ANNUAL REPORT 2005

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Meniscus Behavior

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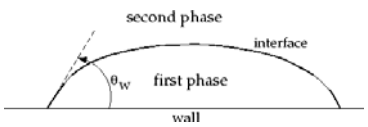
Objectives

- 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

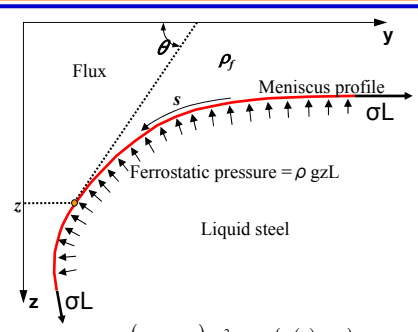
- CFD and Volume of Fluid (VOF) model:
  - Fluid flow of molten steel and liquid slag with Navier-Stokes equations.
  - Calculation of phase fractions with VOF model. Interfacial forces between non-interpenetrating fluids.
  - Calculation of temperature field with energy equations



Surface Tension	1.6N/m
θ_W Solid Steel-Liquid Steel	0
θ_W Mold-Liquid Steel	160

Bikerman's Equation

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



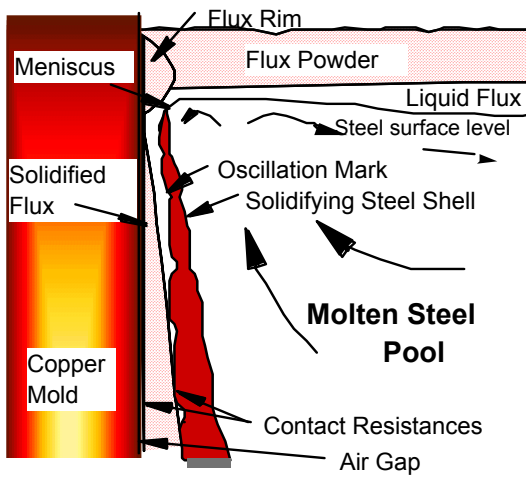
$$\frac{d\theta}{ds} = -\frac{\Delta P}{\sigma} \longrightarrow \frac{dy}{dz} = -\frac{2\sigma(\rho_S - \rho_f)gz^2 - 4\sigma\{R(z)+\sigma\}}{\left[(\rho_S - \rho_f)^2 g^2 z^4 - 4(\rho_S - \rho_f)\{R(z)+\sigma\}gz^2 + 4R(z)\{R(z)+2\sigma\}\right]^{1/2}}$$

$$y = -\sqrt{2a^2 - z^2} + \frac{\sqrt{2a^2}}{2} Ln\left(\frac{\sqrt{2a^2} + \sqrt{2a^2 - z^2}}{z}\right) + 0.3768a$$

$$R(z) = \int_0^z \{P(z) - \rho_f gz\} dz$$

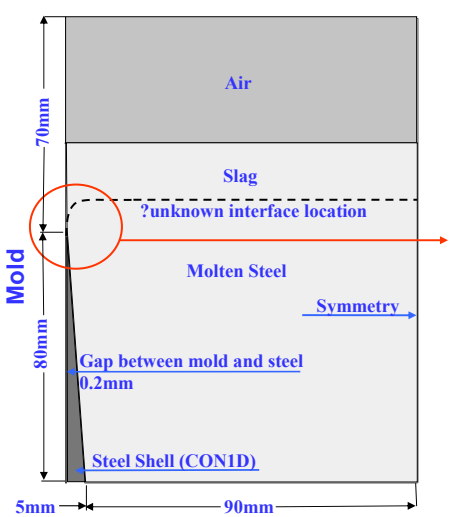
$$a^2 = \frac{2\sigma}{(\rho_s - \rho_f)g}$$

Meniscus region

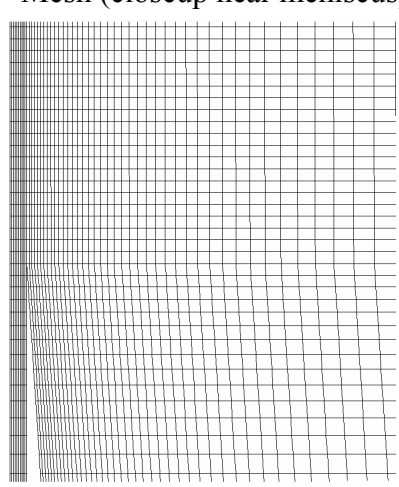


Stagnant Case, Geometry

Domain

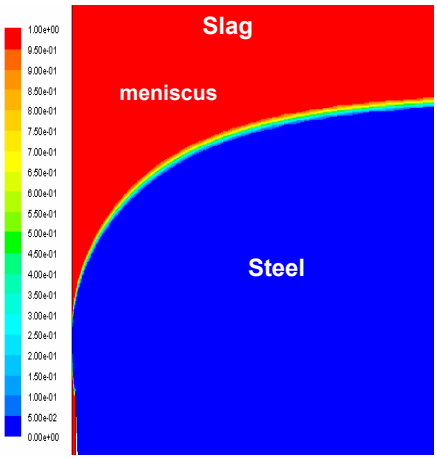


Mesh (closeup near meniscus)

