# Computer simulation for secondary metallurgy processes in the framework of RFCS

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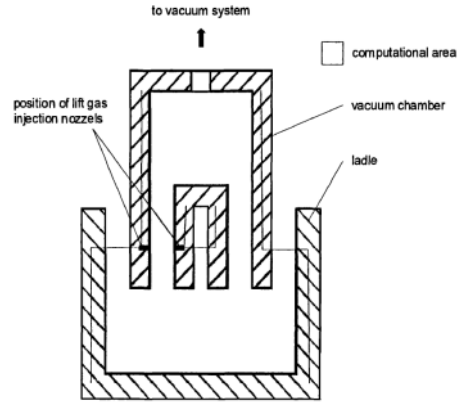
# Control of inclusions in RH degassing processes

- 2D schematic representation:




The following assumptions are made:

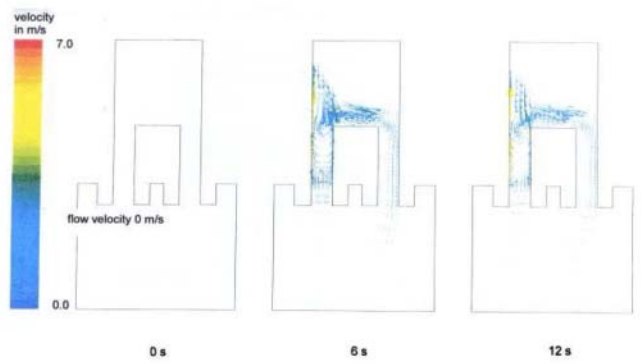
The following proccesses have been taken into account:
- Interaction between gas and melt
- Vacuum
- Movment of free surface
- Time-dependent flow

The gas phase consist of:
- CO
- Ar

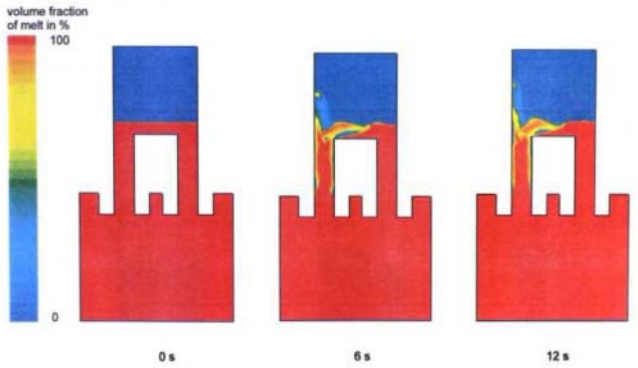
Liquid melt contains:
- C
- O
- Non-reacting liquid metal

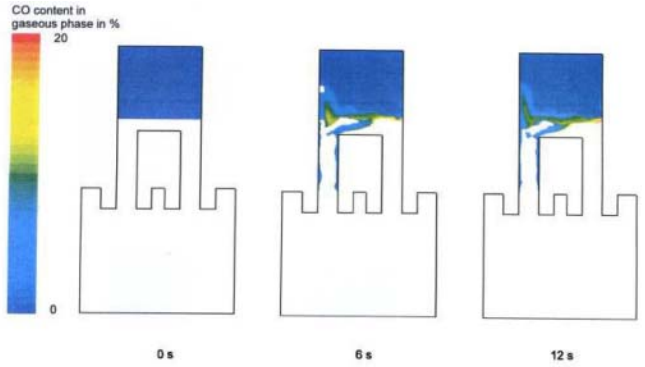
# Control of inclusions in RH degassing processes

Velocity Vector Field [m/s]

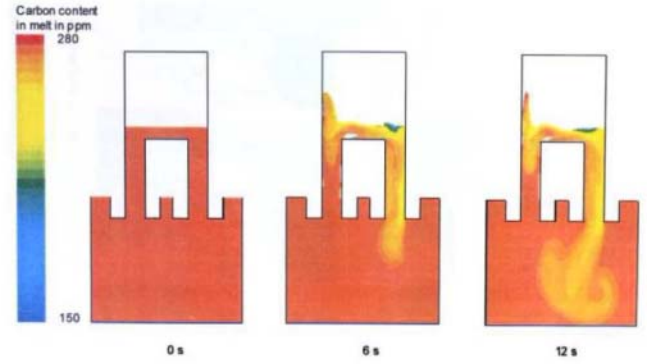



Volume Fraction



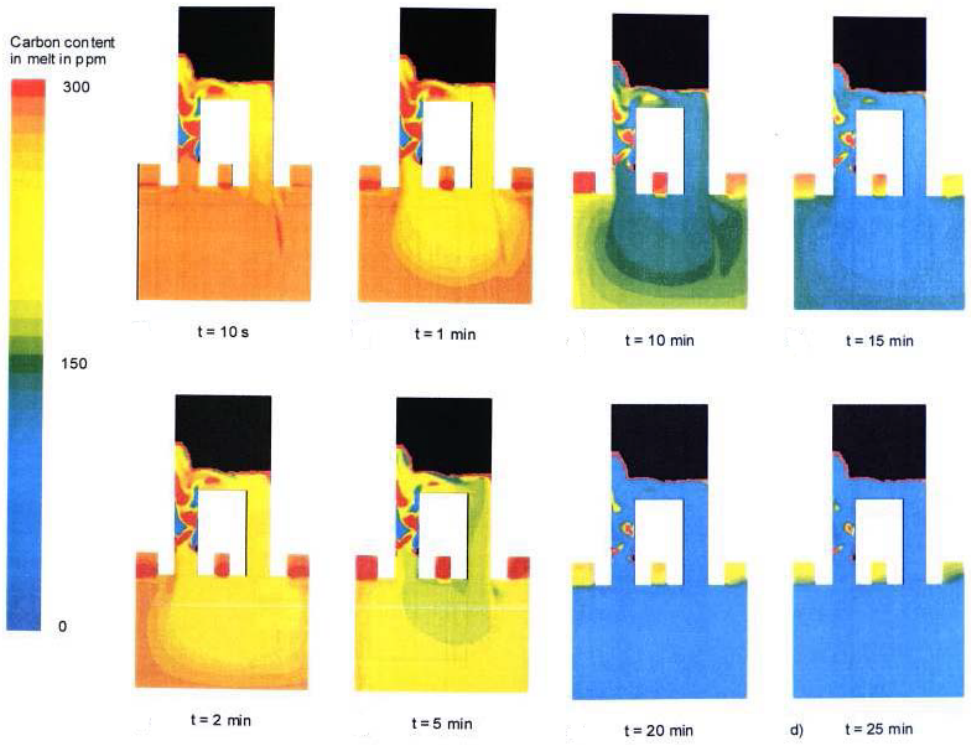

CO Content in gaseous phases




Carbon content in the melt [ppm]

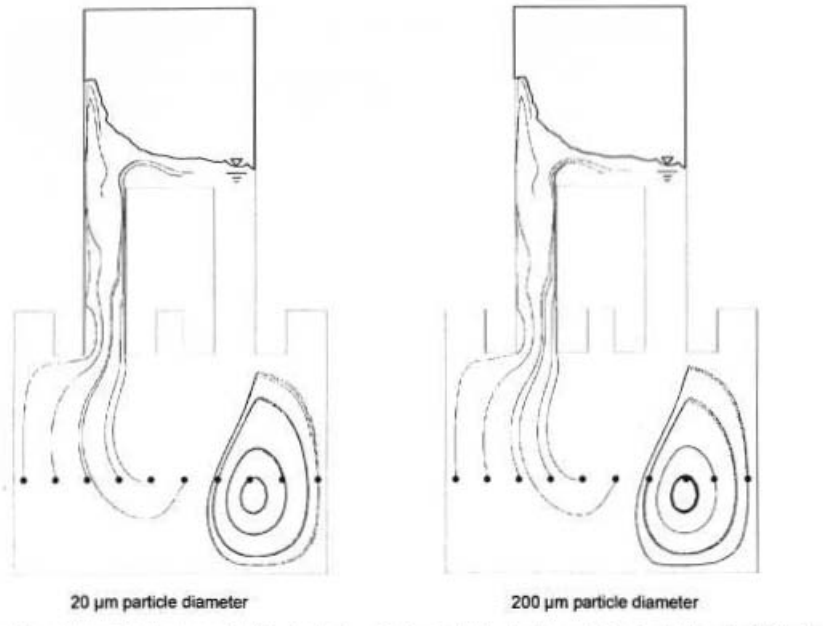
# Control of inclusions in RH degassing processes

- Carbon content in the melt with respect to time:



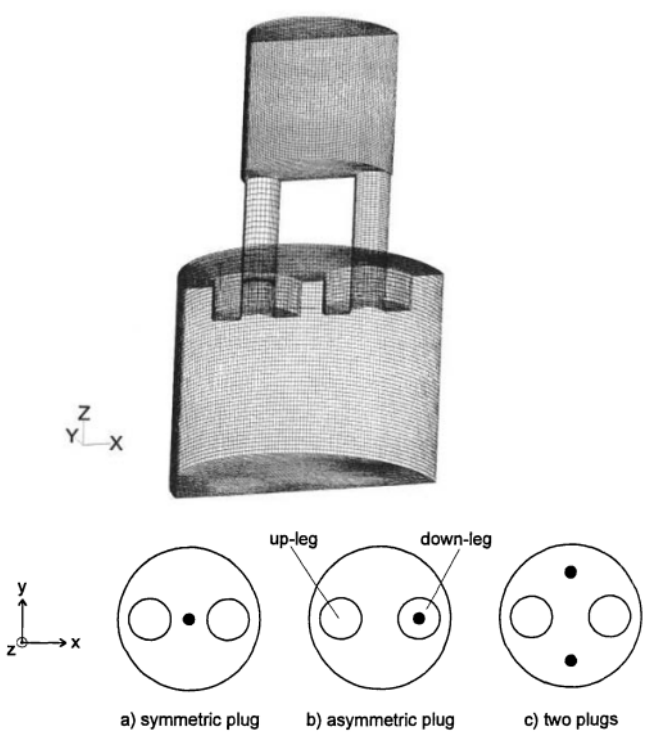
# Control of inclusions in RH degassing processes

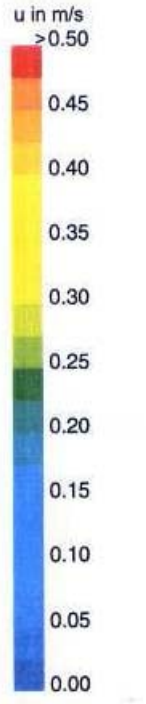
- Trajectory of inclusion:

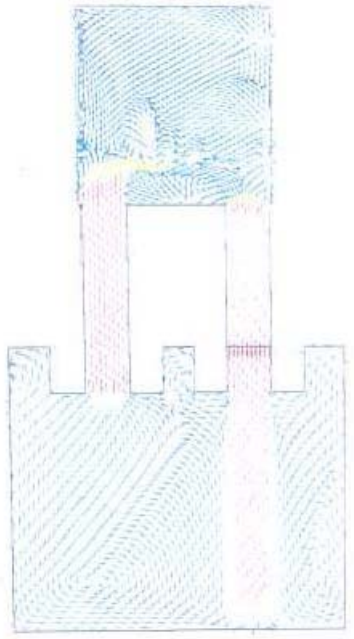


# Control of inclusions in RH degassing processes

- Domain of calculation for the 3D simulation:



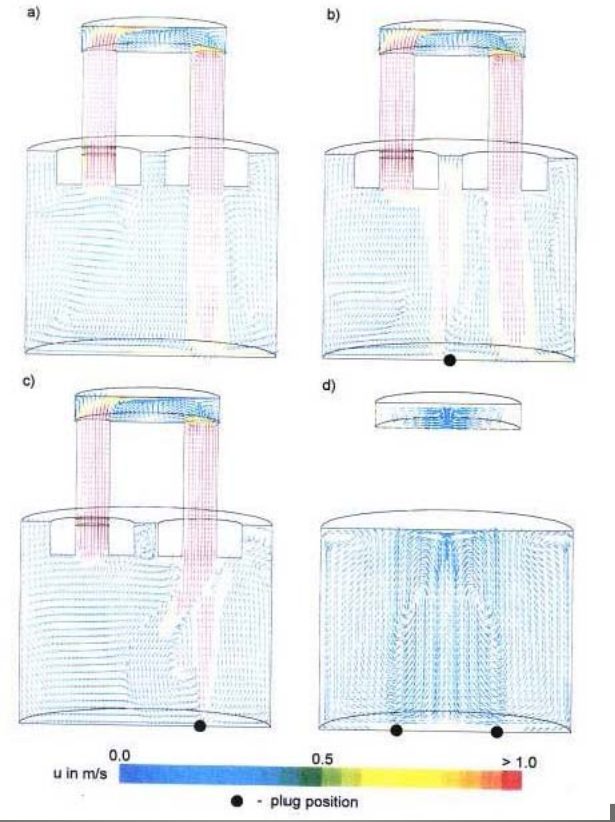



Velocity vector field

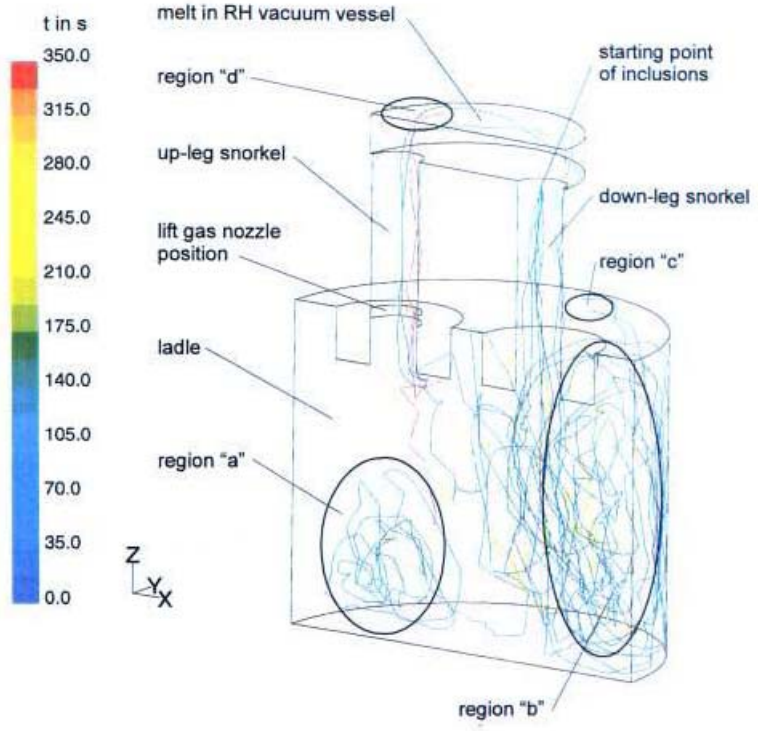
# Control of inclusions in RH degassing processes

