Characterisation and optimisation of ladle stirring systems for The steelmaking industry

DISSTECH WORK SHOP
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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 inclusion, slag foaming and temperature in vacuum degassing

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

<table>
<thead>
<tr>
<th>Case</th>
<th>Flow rate [l/min]</th>
<th>Slag Thickness [cm]</th>
<th>Slag viscosity [Pa.s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80</td>
<td>10</td>
<td>4.3e-4</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>25</td>
<td>4.3e-4</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
<td>10</td>
<td>8.0e-3</td>
</tr>
<tr>
<td>4</td>
<td>120</td>
<td>10</td>
<td>8.0e-3</td>
</tr>
</tbody>
</table>

\[ k_r^N = \frac{0.015 \cdot f^2_N}{1 + 161 \cdot a_o + 63.4 \cdot a_s} \]

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

- Concentration profile of nitrogen

![Images showing concentration profile of nitrogen at different times](image_url)

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

[N] wt%
Improvement of inclusion floatation during RH treatment

- Geometry and its schematic:
Development of advanced methods for the control of ladle stirring process

• Open eye for eccentric 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, $\nu$ (slag) = 4.6e-5 m2s-1
  - Q=200 l/min, $\nu$ (slag) = 4.6e-4 m2s-1
  - Q=200 l/min, $\nu$ (slag) = 4.6e-3 m2s-1
  - Q=200 l/min, $\nu$ (slag) = 4.6e-2 m2s-1
  - Q=200 l/min, $\nu$ (slag) = 4.6e-1 m2s-1
  - Q=50 l/min, $\nu$ (slag) = 4.6e-1 m2s-1
Development of advanced methods for the control of ladle stirring process

- Water model:

  \begin{itemize}
  \item Q=3.6 \text{l/min}
  \item Q=9.2 \text{l/min}
  \item Q=25.2 \text{l/min}
  \end{itemize}

  \begin{itemize}
  \item Oil height: 2 cm, centric plug
  \item Q=3.6 \text{l/min}
  \item Q=7.0 \text{l/min}
  \item Q=20.2 \text{l/min}
  \end{itemize}
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
Development of advanced methods for the control of ladle stirring process

- CFD vs. Water model

![CFD model](image1.png)  ![Water model](image2.png)

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

- Flow profile for different variants:

<table>
<thead>
<tr>
<th>Case</th>
<th>Plug 1 [l/min]</th>
<th>Plug 2 [l/min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>200</td>
</tr>
</tbody>
</table>
Improved control of inclusion chemistry and steel cleanness in the ladle furnace

Case 1

Case 2

Case 3

Case 4
Improved control of inclusion chemistry and steel cleanness in the ladle furnace

- Inclusions separation:
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 composition
  - 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!
Why stirring?

• Improves the kinetics so that equilibrium conditions are met faster
• Homogenization with respect to dissolved elements as well as temperature
• Promote the separation of inclusions to slag
Porous plugs

Slot plug  Segment plug  Hybrid plug
Bubble columns

Slot plug  Segment plug  Hybrid plug
Homogenization Times

- **Slot plug**
  - Median = 85 s
  - Standard deviation = 14 s

- **Segment plug**
  - Median = 99 s
  - Standard deviation = 16 s

- **Hybrid plug**
  - Median = 102 s
  - Standard deviation = 19 s
Gas Stirring

- Refining Time (s)
- Open Eye Size (m2)

Time (s)

0 150 300 450 600

Gas Flow (m²)

Open Eye Size (m²)

0 0,3 0,6 0,9 1,2

Graph showing the relationship between gas flow, refining time, and open eye size.
Symmetric gas flow
Asymmetric gas flow
Effect on flow

Steel velocities

Open eye size

Homogenization time
Number of plugs

26
Refining times

Number of Plugs

- Homogenization
- Gas/Metal Reactions
- Slag/Metal Reactions

Time

4 Plugs
2 Plugs
Ladle age
Electromagnetic stirring forces
Open eye size

![Diagram showing open eye size](image-url)
Geometries

H/D = 1

H/D = Height/Diameter

H/D = 2

H/D = 0.5
Refining operations
Ladle geometry

Comparison

![Graph showing refining time vs. height/diameter ratio for different processes: Gas/Metal (yellow), Slag/Metal (green), Homogenization (blue), Mean (red).](image-url)
Plug placement
Gas plumes
Industrial ladles

Combined Stirring

Industrial Ladle 1

- Time (s)
- Low Current
- Medium Current
- High Current

Industrial Ladle 2

- Refining Time (s)
- Low Current
- Medium Current
- High Current

Gas Flow (nl/min)

Open Eye Size (m²)
Scientific Work for Industrial Use
www.swerea.se