Modeling Velocity Flow in Funnel Mold Casters

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Objectives

- Compare two different thin-slab caster nozzle designs
  - Examine velocity outlet characteristics

- Examine fluid flow in a funnel mold caster
  - Draw comparisons with traditional parallel mold thin-slab casters
  - Investigate the effect of varying parameters (eg. casting speed) on the fluid flow profile
  - Analyze particle trajectory/entrapment in a funnel mold
Nozzle 1: Geometry and Operating Conditions

- Casting Speed = 4.8 m/min
- (slab size = 90x1450 mm)
- Inlet velocity (downward) = 1 m/s
- Steel density = 7000 Kg / m³
- Steel viscosity = 0.006 Kg/m.s
- Port Dimensions = 25 x 77 mm

All Dimensions are in mm

Front View

Side View

Nozzle 2: Geometry and Operating Conditions

- Casting Speed = 3.6 m/min
- (slab size = 90x1450 mm)
- Inlet velocity (F.S.) = 1.56 m/s
- Steel density = 7000 Kg / m³
- Steel viscosity = 0.006 Kg/m.s

All Dimensions are in mm

Front View

Side View
Velocity Contour Comparison

Nozzle 1

Nozzle 2

Front View Side View

Lower Nozzle Velocity Contours

Nozzle 1

Nozzle 2

Zoomed Bottom View
Nozzle 1: Velocity Vectors (nozzle bottom)

Nozzle 1: Back Flow At Port Outlet
Jet Characteristics

<table>
<thead>
<tr>
<th></th>
<th>At Ports (Nozzle_1)</th>
<th>At Ports (Nozzle_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casting Speed (m/min)</td>
<td>4.8</td>
<td>3.6</td>
</tr>
<tr>
<td>Jet Speed (m/s)</td>
<td>3.25 (2.4 at 3.6 m/min casting speed)</td>
<td>1.14</td>
</tr>
<tr>
<td>Vertical Jet Angle (degrees)</td>
<td>32</td>
<td>79.4</td>
</tr>
<tr>
<td>Port-to-bore Ratio</td>
<td>1.24</td>
<td>1.62</td>
</tr>
<tr>
<td>Back Flow Zone Percentage</td>
<td>&lt;4%</td>
<td>&lt;4%</td>
</tr>
</tbody>
</table>
Comparison of Two Nozzles

- Velocity increases midway down nozzle due to the drop in cross-sectional area, especially in Nozzle 1.
- The outlet ports of Nozzle 1 have two regions of backflow (both top and bottom of ports). The bottom backflow zone is likely due to the nozzle's elongated well shape.
- Nozzle 1:
  - Smaller ports than nozzle 2, producing a higher velocity jet.
- Nozzle 2:
  - Good uniform spread of flow leaving ports despite a large port to bore ratio.
  - Steeper downward jet, resulting in a slower flow on the top fluid surface. A higher casting speed can be run with this nozzle without the presence of EMBR.

Mold Parameters

- CON1D used to predict shell thickness.
- Mass and momentum "sinks" used at fluid boundaries to simulate solidification:
  - Sinks are a function of shell curvature.

\[
\text{MassSink} = -\rho \cdot V_c \cdot \frac{v_z}{C.V.},
\]

\[
\text{MomentumSink} = -\rho \cdot V_c \cdot \frac{v_z \cdot v_i}{C.V.}.
\]

- Standard k-epsilon turbulence model.
- FLUENT solves N.S. equations for steady, single phase flow.
Model Validation

- Comparison to previous work performed by Quan Yuan on a parallel mold thin-slab caster