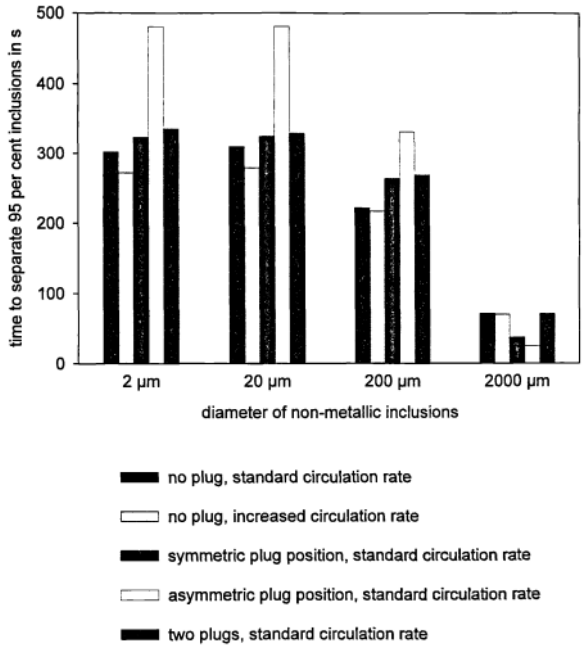
- Velocity vector field with respect to plugs



# Control of inclusions in RH degassing processes

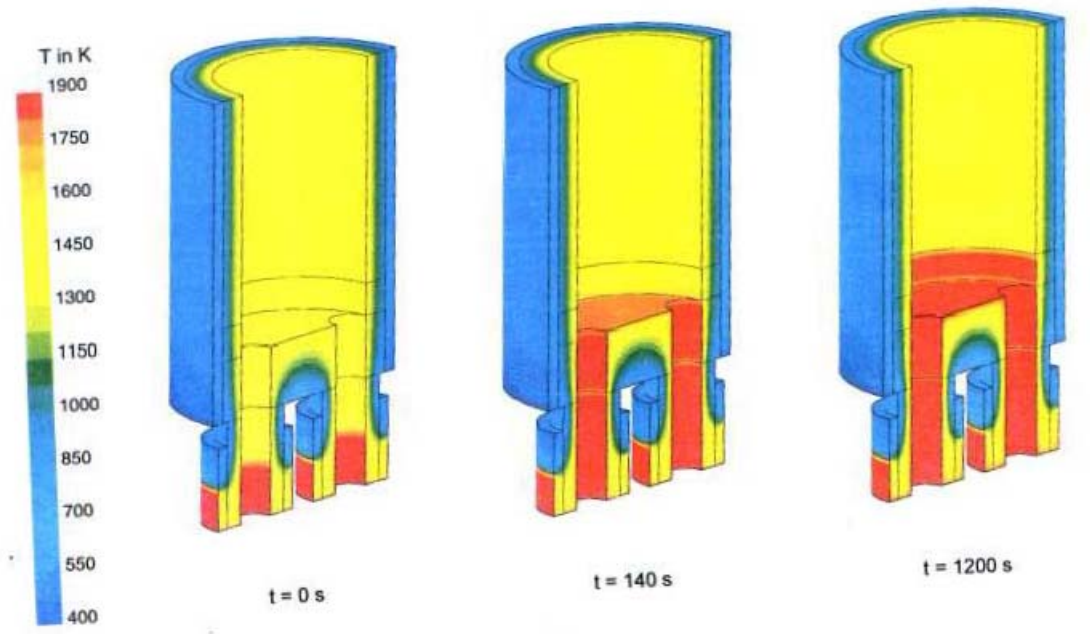
- Trajectory of inclusions in a 3D vessel:

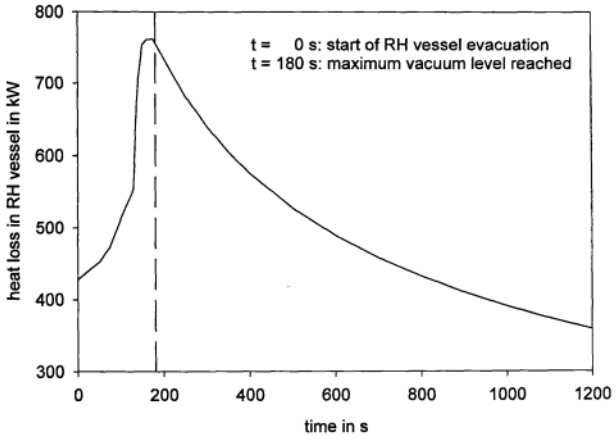


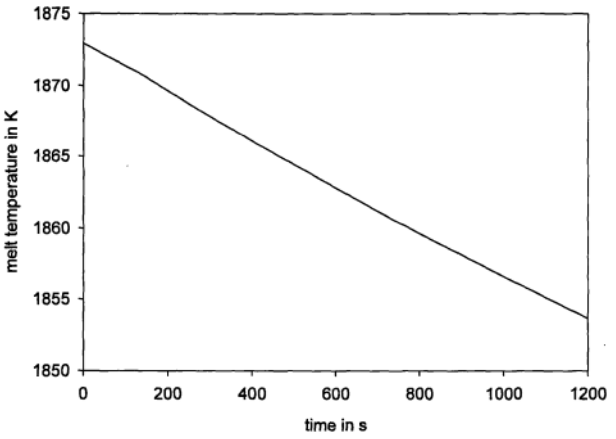



# Control of inclusions in RH degassing processes

- Temperature distribution and heat loss:

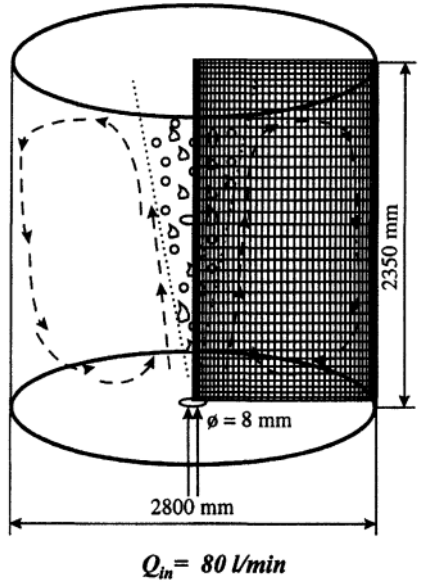


# Control of inclusion, slag foaming and temperature in vacuum degassing

- A 2D domain has been used:




Two flow rates have been used:

- 80 l/min
- 160 l/min

Model assumptions:

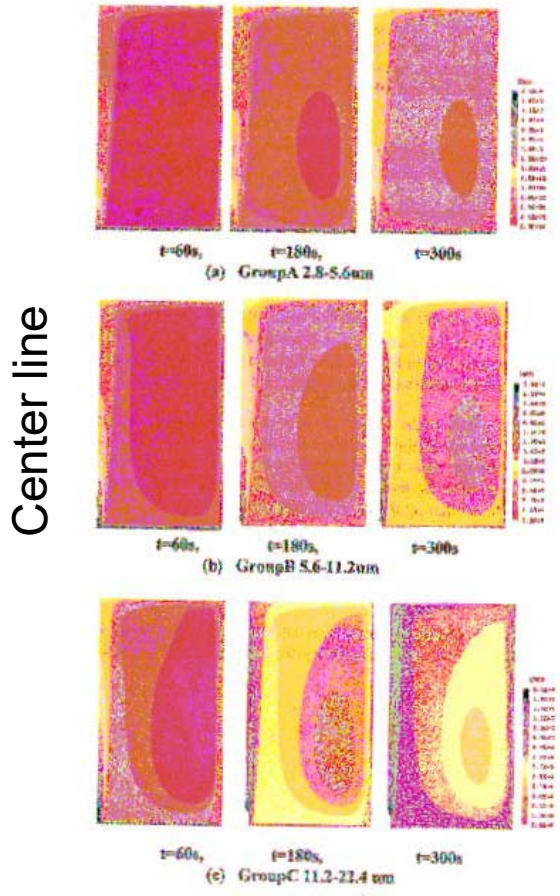
- One-way inclusion coupling
- Inclusions generation ignored
- Inclusions chemistry: Al2O3
- Inclusions are spherical
- Slag layer is ignored
- Flat free surface

# Control of inclusion, slag foaming and temperature in vacuum degassing

- Inclusions particle density:
  - Group A: 2.8-5.6 um, 2.3e10 l/m3
  - Group B: 5.6-11.2 um, 3.1e9 l/m3
  - Group C: 11.2-23.4 um, 2.3e8 l/m3

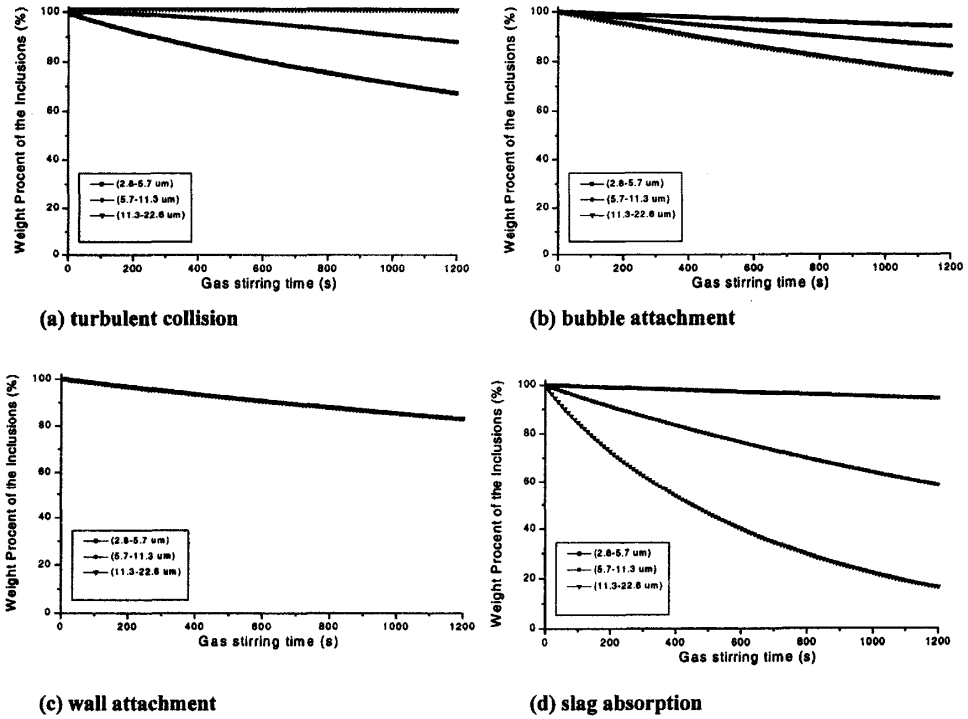
Mechanisms related to inclusion growth and removal:

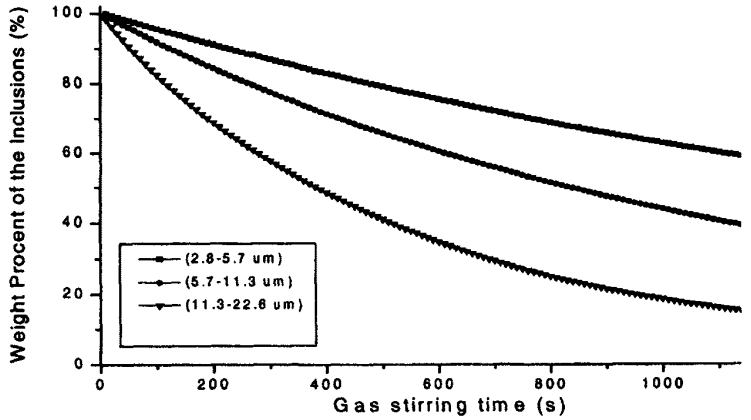
- Inclusion growth due to the stokes collision
- Inclusion growth due to the turbulent collision
- Inclusion growth due to the Brown collision
- Inclusion removal due to the bubble attachment
- Inclusion removal due to the slag absorption
- Inclusion removal due to its sticking on the wall



