Meniscus Behavior

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Objectives

• Predict with mathematical models the transient phenomena in meniscus region.
  – Flow of steel in meniscus region
  – Flow and consumption of flux into the gap
  – Liquid slag-Liquid steel interface evolution
  – Solid slag rim formation and effect on gap pressure
  – Heat transfer in meniscus region including meniscus freezing
  – Overflow of steel
• Validate the Model(s)
  – Validation of Bikerman Equation
• Validate hook & oscillation mark formation mechanisms.
CFD with VOF Model

- CFD and Volume of Fluid (VOF) model:
  - Fluid flow of molten steel and liquid slag with Navier-Stokes equations.
  - Calculation of phase fractions with VOF model. Interfacial forces between non-interpenetrating fluids.
  - Calculation of temperature field with energy equations

<table>
<thead>
<tr>
<th>Surface Tension</th>
<th>1.6N/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta_w$ Solid Steel-Liquid Steel</td>
<td>0</td>
</tr>
<tr>
<td>$\theta_w$ Mold-Liquid Steel</td>
<td>160</td>
</tr>
</tbody>
</table>

Bikerman’s Equation

Calculate meniscus shape by balancing ferrostatic pressure force with surface tension force

\[
\frac{d\theta}{dz} = \frac{\Delta P}{\sigma} \quad \quad \quad \frac{dy}{dz} = \frac{2\sigma (\rho_L - \rho_s) gz^2 - 4\sigma [R(z) + \sigma]}{[\rho_s - \rho_s] g^2 z^2 - 4(\rho_L - \rho_s) [R(z) + \sigma] z^2 + 4 R(z) [R(z) + 2\sigma]}
\]

\[
y = -\sqrt{2a^2 - z^2} + \frac{\sqrt{2a^2}}{2} \ln \left( \frac{\sqrt{2a^2} + \sqrt{2a^2 - z^2}}{z} \right) + 0.376a
\]

\[
a^2 = \frac{2\sigma}{(\rho_L - \rho_s) g}
\]

\[
R(z) = \int_a^{R(z)} [\rho(z)] - \rho_s \, dz
\]
Meniscus region

Stagnant Case, Geometry
Stagnant Case, Results

Slag volume fraction

Meniscus shape

FLUENT = BIKERMAN

Movement of the Mold Wall
Domain with Solid Slag Rim


Shell thickness from CON1D

Steel Slag Interface

Units in mm

Free Surface 88.5mm

Steel shell tip 80mm
Thermal Properties of Slag

- **Thermal Conductivity**
- **Enthalpy**


Heat Transfer Analysis

- **Liquid slag**
- **Steel**
Heat Flux and Melting Rate

- Lower part of the solid slag rim remelting
  - Maximum heat flux and maximum melting rate 11mm above the steel shell tip, -0.75MW/m², -0.8mm/s.
  - For a oscillation frequency of 174 cpm → 0.35s/oscillation → remelting time = 0.35/2 = 0.175s
  - Maximum remelting of solid rim = 0.175s*0.8mm/s = 0.14mm

- Higher part of the solid slag rim solidification in case of level fluctuations.
Future Work

- Incorporate temperature-dependent slag viscosity into transient flow model
- Prediction of slag flow and mold powder consumption.
- Study of meniscus freezing.
- Effect of molten steel fluid flow on interface behavior.
- Prediction of hook formation – overflow and remelting of meniscus.
- Prediction of Oscillation Marks formation.
- Study of 3D effects.
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