<table>
<thead>
<tr>
<th>Parameter/Property</th>
<th>Case 2-S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mold Width (mm)</td>
<td>984</td>
</tr>
<tr>
<td>Mold Thickness (mm)</td>
<td>132</td>
</tr>
<tr>
<td>Mold Length (mm)</td>
<td>1200</td>
</tr>
<tr>
<td>Domain Width (mm)</td>
<td>984 (top)</td>
</tr>
<tr>
<td></td>
<td>934.04 (domain bottom)</td>
</tr>
<tr>
<td>Domain Thickness (mm)</td>
<td>132 (top)</td>
</tr>
<tr>
<td></td>
<td>79.48 (domain bottom)</td>
</tr>
<tr>
<td>Domain Length (mm)</td>
<td>2400</td>
</tr>
<tr>
<td>Nozzle Port Height × Thickness (mm × mm)</td>
<td>75 × 32 (inner bore)</td>
</tr>
<tr>
<td>Bottom nozzle Port Diameter (mm)</td>
<td>32</td>
</tr>
<tr>
<td>SEN Submergence Depth (mm)</td>
<td>127</td>
</tr>
<tr>
<td>Casting Speed (mm/s)</td>
<td>25.4</td>
</tr>
<tr>
<td>Fluid Kinematic Viscosity (m²/s)</td>
<td>7.98 × 10⁻⁷</td>
</tr>
</tbody>
</table>

Model Validation (cont.)

- Horizontal Velocity at Top Surface WF Centerline
Model Validation (cont.)

- Downward Velocity along WF Centerline, 0.5m from top surface

![Graph showing downward velocity data](image)

Funnel Mold Design

Dimensions:
- Narrow Face: 90 mm
- Wide Face: 1450 mm
- Mold Length: 1200 mm
- Max. Funnel Width: 170 mm
- SEN Submergence: 265 mm
Funnel Mold Design

Mold Top

Mold Thickness [mm]

900 mm below Mold Top → Bottom Surface

Mold Thickness [mm]

Funnel Taper through Mold (not to scale)  All units are in mm

Funnel Mold Model

- 3.6 m/min casting speed
- Nozzle 2 results will be used as mold fluid inlet data

<table>
<thead>
<tr>
<th>Parameter/Property</th>
<th>Case 3.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mold Width (mm)</td>
<td>1450</td>
</tr>
<tr>
<td>Mold Thickness in top funnel region (mm)</td>
<td>170</td>
</tr>
<tr>
<td>Mold Thickness at narrow face (mm)</td>
<td>90</td>
</tr>
<tr>
<td>Mold Length (mm)</td>
<td>1200</td>
</tr>
</tbody>
</table>
| Domain Width (mm)                      | 1450 (top)
|                                         | 1414 (domain bottom) |
| Domain Thickness (mm)                  | 90 (top)
|                                         | 50.84 (domain bottom) |
| Domain Length (mm)                     | 2500     |
| Nozzle Port Effective Height × Thickness (mm × mm) | 201.53 × 28 |
| SEN Submergence Depth (mm)             | 265      |
| Casting Speed (m/min)                  | 3.6      |
| Fluid Kinematic Viscosity (m²/s)       | 8.57 × 10⁻³ |
Funnel Mold: W.F. Centerline Velocity Plots

- Funnel Mold: Top Surface Pressure
  - Pressure contour at the top surface of the mold
    - Higher pressures near the meniscus and the nozzle
Funnel Mold: Top Surface WF Centerline Pressure

Knowing the pressure, top surface height can be approximated using:

\[
\text{height} = \frac{p - p_{\text{mean}}}{(\rho_{\text{steel}} - \rho_{\text{flux}}) \mathbf{g}}
\]

Funnel Mold: Velocity Near Top Surface along WF Centerline

Velocity along WF Centerline at 10 mm below top surface (boundary conditions imposed at top surface yield zero velocity)
Funnel Mold: Velocity Near Top Surface

Funnel Mold: Velocity at Bottom Surface along WF Centerline
Funnel Mold Observations

- Classic double-roll flow pattern is observed
- Top surface velocity reaches a maximum of 0.35 m/s, within reasonable limits (although on the high side)
- Funnel effect is small; no steady state eddies are observed in funnel region
- There is no recirculation zone at the bottom pressure outlet. Particles may be more likely to become trapped in the strand.

Future Research Work

- Further postprocess data to investigate differences between a funnel mold and a parallel wall thin-slab mold
- Obtain data for 4.8 m/min casting speed, and draw comparisons between the 3.6 m/min casting speed
- Introduce particle/inclusion tracking into the model
  - Determine likelihood of particle entrapment
  - Track particle pathways
Acknowledgements

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- Brian Thomas