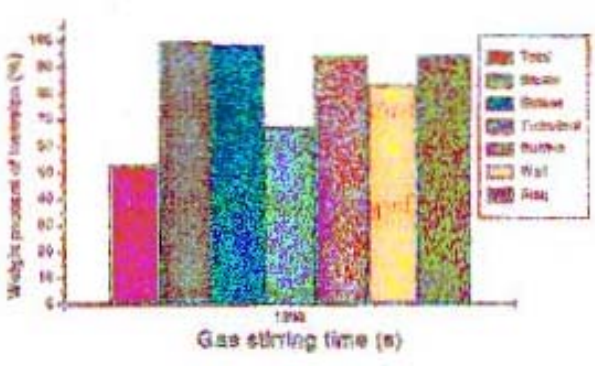
# Control of inclusion, slag foaming and temperature in vacuum degassing

- Effects of mechanisms on inclusion removal:

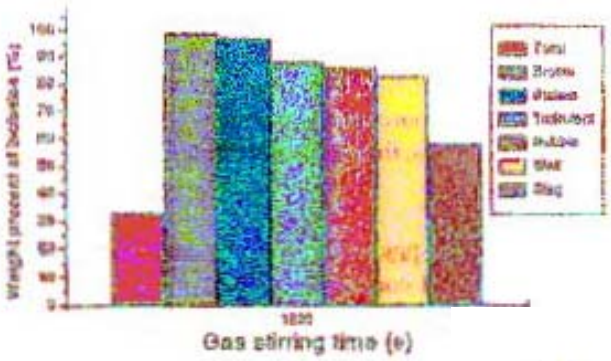


# Control of inclusion, slag foaming and temperature in vacuum degassing

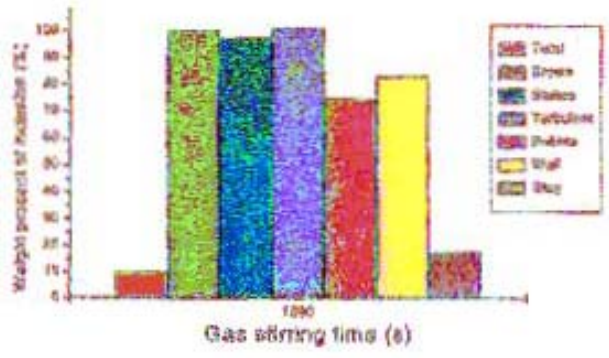



Group A




Group B

Group C

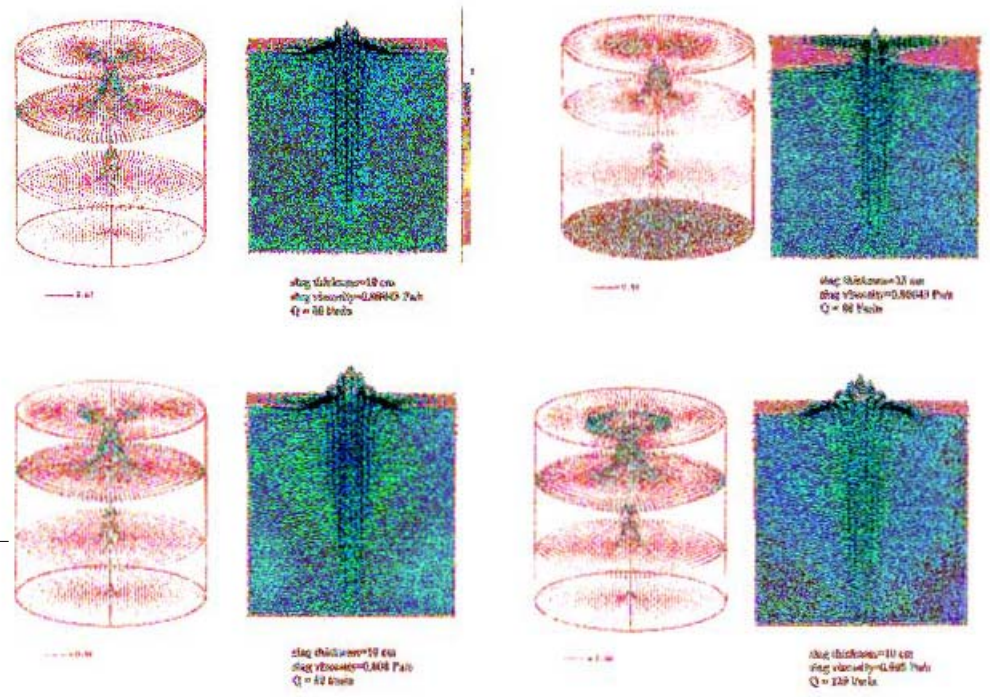


# Control of inclusion, slag foaming and temperature in vacuum degassing

- Open eye size vs. Slag viscosity and flow rate:

| Case | Flow rate [l/min] | Slag Thickness [cm] | Slag viscosity [Pa.s] |
|---|---|---|---|
| 1 | 80 | 10 | 4.3e-4 |
| 2 | 80 | 25 | 4.3e-4 |
| 3 | 80 | 10 | 8.0e-3 |
| 4 | 120 | 10 | 8.0e-3 |

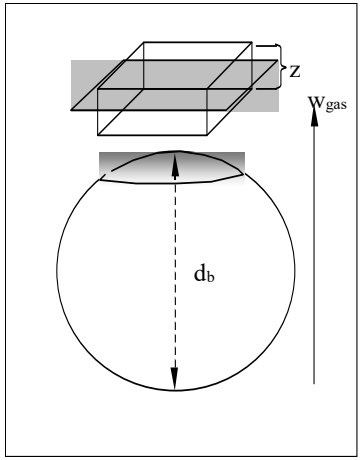
$$k_r^N = \frac{0.015 \cdot f_N^2}{1 + 161 \cdot a_O + 63.4 \cdot a_S}$$

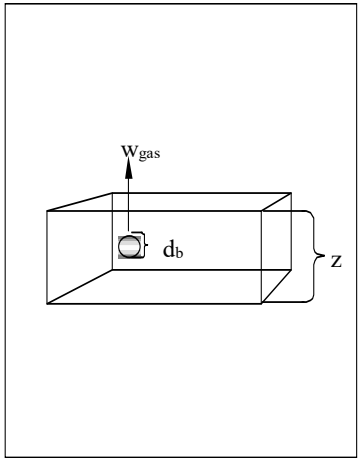


Q=80 l/min, Slag Thickness: 10 cm, slag viscosity: 4.3e-4 Pa.s

# Production of EAF steels with low content of N2 and S through vacuum treatment

- Two cases were considered:
  - Case a
    **small cell or big bubble $d_b$>Z**
  - Case b
    **small bubble $d_b$<Z**
- Z is the vertical extension of a c



# Production of EAF steels with low content of N2 and S through vacuum treatment

- Nitrogen Transport

$$N_N^m = \frac{n_N}{dt}\frac{A\cdot\delta}{100\cdot 14}k_r^N\left\{[\%N]^2{}_i - [\%N]^2{}_e\right\}$$

$$k_r^N = \frac{0.015\cdot f^2{}_N}{1+161\cdot a_O+63.4\cdot a_S}$$

# Production of EAF steels with low content of N2 and S through vacuum treatment

- Profil ARBED modified sulphur content in slag

Initial compositions

**Slag**

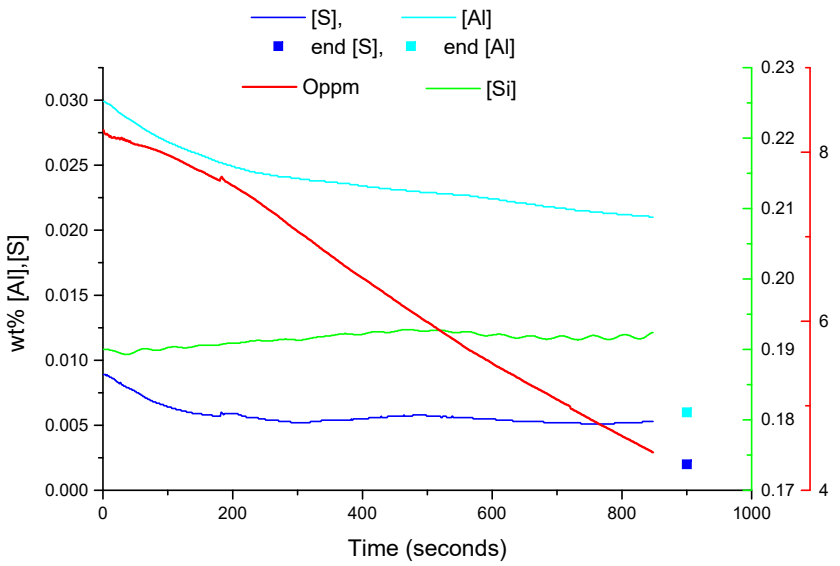
$\%Al_2O_3$=11.77, %CaO=58.21, %FeO=0.73
%MgO=7.39, %MnO=0.16, $\%SiO_2$=17.89
%S=0.5

**Steel**

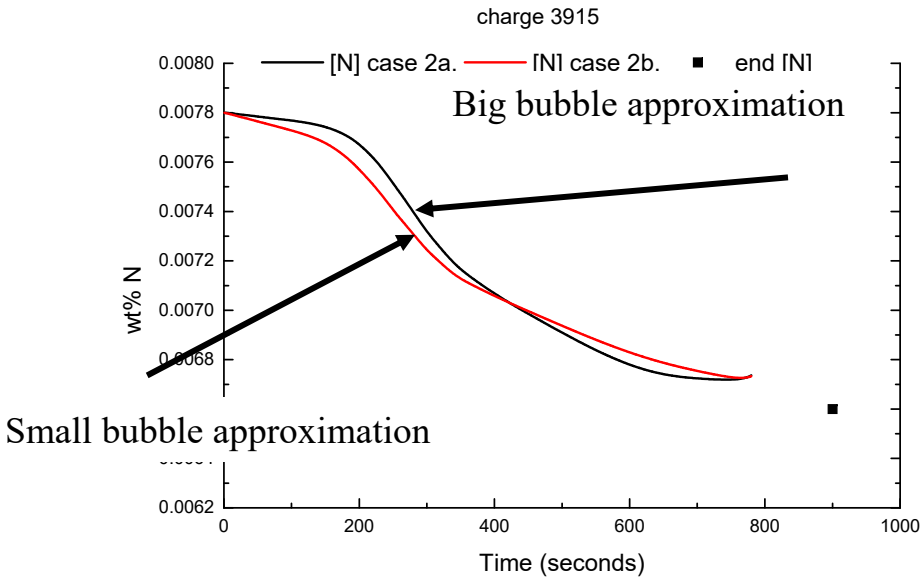
%Al=0.0277, %C=0.0806, %Mn=1.16
%Si=0.184, %S=0.009 **$\%N=7.8 \cdot 10^{-3}$**