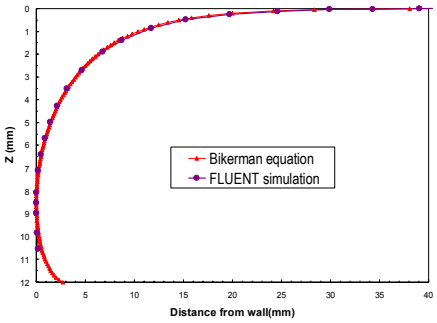


Stagnant Case, Results

Slag volume fraction

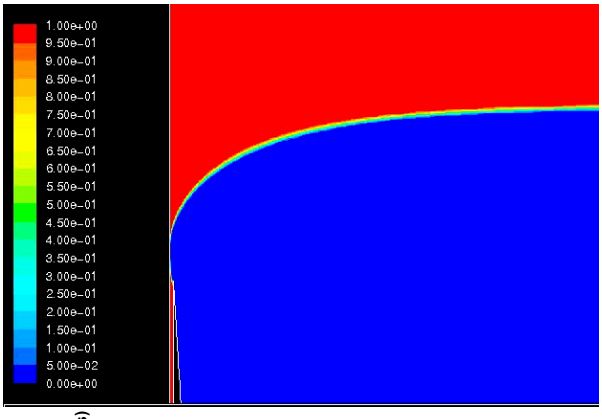


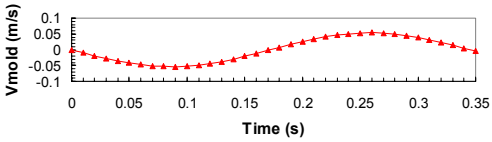
Meniscus shape



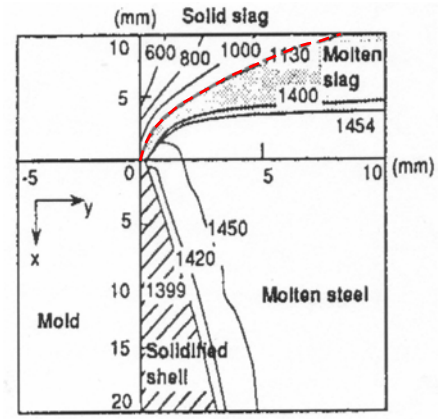
FLUENT ≈ BIKERMAN

Movement of the Mold Wall

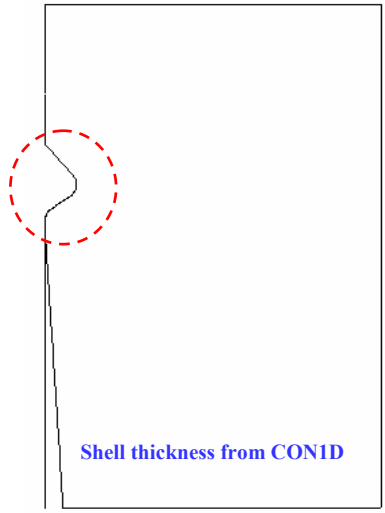




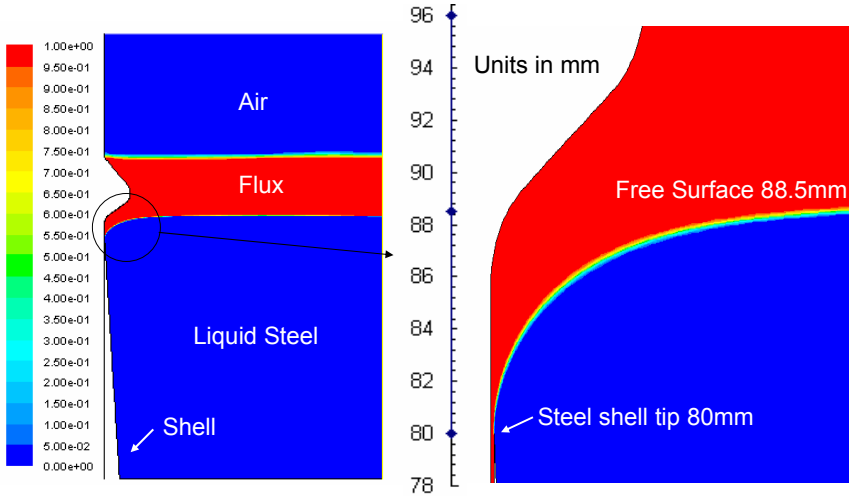
Domain with Solid Slag Rim



Takeuchi et al., "Steelmaking Conference Proceedings", 1991, pp 73-77

