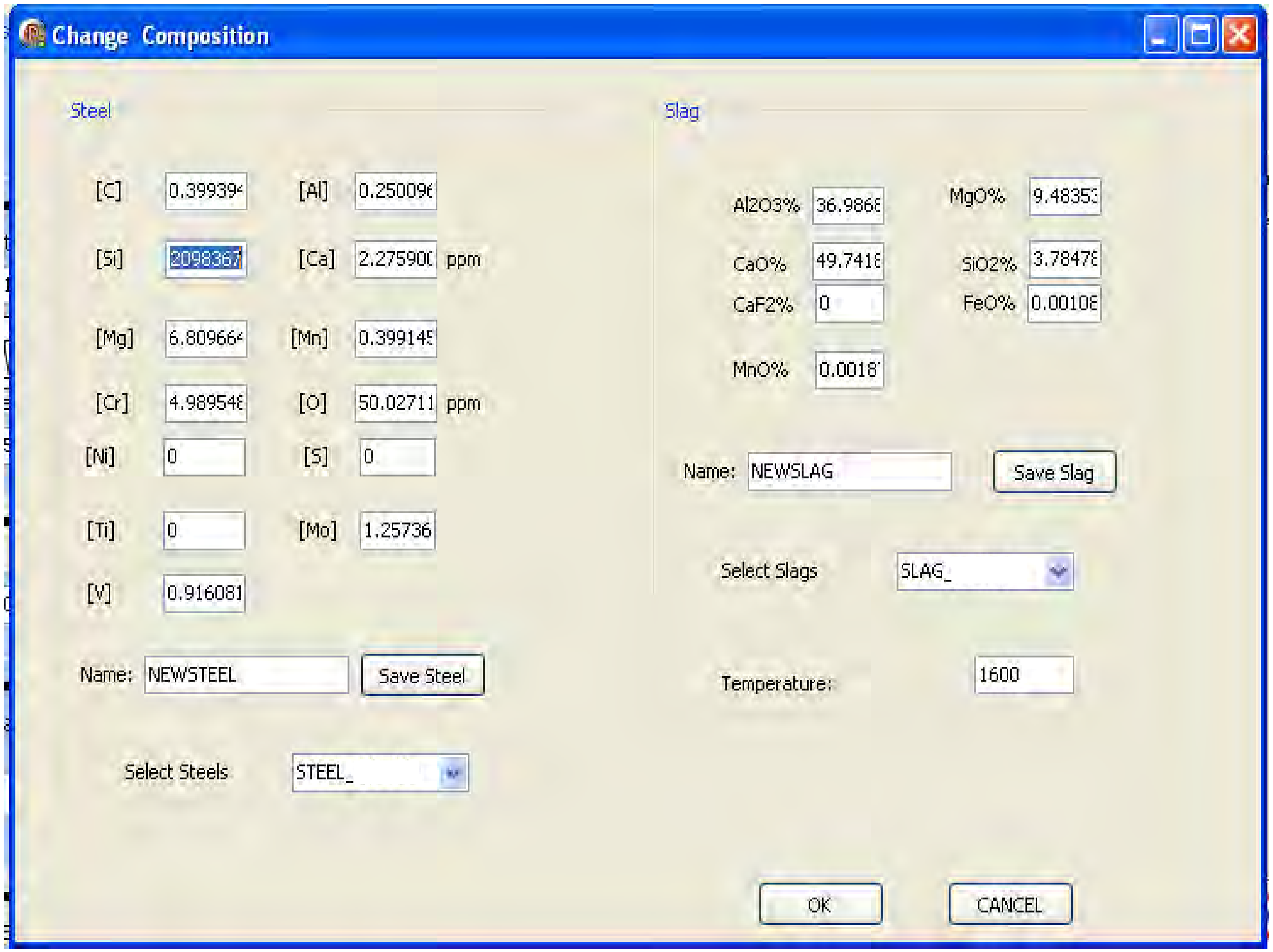
Effect of Lining Material

Inclusion evolution in ladle with **dolomite lining**



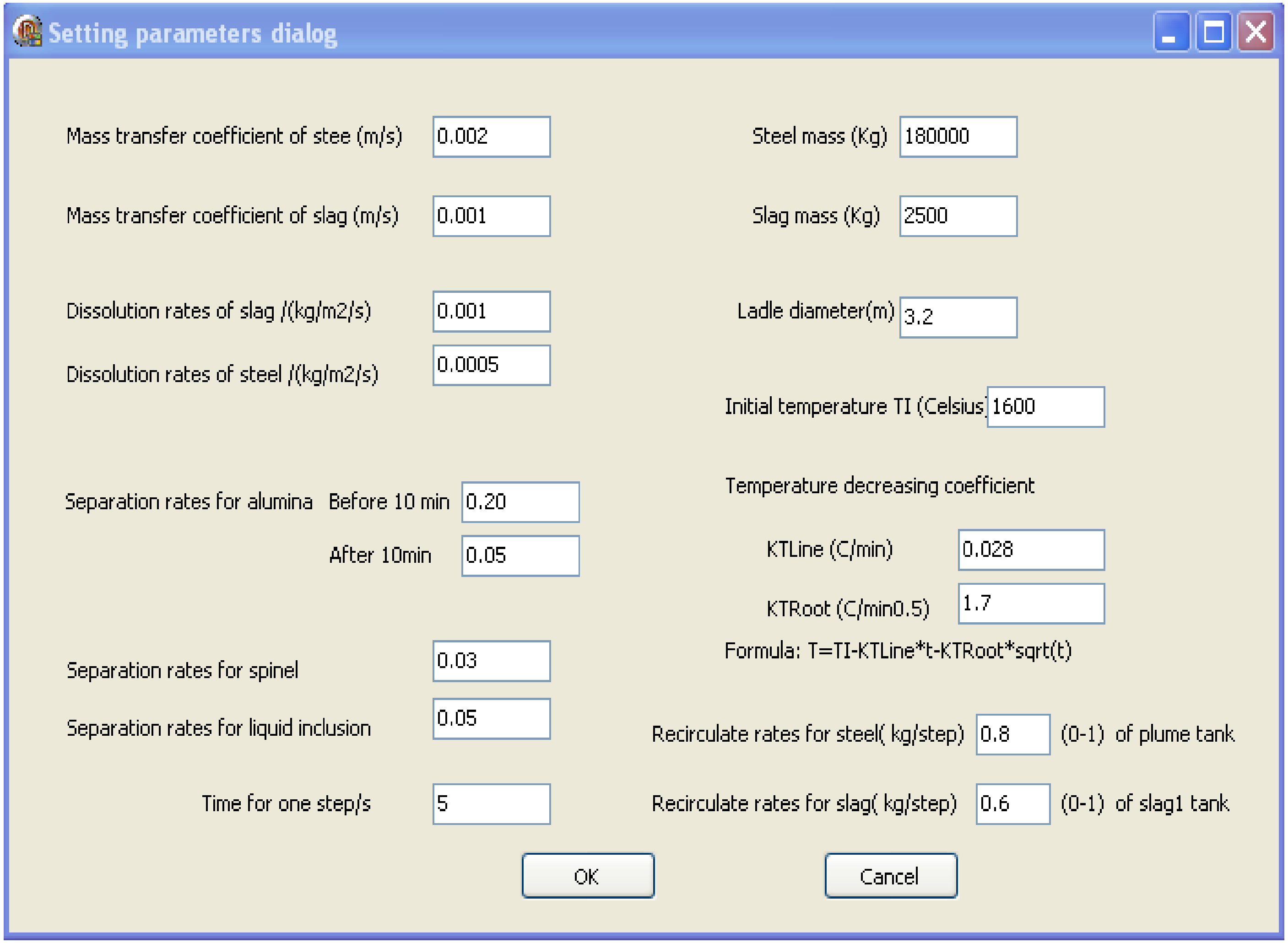
→ **final inclusions:** liquid aluminates and minor aluminates and Mg-Al spinels; dolomite lining supports the transformation of solid aluminates, spinel into liquid aluminates (by dissolution of Ca into steel and slag)