# Production of EAF steels with low content of N2 and S through vacuum treatment

- Average [Al], [S], [Si] and [O] contents in the steel melt

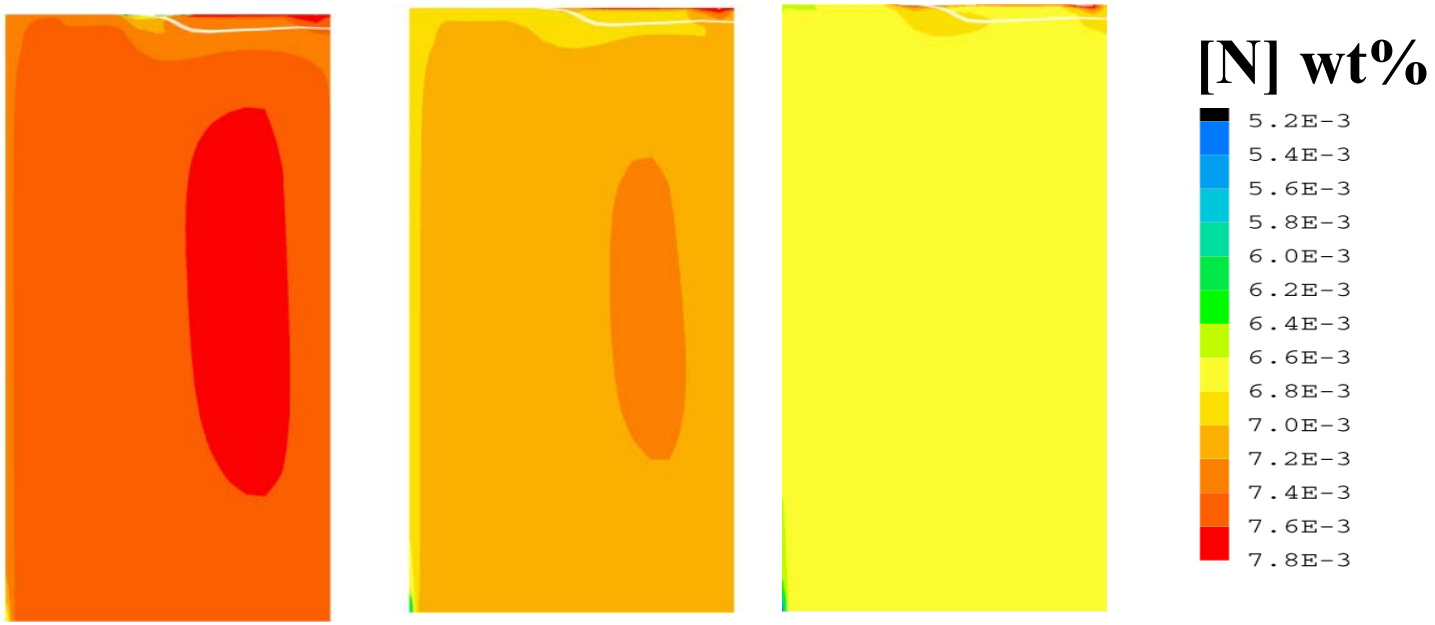



- Average [N] contents in the steel melt



# Production of EAF steels with low content of N2 and S through vacuum treatment

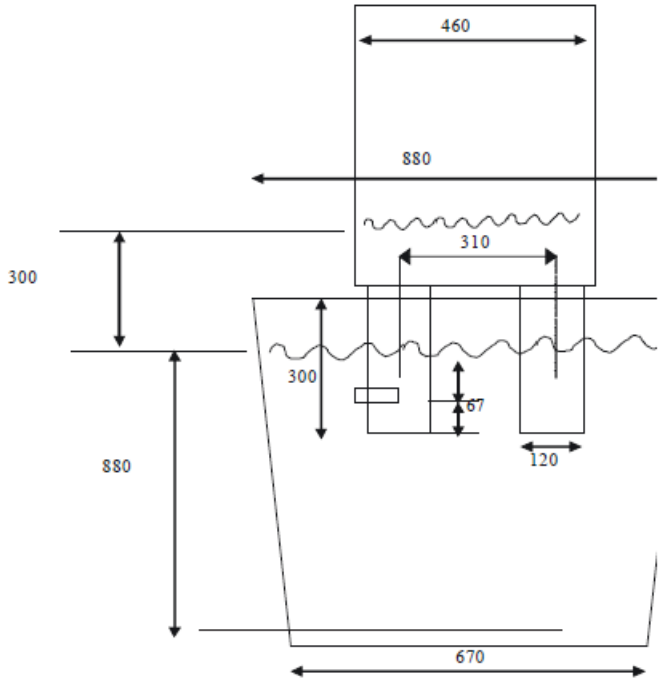
- Concentration profile of nitrogen




T=3.8 min T=6.3 min T=12.9 min

# Improvment of inclusion floatation during RH treatment

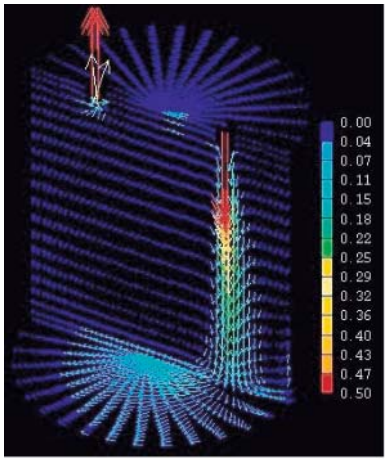
- Geometry and its schematic:

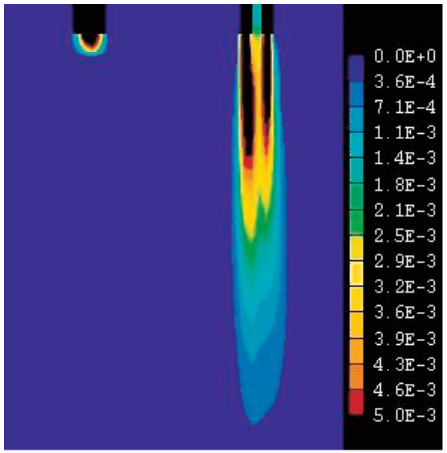


# Improvment of inclusion floatation during RH treatment

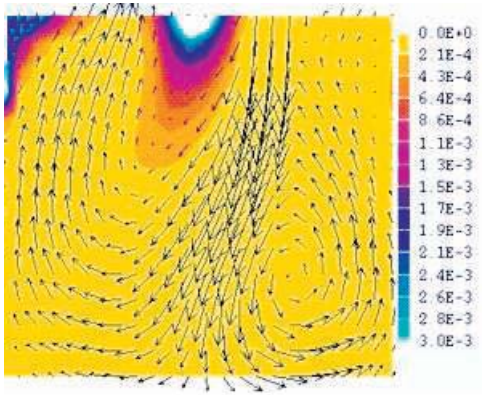
- Profile of the flow inside the vessel:

Velocity vector profile

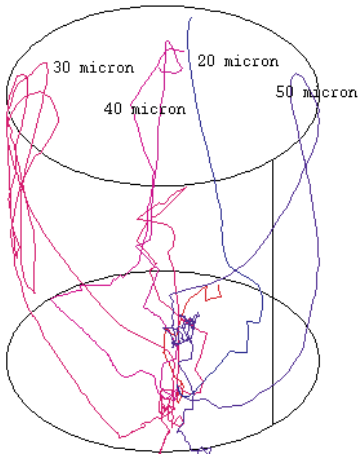



Turbulent energy dissipation



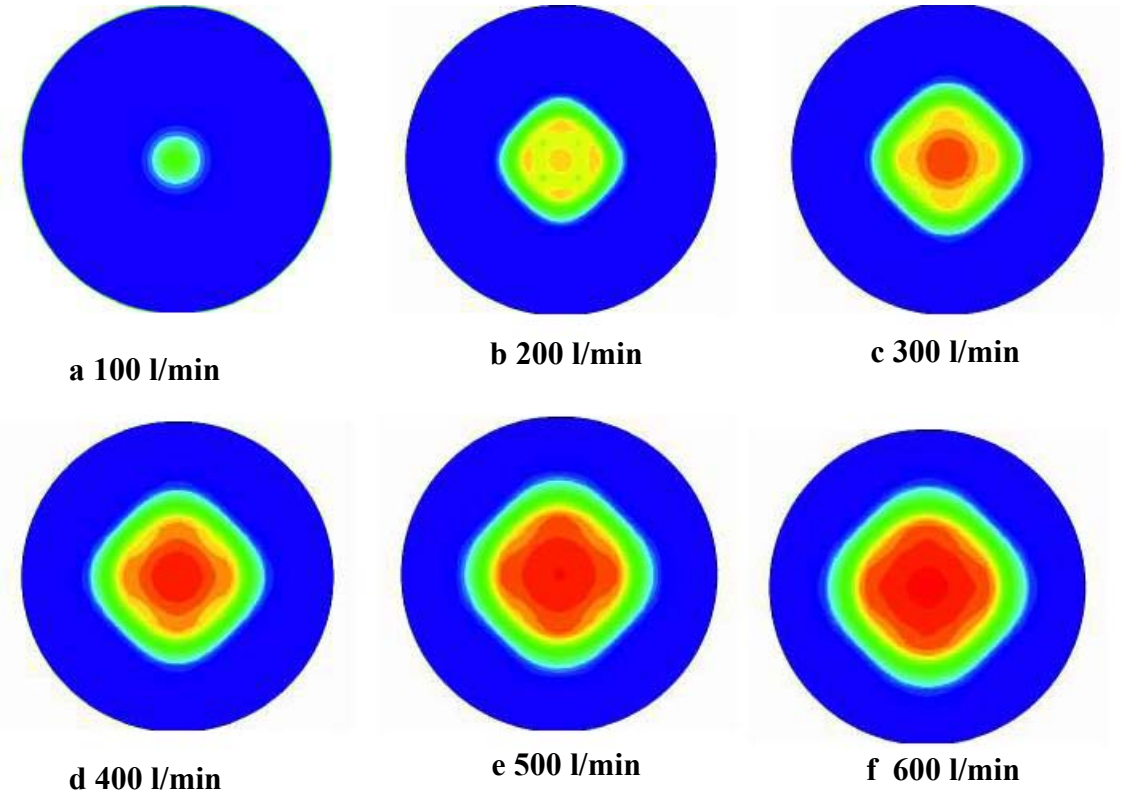

Particle concentration




Particle trajectory

# Development of advanced methods for the control of ladle stirring process

- Open eye for center plug

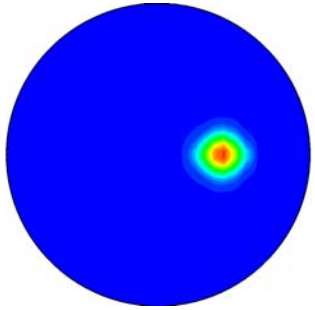


a 100 l/min | b 200 l/min | c 300 l/min

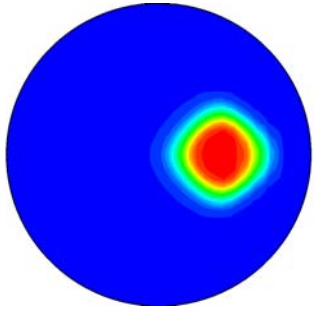
d 400 l/min | e 500 l/min | f 600 l/min

# Development of advanced methods for the control of ladle stirring process

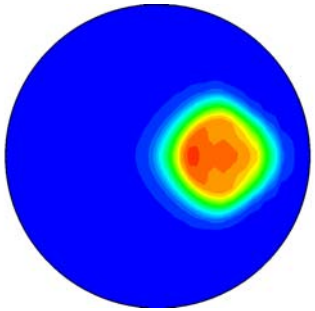
- Open eye for ecentric plug



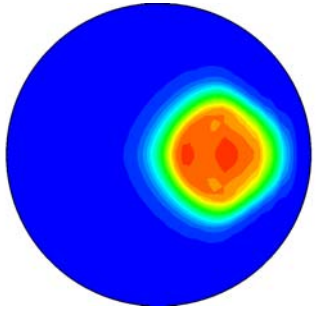
a 100 l/min



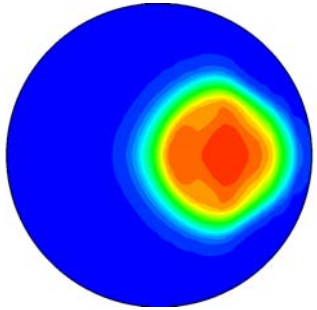
b 200 l/min



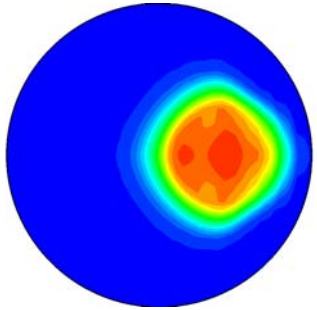
c 300 l/min



d 400 l/min



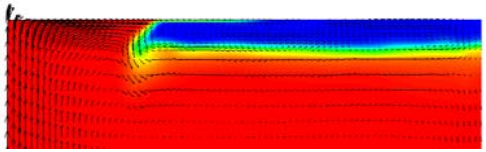
e 500 l/min



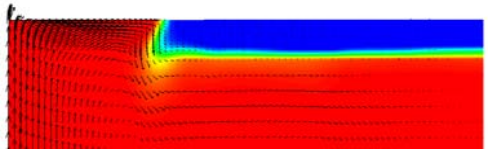
f 600 l/min

# Development of advanced methods for the control of ladle stirring process

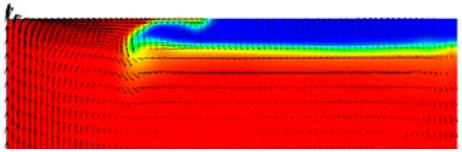
- Effects of viscosity on the size of the open eye:



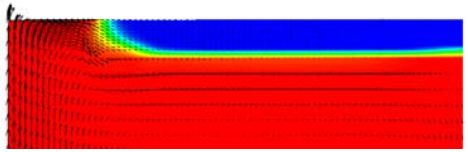
Q=200 l/min, υ (slag) = 4.6e-5 m2s-1



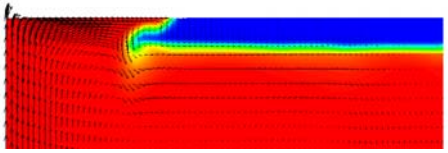
Q=200 l/min, υ (slag) = 4.6e-2 m2s-1



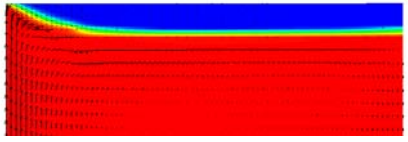
Q=200 l/min, υ (slag) = 4.6e-4 m2s-1



Q=200 l/min, υ (slag) = 4.6e-1 m2s-1

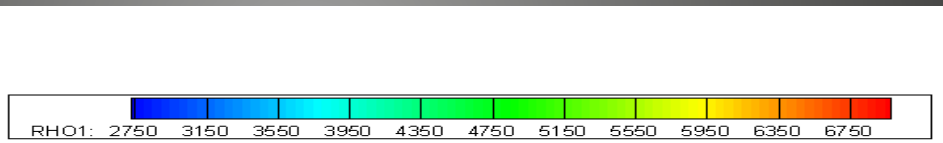


Q=200 l/min, υ (slag) = 4.6e-3 m2s-1



Q=50 l/min, υ (slag) = 4.6e-1 m2s-1

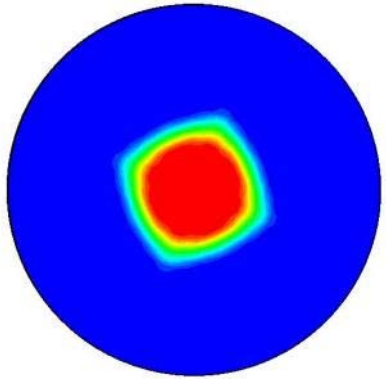


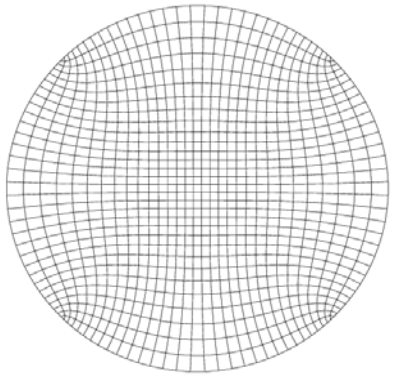


# Development of advanced methods for the control of ladle stirring process

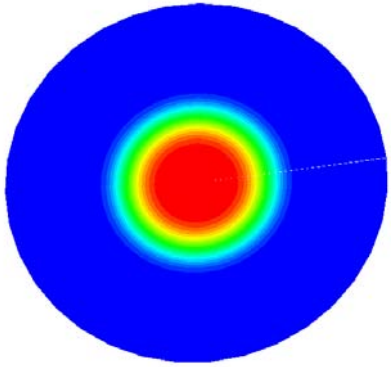
- Effect of grid on the solution:

