CFD modelling of argon stirred ladle

FIMECC
Advanced Melt Metallurgy (AMMe) -project
AMMe -project

- Demands for advanced steels have increased the complexity of secondary metallurgy.
- Requires very good control of steelmaking processes.
- To ensure fast implementation of a new steel grade to profitable production a holistic model of secondary processes with fundamental based sub-models are needed.
- Participants of the project are Rautaruukki Metals Oy, Outokumpu Stainless Oy, Process Metallurgy and Mass and Heat Transfer Process laboratories of University of Oulu, Aalto University and VTT.

Duration: 11/05/2009 – 31/12/2014.

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Aim of AMMe -project

- Treat the set of holistic process oriented models describing dominating phenomena (e.g. behavior of supersonic oxygen jet, foaming etc) similar to all secondary metallurgy process units and
- Develop new concepts to produce advanced steels and ferroalloys with secondary metallurgy units and simulate process procedures in case specific studies (vacuum, AOD, CAS-OB and BOF processes).
CAS-OB process

Composition adjustment by sealed argon bubbling – oxygen blowing
Temperature and composition of the steel melt is adjusted for continuous casting.
Argon injection from bottom of ladle is used for mixing the steel and to form and open-eye through the slag layer.
MODEL

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CFD model

- VOF multiphase model
- Realizable $k$-$\varepsilon$ and WALE LES turbulence models compared
- $k$-$\varepsilon$ gives time-averaged results, designed for steady-state modelling
- LES gives space-averaged results
- Isothermal conditions assumed
- Calculation times several weeks

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Geometry

- Geometry consists of 2 argon inlets (blue) and 1 common outlet (red) for all phases.
- Height of the domain is 3.0 m for k-ε and 3.5 m for LES-simulations.
- Argon inlet diameters 0.24 m
- Outlet diameter 1.28 m
- Phase initialization
- Molten steel: 0-2.655 m
- Slag: 2.655-2.705 m
- Argon: 2.705-3.0 m

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Meshes used in simulations

Mesh for k-ε simulations
(~759,000 cells)

Mesh for LES simulations
(~1,372,000 cells)

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## Material properties

<table>
<thead>
<tr>
<th></th>
<th>Argon</th>
<th>Slag</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argon</td>
<td>$\rho=0.5 \text{ kg/m}^3$</td>
<td>$\sigma=0.59 \text{ N/m}$</td>
<td>$\sigma=1.52 \text{ N/m}$</td>
</tr>
<tr>
<td></td>
<td>$v=1.87 \times 10^{-5} \text{ kg/(ms)}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$m_{\text{tot}}=3.9 \times 10^{-2} \text{ kg/s}$</td>
<td></td>
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</tr>
<tr>
<td>Slag</td>
<td>$\sigma=0.59 \text{ N/m}$</td>
<td>$\rho=2750 \text{ kg/m}^3$</td>
<td>$\sigma=1.05 \text{ N/m}$</td>
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<tr>
<td></td>
<td>$v=0.3 \text{ kg/(ms)}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>$\sigma=1.52 \text{ N/m}$</td>
<td>$\sigma=1.05 \text{ N/m}$</td>
<td>$\rho=6800 \text{ kg/m}^3$</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>$v=4.9 \times 10^{-3} \text{ kg/(ms)}$</td>
</tr>
</tbody>
</table>

- Density, $\rho$, viscosity, $v$, and surface tension, $\sigma$, for different phases
- Slag layer thickness in the beginning of the simulation is 5 cm.
- $m_{\text{tot}}$ is the combined massflow from both inlets

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RESULTS
Velocity distribution around bubbles

\[ \text{k-\(\varepsilon\)} \]

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\[ \text{LES} \]
Conclusions about bubble velocities

- With LES model the bubbles are more dispersed than with \( k-\varepsilon \)
- The dispersion is caused due the nature of the model (time averaged vs. space averaged)
- Also the used grid in LES simulations is denser, so it can distinguish more delicately the bubbles
- The velocities are mainly under 5 m/s
Phase distribution of steel (red) and slag (blue)

k-ε
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LES
Surface area between steel and slag

Approximation of surface area with time
(at least 5% steel and slag in each computational cell)

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Conclusions about phase distribution

- LES model shows more dispersed phase distribution on the surface than $k-\varepsilon$
- $K-\varepsilon$ gives much smaller surface area than LES for slag and steel interface
- The interfacial surface area seems to be mesh dependent
Validation

Contours of Volume fraction (slag) (Time=8.4247e+00)
ANSYS FLUENT 14.0 (3d, dp, pbre, vof, LES, transient)

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Conclusion about validation

- Simulation results with LES seems to correspond to the image of the real process better than with k-ε
- The process conditions are strongly time-dependent
- It is difficult to determine the slag-steel interphase from process images

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Summary

- LES model shows more dispersed phase distribution than k-ε
- Flow velocities are mainly below 5 m/s with both models
- Simulation results with LES seems to correspond the image of the real process
- Simulation times with LES are significantly longer than with k-ε
- Next step is include some reactions into the model and determine the mass transfer coefficients between the phases