Use for process assistance



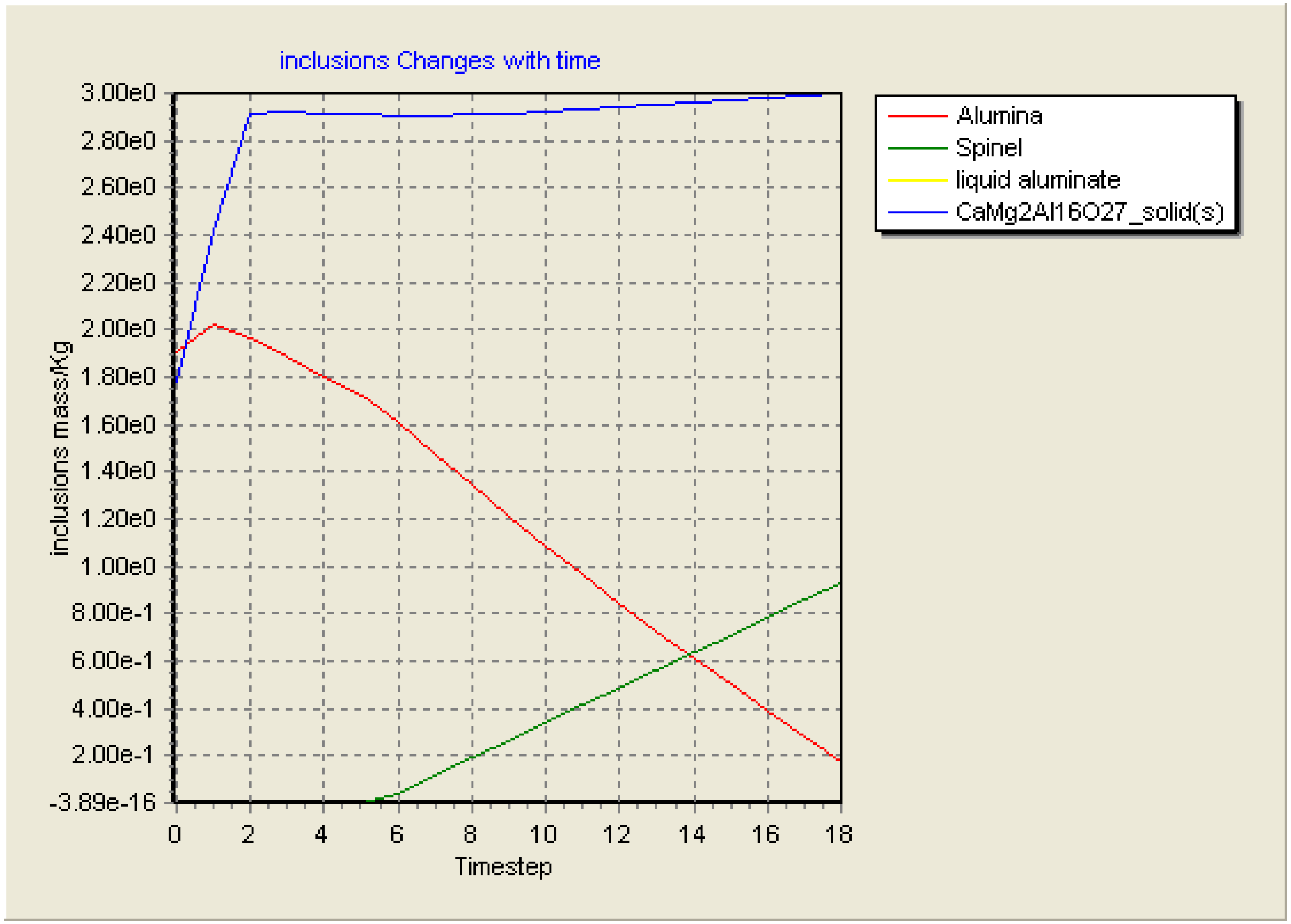
Interface for input of steel and slag composition – during the process

Use for process assistance



Interface for setting model and process parameters

Use for process assistance



Plot module (on line) for simulation results

Conclusions

- A comprehensive model for inclusion development in gas-stirred ladle was established by taking mixing, slag-steel reaction, inclusion separation and lining wear and dissolution into consideration

- The effects of slag composition and nature of lining refractory on the inclusion evolution were also investigated. The slag composition in the range investigated has a small effect on the inclusion evolution, while ladle refractory could have important effects. The strongest effect has the separation of inclusions

- The comparisons between calculated and industrial data show that the present model can predict inclusion evolution consistent with industrial practice

Thank You

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