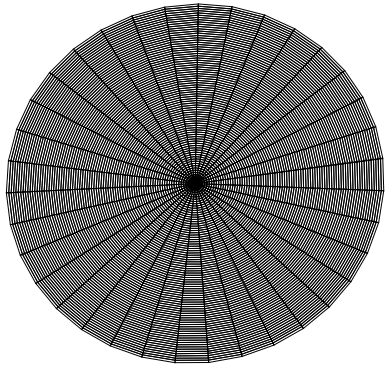
BFC grid





cylindrical grid



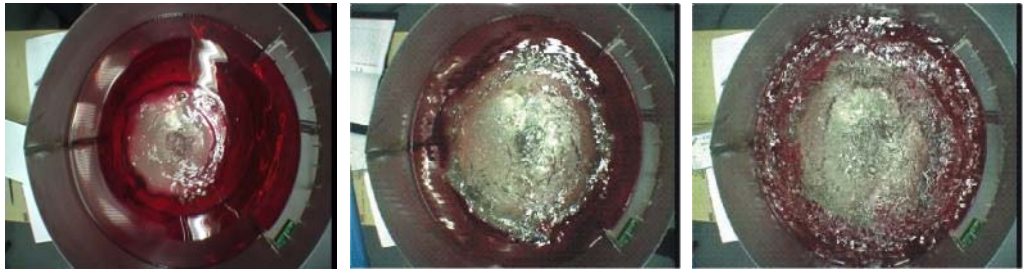


# Development of advanced methods for the control of ladle stirring process

- Water model:

Q=3.6 l/min  Q=9.2 l/min  Q=25.2 l/min

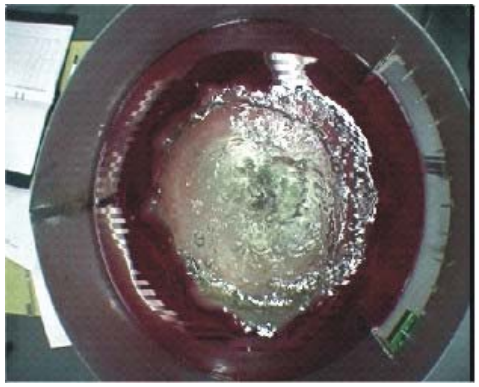
oil height: 2 cm, centric plug



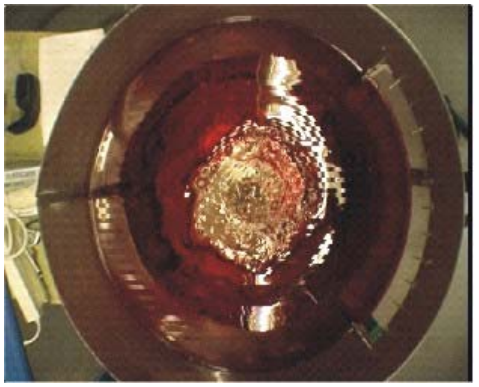
Q=3.6 l/min  Q=7.0 l/min  Q=20.2 l/min

# Development of advanced methods for the control of ladle stirring process

- Open eye size vs. Oil height



**H = 20 mm**

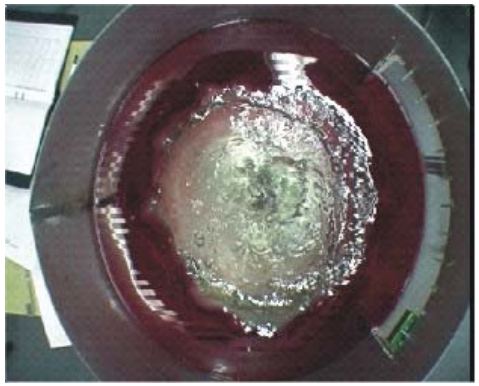


**H = 40 mm**

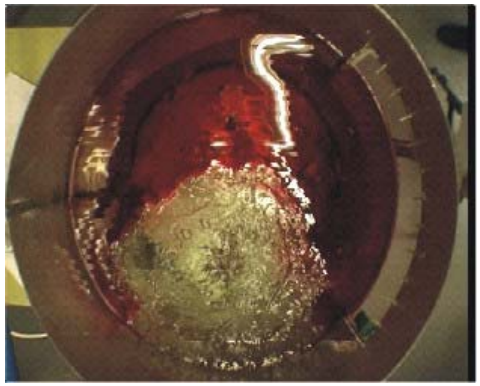
**gas flow: 3.6 l/min, centric plug**

# Development of advanced methods for the control of ladle stirring process

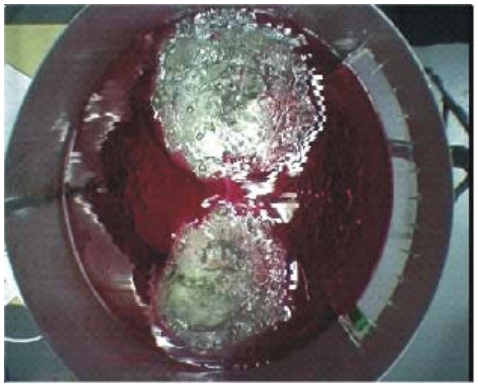
- Open eye vs. Plug position and number



**Centric**



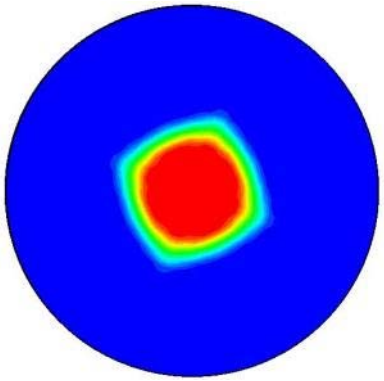
**Eccentric**



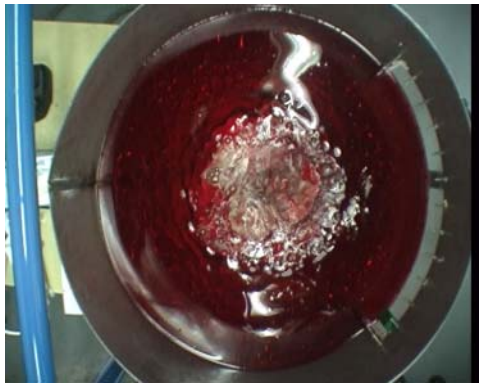
**Double lance**

# Development of advanced methods for the control of ladle stirring process

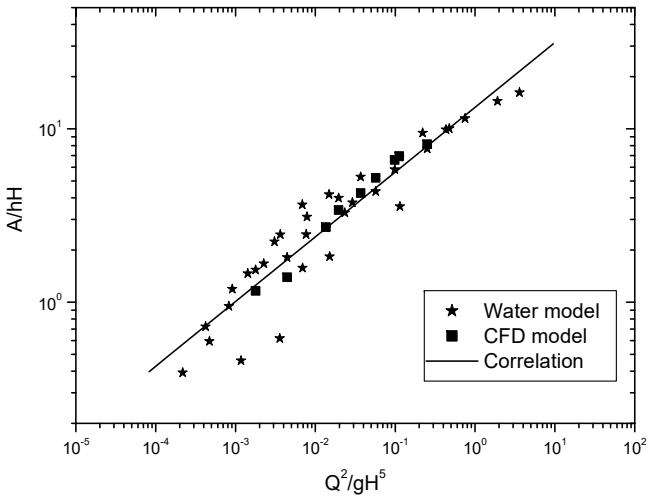
- CFD vs. Water model



a CFD modell



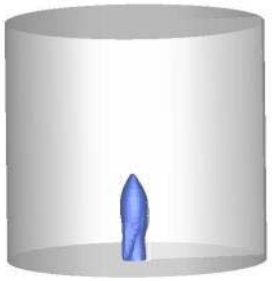
b Vatten modell



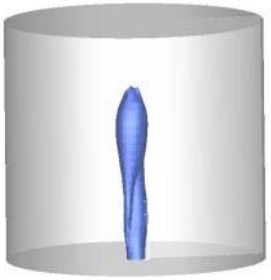

**gas flow: 7 l/min, centric plug, oil height: 6cm**

# Development of advanced methods for the control of ladle stirring process

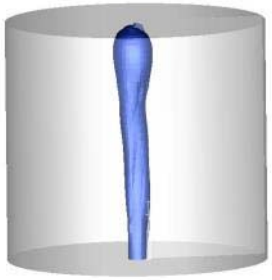
- 3D gas plume:



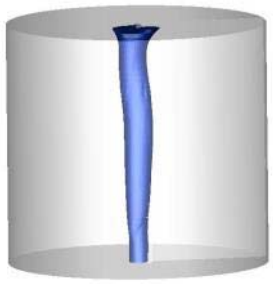
t=0.3s



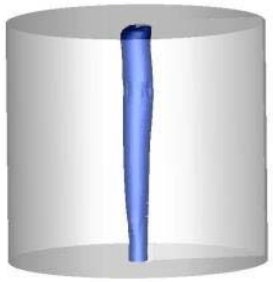
t=0.6s



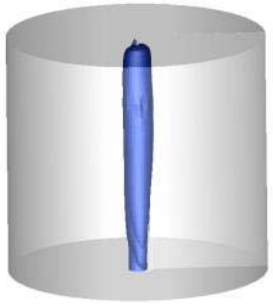
t=0.9s



t=1.2s



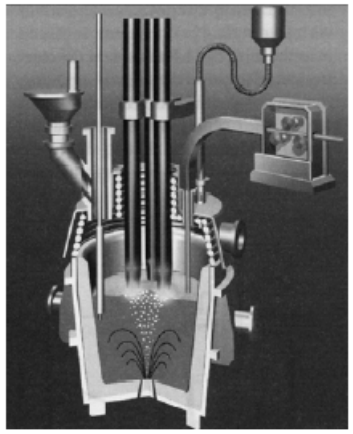
t=1.5s



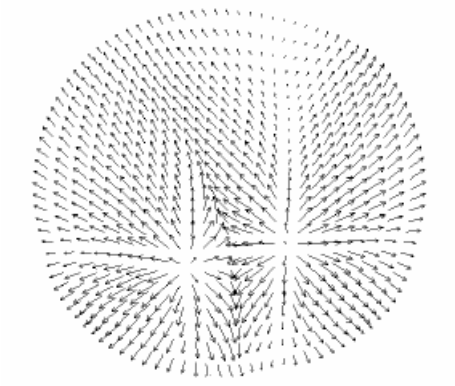
t=3s

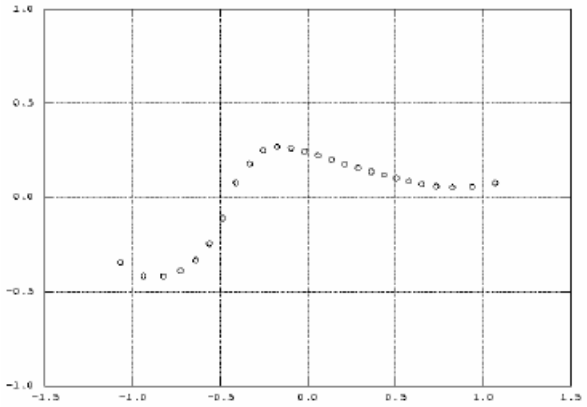
# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

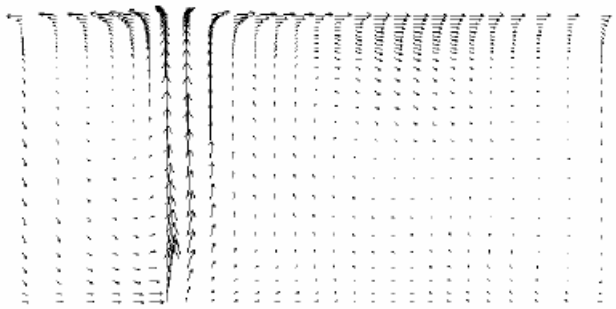
- Schematic:



