Modeling of Fluid Flow, Mixing and Inclusion Motion in Bottom Gas-Stirred Molten Steel Vessel

Development of a Process to Continuously Melt, Refine, and Cast High-Quality Steel

Lifeng Zhang, Brian G. Thomas
University of Illinois
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Conceptual layout for 110 tph process

- Heated holding ladle (for EAF or tundish), or pig the steel
- CaO, MgO alloys
- Deoxidizer, CaO, MgO
- Oxidize: \( \text{O}_2 + \text{Ar} \)
- Reduce: \( \text{Ar} \)
- Melt: \( 0.15\% \text{C} \)
- Homogenize & float

Figure from Jorg Peter, UMR
Geometry of Vessel II

Gas Injection inlets:
Position: 1/4 and 3/4 diameter of the bottom
Din=0.2m
Geometry of Vessel II

Inlet
(Din=0.14m, Dout=0.2m, Submergence depth: 0.15m
Simulated inlet SEN length: 0.5m
Distance of inlet center line to left wall: 0.2m
Vin=0.23m/s
Kin=0.01m²/s²
in=0.06m²/s³)

Vessel II
(Din=1.4m, Depth: 2.0m)

Outlet SEN
(Din=0.14m, Dout=0.2m, Length: 1.1m, no slide gate
Distance of outlet center line to right wall: 0.2m)

Outlet Launder:
Thickness: 0.3m

Inlet Launder:
Left depth: 0.3m
Right depth: 0.6m
Length: 1m
Thickness: 0.3m

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Geometry of Vessel II

- Inner diameter: \( D = 1.4 \text{m} \)
- Steel bath height: \( H_{\text{steel}} = 2.0 \text{m} \)
- Slag depth: \( H_{\text{slag}} = 0.2 \text{m} \)
- Diameter of gas porous plug: 0.2m (two plugs)
- Inlet nozzle inner diameter: \( D_{\text{steel, in}} = 0.14 \text{m} \)
- Inlet nozzle outer diameter: 0.2m
- Inlet submergence depth: 0.15m
- Inlet SEN length: 1.1m
- Modeled inlet length: 0.5m
- Distance from inlet center line to right side wall: 0.2m
- Molten Steel temperature: \( T_o = 1900 \text{K} \)
- Inlet and outlet launders on opposites of vessels and directed radially
Input Flow Conditions

Steel flow rate: 99.5 tons/hour
Steel density: 7020 kg/m³
Mean inlet velocity: 0.232 m/s

Cold argon gas flow rate: 0.49 m³/min
Hot argon gas flow rate: 1.314 m³/min
Mean bubble injection velocity: 0.35 m/s
Mean bubble size: 48mm

Discrete multiphase transient flow input: 19 bubbles/0.1s at each of the two gas inlets at the bottom
Fluid Flow and Particle Motion with Argon Injection
Fluid Flow with Argon Injection

Fluid flow velocity

Gas concentration
Fluid Flow with Argon Injection

Contours of Turbulent Kinetic Energy (k) (m²/s²)

Contours of Turbulent Dissipation Rate (Epsilon) (m²/s³)

Turbulent Energy

Turbulent Energy Dissipation Rate
Typical Trajectories of Alumina Inclusions
(300µm, 3500 kg/m³) (With Argon Injection)
Transient Fluid Flow with Argon Injection

500 Bubbles injection per seconds

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Fluid Flow and Particle Motion without Argon Injection
Fluid Flow Velocities
Typical Trajectories of Tracer Particle (Without Random Motion)
Typical Trajectories of Particles (With Random Motion)

Tracer particles

Alumina Inclusions
Fluid Flow, Particle Motion, and Mixing in a Argon-Stirred Ladle

(300 ton, 4.5m height, 0.5 m³/min argon injection, bubble size: 33mm)
Fluid Flow
Particle Motion and Mixing Time

Inclusion Trajectories

- 100 µm inclusion: 47.0 m (285 s);
- 33 mm bubble: 5.0 m (3.9 s)

Mixing Time

Stirring power, \( \varepsilon \) (Watt/ton)

- 50 t ASEA-SKF
- 50 t Ar-stirred
- 58.9 t Ar-stirred
- 6 t Ar-stirred
- 200RH
- 65 kg Water model

\( \tau = 523 \varepsilon^{-0.4} \)

Current 300 tonne Ar-stirred ladle
Dissolution of Aluminum Alloy in Ladle

0s

3s

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Overall process summary

10s

50s

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Conclusions

1. The developed Lagrangian-Lagrangian multiphase model can predict the fluid flow, inclusion motion and mixing in vessels of this continuous steelmaking process

2. Without gas injection
   - Generating short circuiting flow pattern (from the inlet launder quickly and directly to the outlet launder), very detrimental for the process.
   - The inlet jet impinges strongly against the shallow bottom of the inlet launder, so possible splashing and erosion of the refractory bricks
   - Possible improvement: making the outlet launder not align directly across the vessel from the inlet.
Conclusions

3. With gas injection
   - Generating a strong recirculation in the whole height of the vessel.
   - Particles recirculate a long time, good for reactions.

4. Useful researches for this project (now and future):
   - Solute mixing (such as alloy dissolution) (done by L. Zhang and J. Aoki for gas stirred ladles)
   - Reactions such as deoxidation, impurity element and inclusion removal, depending on mixing phenomena at the interface of slag / metal and gas/metal.
   - Modeling inclusion nucleation, growth, collision (done by Lifeng) and interact with gas bubbles (done by Lifeng and Jun Aoki in gas stirred ladles)
   - Investigating the emulsification of the top slag