- Gas flow:





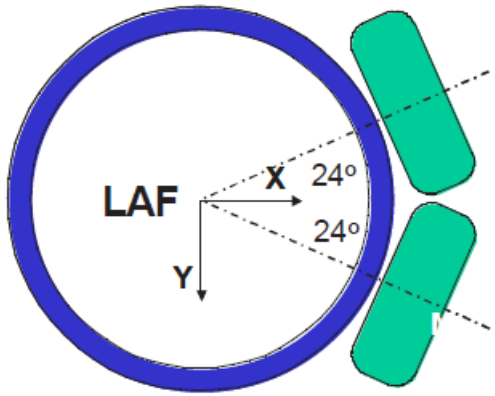


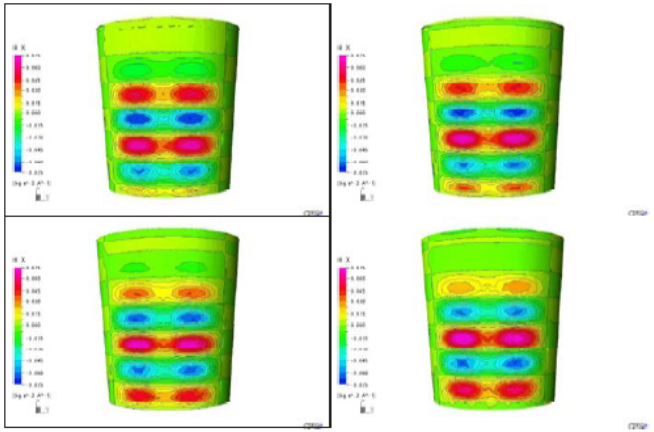
Horizontal velocity at the top surface along a line through nozzel

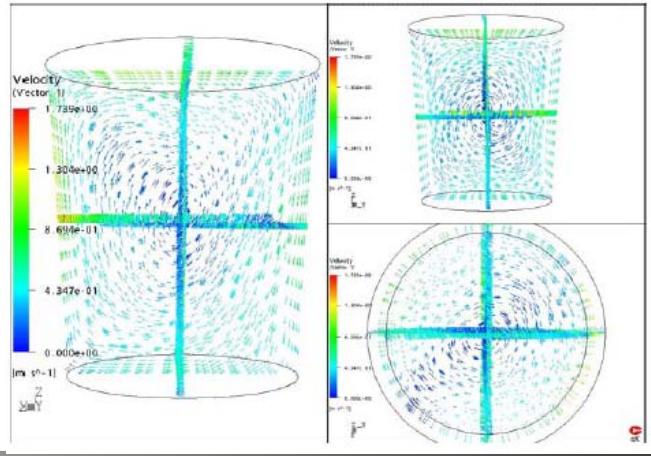
**Velocities for the 35 tonne ladle at Uddeholm Tooling. Gas flow rate 60 Nl/min**

# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

- EMS:

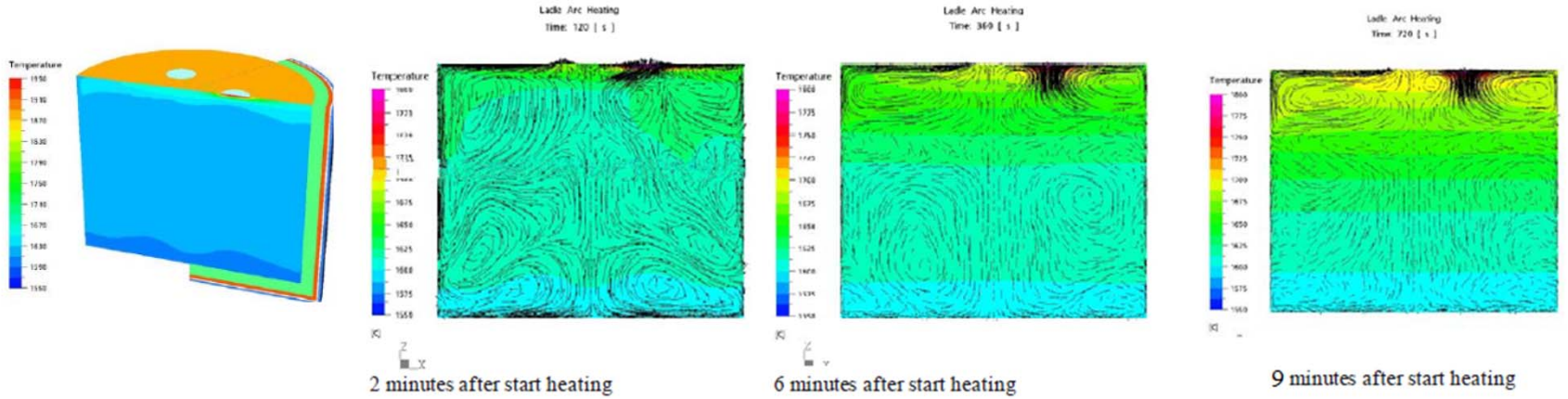




# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

- Heating:



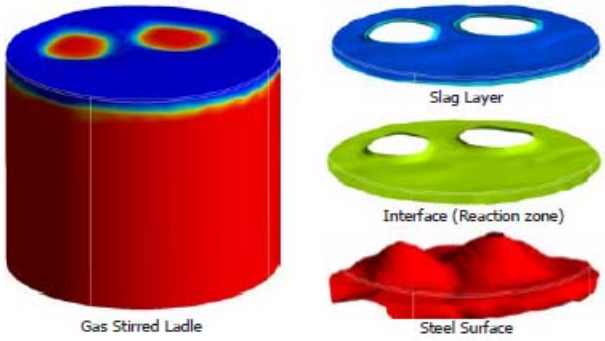

2 minutes after start heating

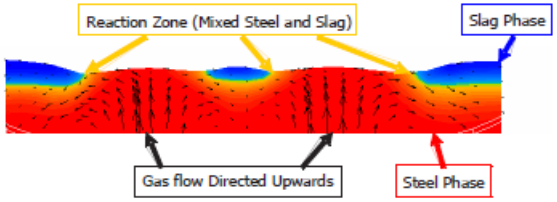
6 minutes after start heating

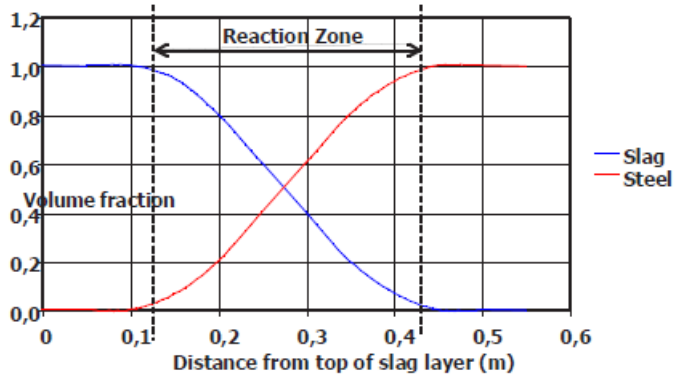
9 minutes after start heating

# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

- Slag-metal interface modelling:

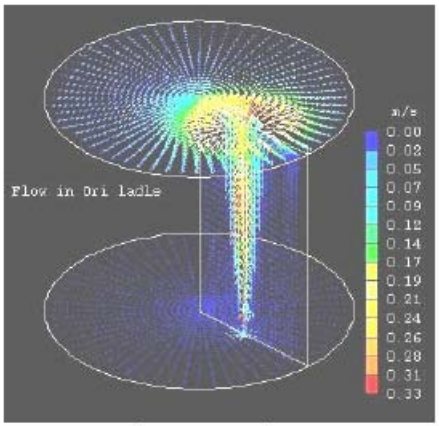


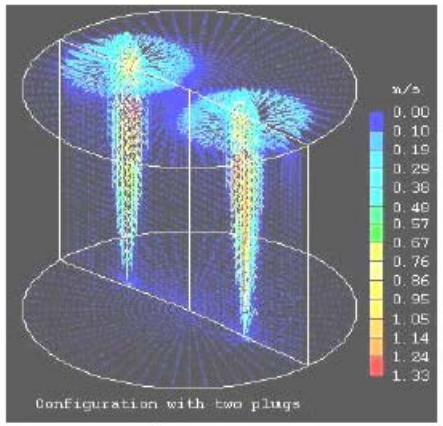



# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

- ORI Martin ladle model:



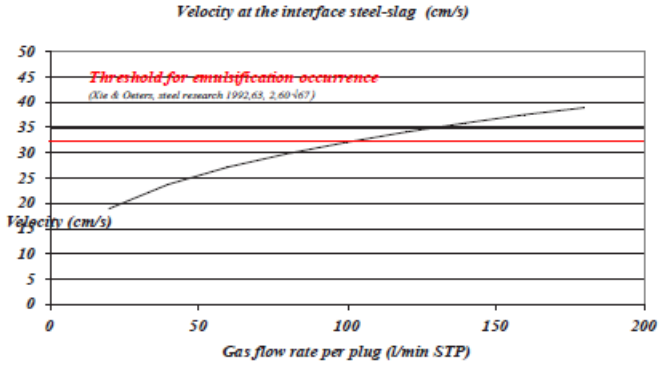

one eccentric porous plug



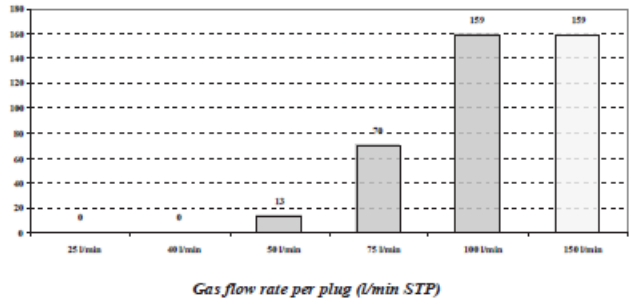

two porous plugs

# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

- Emulsification:



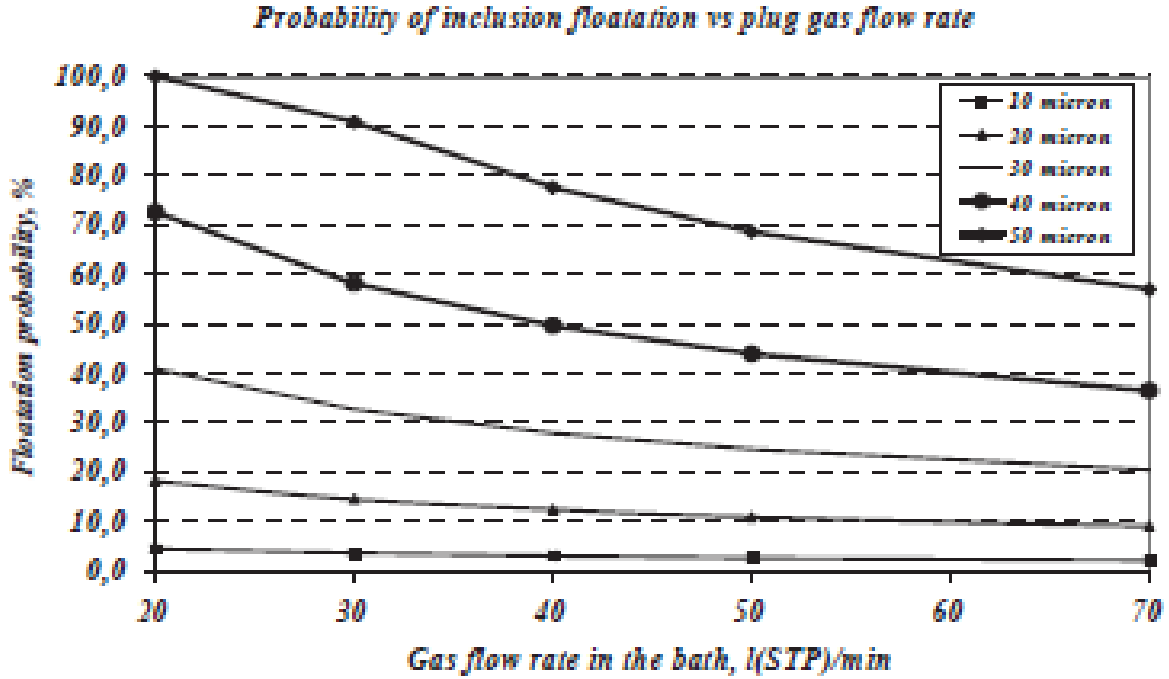

Emulsification threshold




Mass of slag emulsified

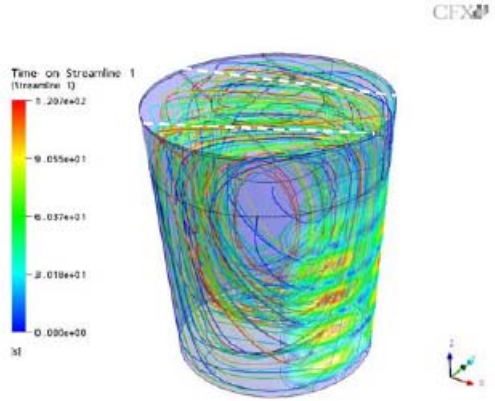
# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

- Floatation probability for particles of different diameter as a function of gas flow rate

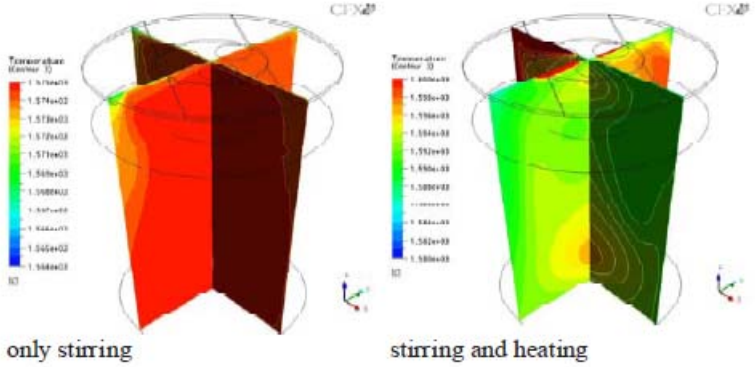


# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

- Corus EMS model:




Streamlines



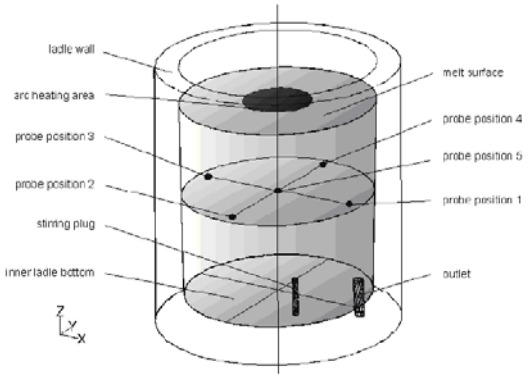

Temperature profile

# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

- Evaluation of heating together with gas stirring

**Plant ladle geometry data and operational parameters**

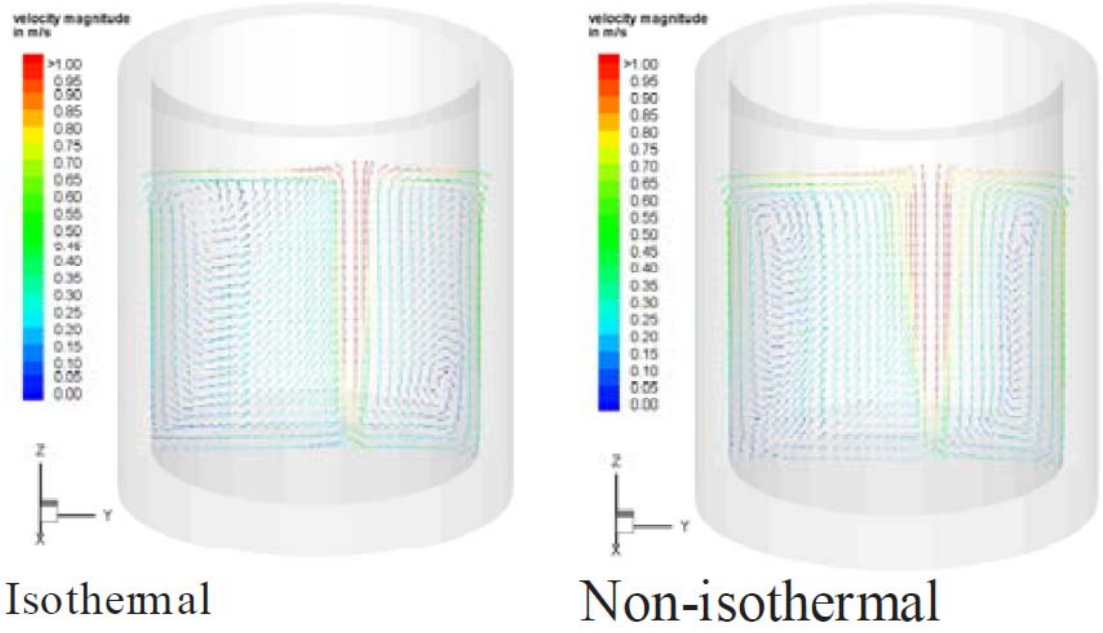
| | |
|---|---|
| Outer ladle diameter | 3.550 m |
| inner ladle diameter (D) | 2.950 m |
| outer ladle height | 4.000 m |
| melt filling height (H) | 2.640 m |
| thickness of slag layer | approx. 0.1 m |
| heat size | approx. 126 t |
| ladle H/D ratio | 0.89 |
| position of plug 1 (main) | y = +0.380 m (+0.25 R) |
| position of plug 2 (alternate) | y = -0.160 m (-0.11 R) |
| stirring gas flow rates uring LF operation | 170 l/min (stp) or 80 l/min (stp) |




**Schematic drawing of the numeric ladle set-up**

# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

- Evaluation of heating together with gas stirring

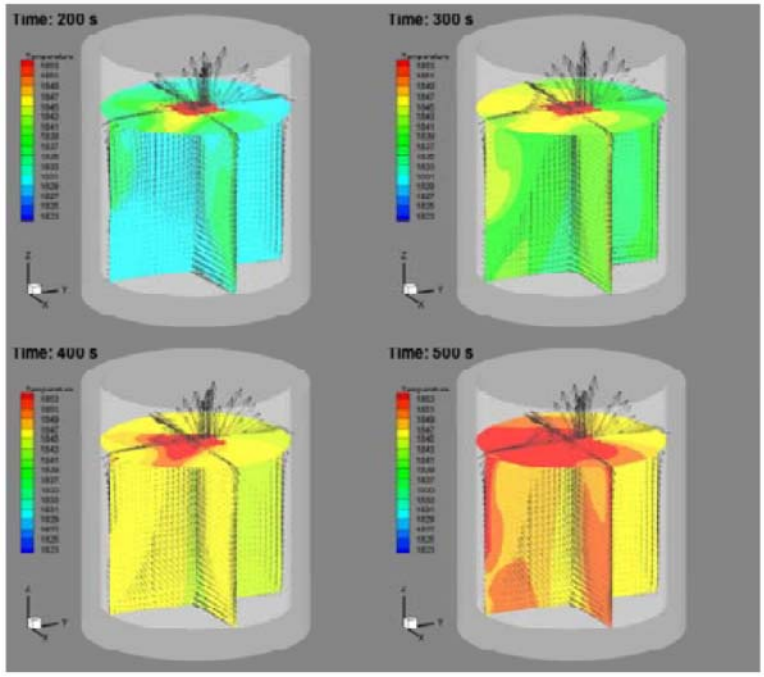



Isothermal Non-isothermal

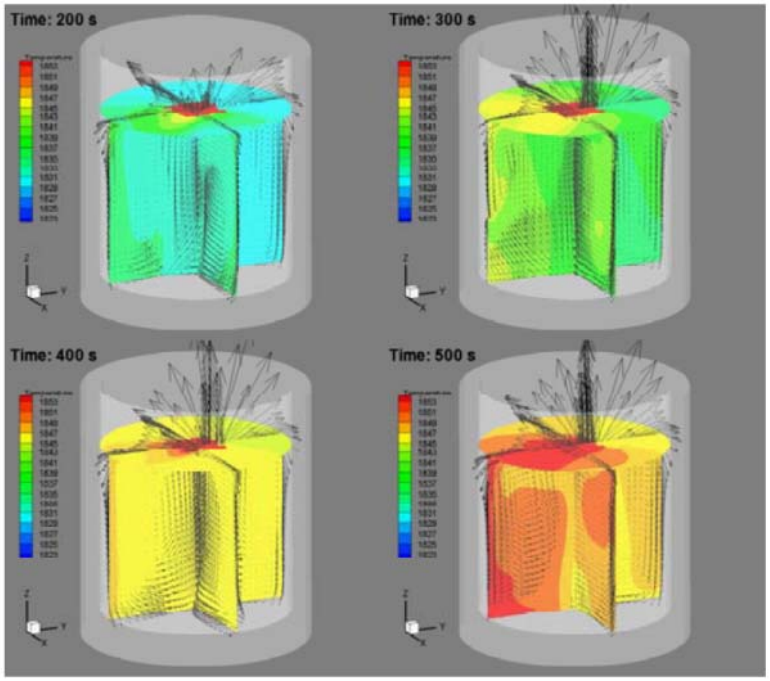
Gas flow rate 800 l/min

# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

- Temperature profile:



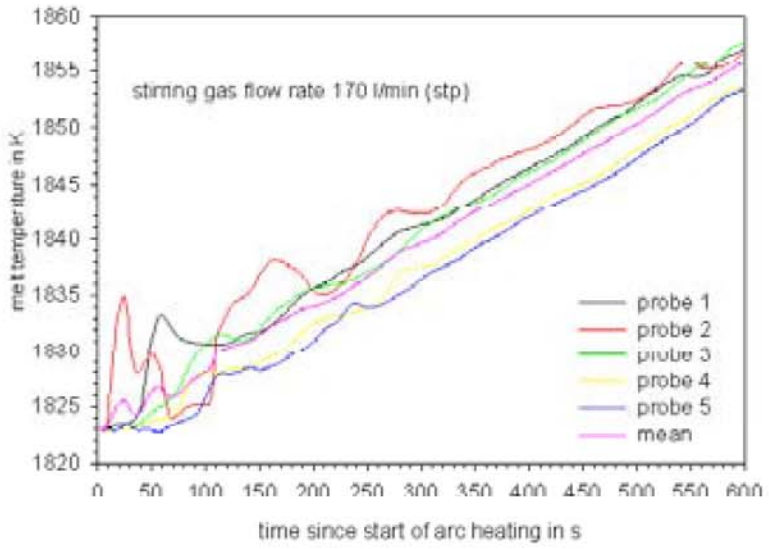

Gas flow rate 170 l/min



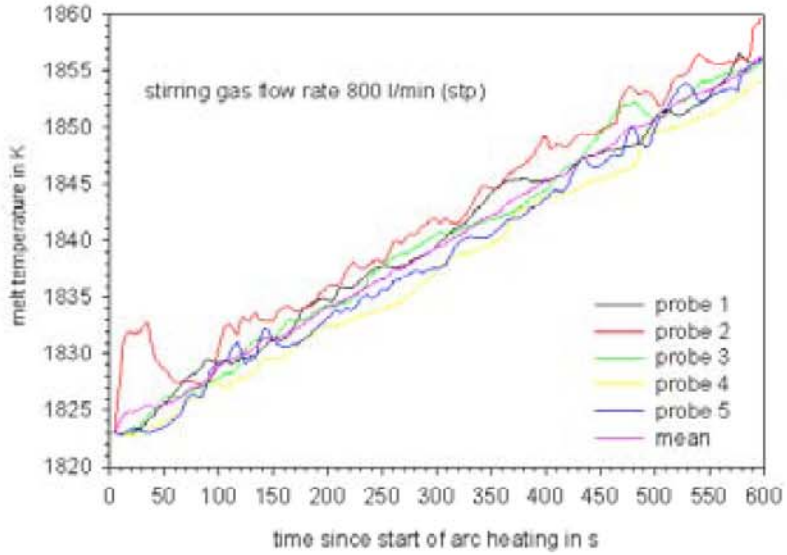

Gas flow rate 800 l/min

# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

- Melt temperature w.r.t time



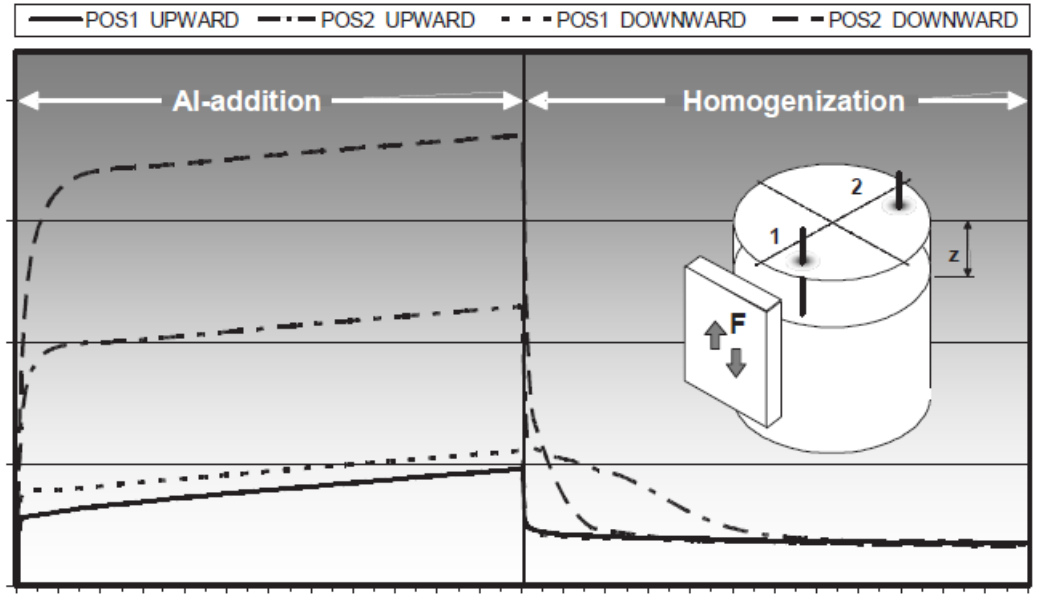

a) stirring gas flow rate 170 l/min (stp)




b) stirring gas flow rate 800 l/min (stp)

# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

- Uddeholm Tooling Al-addition:



# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

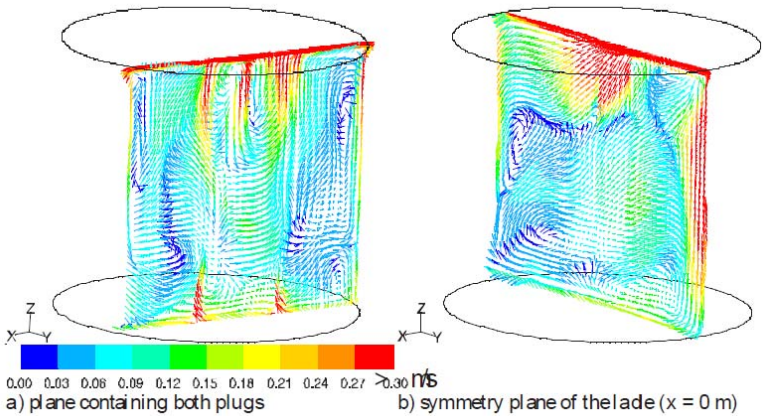
- Flow profile for different variants:

| Case | Plug 1 [l/min] | Plug 2 [l/min] |
|---|---|---|
| 1 | 60 | 60 |
| 2 | 120 | 120 |
| 3 | 200 | 200 |
| 4 | 60 | 200 |

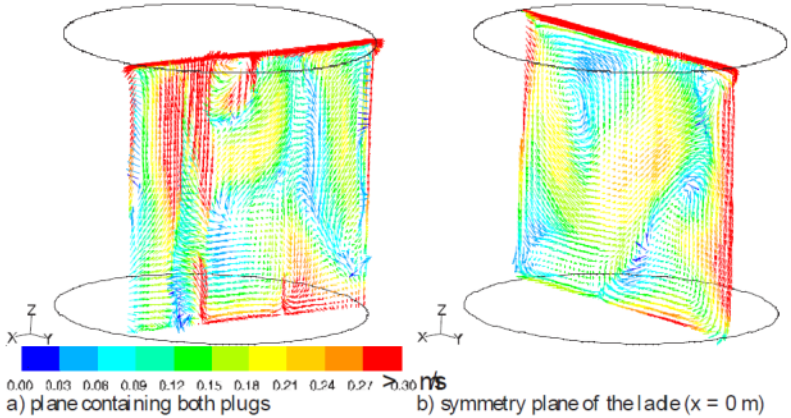
# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

- Flow profile for differetn varients:

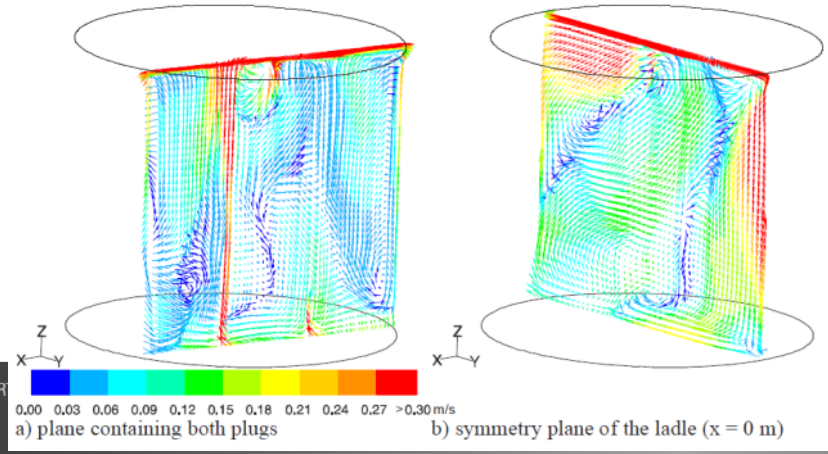
Case 1



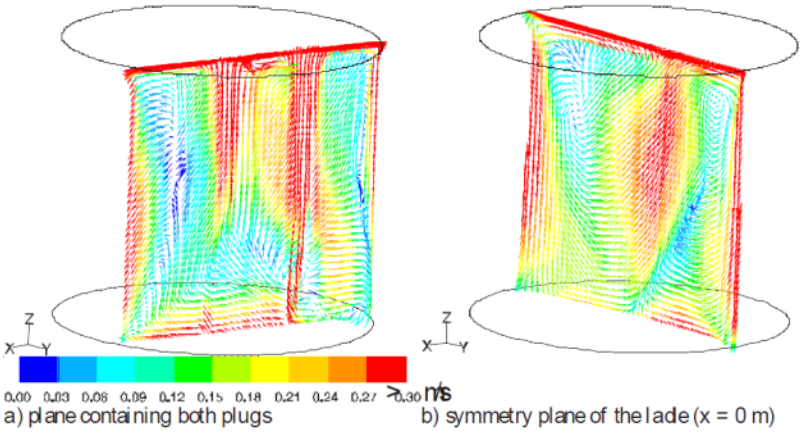

Case 3




Case 2

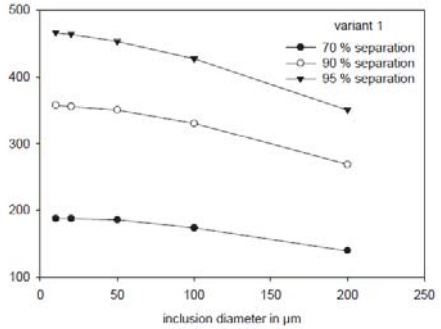



Case 4

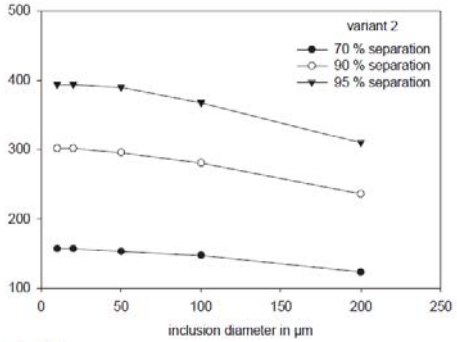


# Improved control of inclusion chemistry and steel cleanness in the ladle furnace

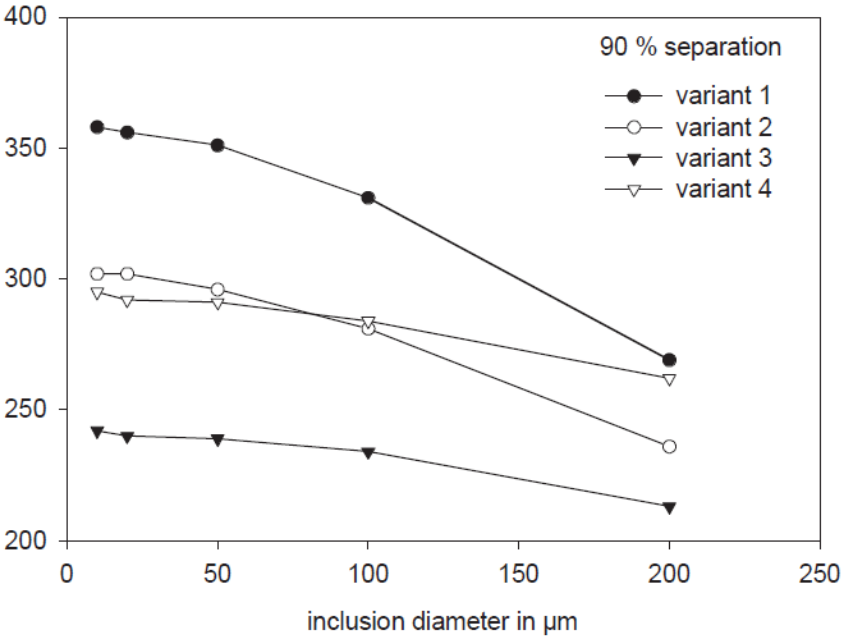
- Inclusions separation:

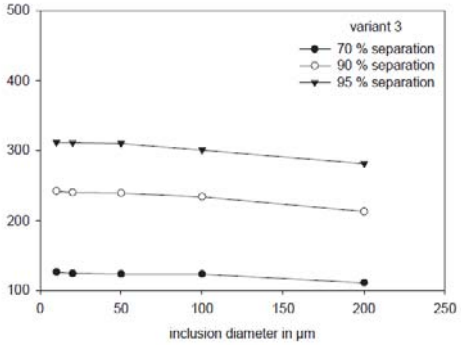



Variant 1

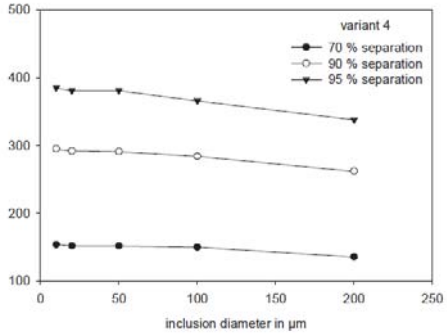



Variant 2



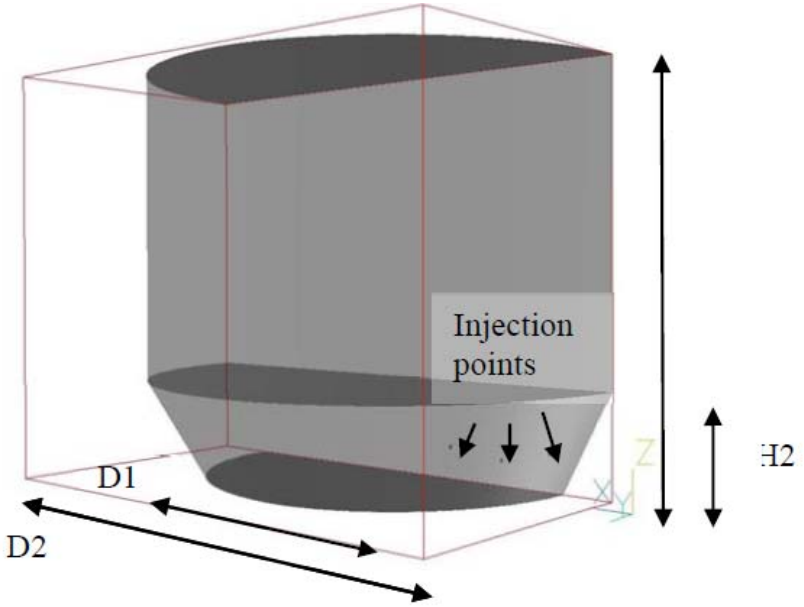

Variant 3




Variant 4

# Resource-saving operation of stainless steel refining in VOD and AOD processes

- Domain of calculation:

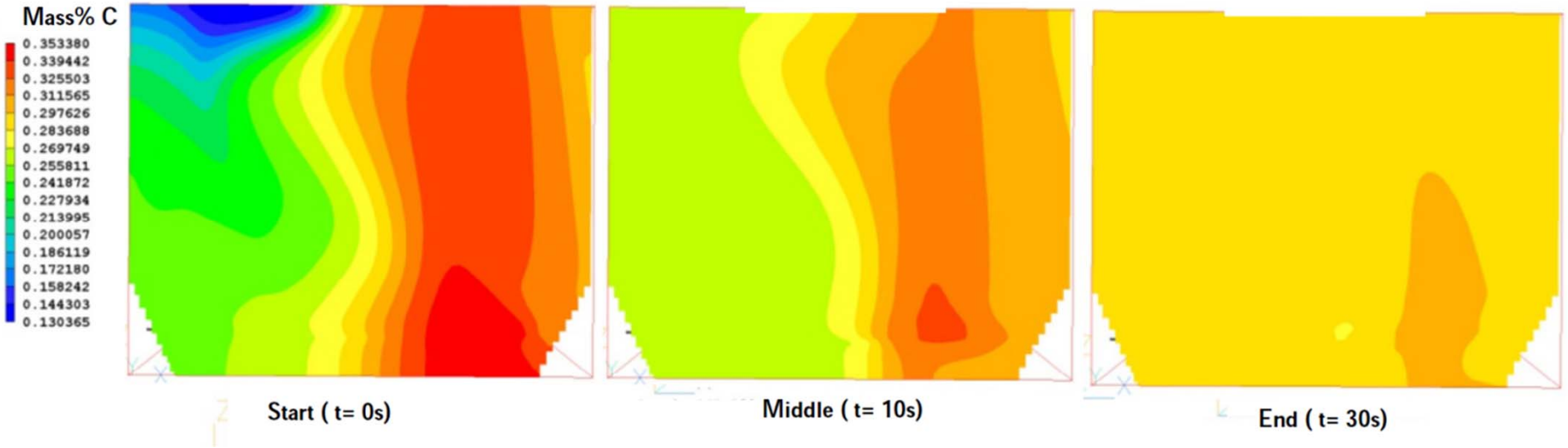



Dimension of computational domain [m]

| H1 | H2 | D1 | D2 |
|---|---|---|---|
| 2.37 | 0.612 | 2.327019 | 2.982 |

# Resource-saving operation of stainless steel refining in VOD and AOD processes

- Distribution of carbon concentrations in % for an AOD heat at start of inert gas blowing, after 10s and after 30s.



# Summary

- RH degasser:
  - Melt conposition
  - Inclusion model
  - Temperature profile and heat transfer
- Ladle:
  - Stirring: gas and/or industion
  - Arc heating
  - Homogenization
  - Melt composition
  - Inclusion model
- AOD and VOD:
  - Melt composition
  - Temperature profile
  - Decarburization
- The newest simulation work is at least 6 years old!

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