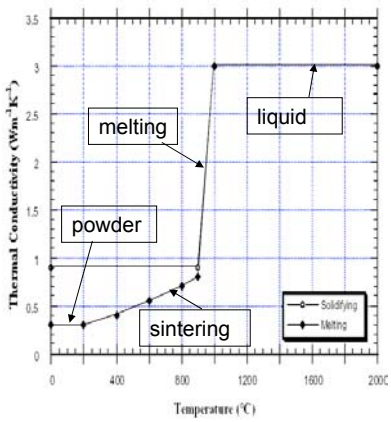


Steel Slag Interface

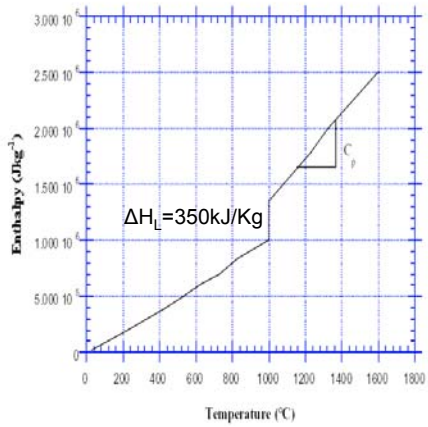


Thermal Properties of Slag

Thermal Conductivity

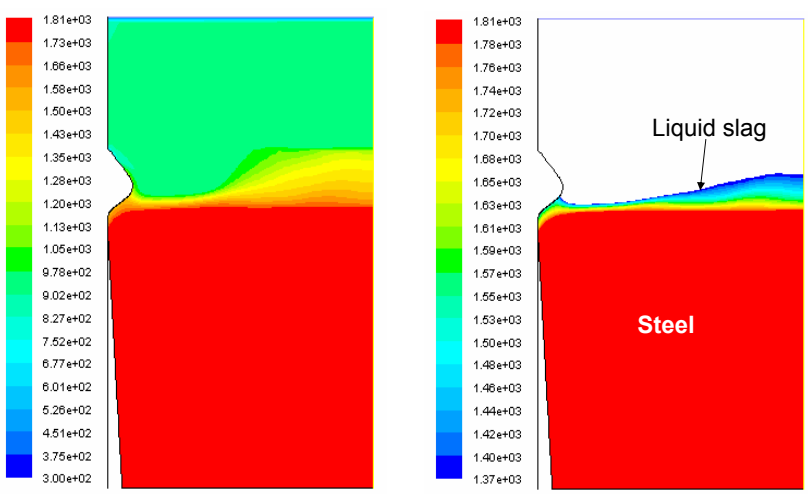


Enthalpy

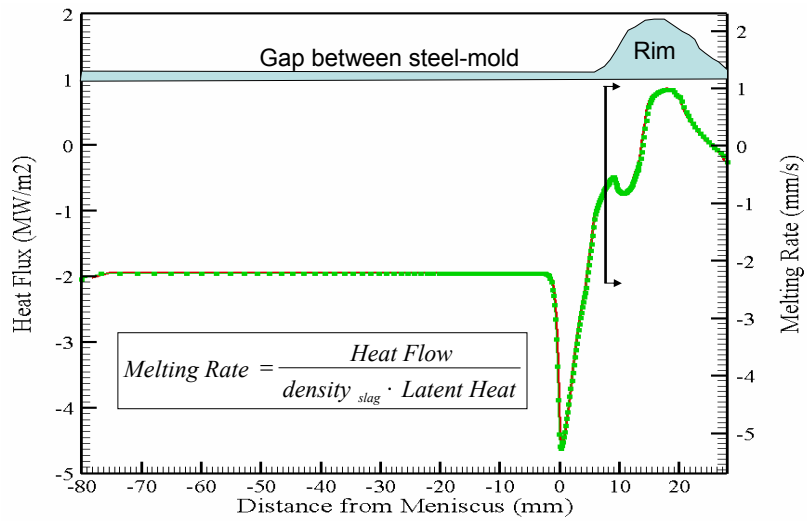


McDavid, R., and B.G. Thomas, Metallurgical and Materials Transactions B, Vol. 27B, No. 4 (August), 1996, pp. 672-685

Heat Transfer Analysis



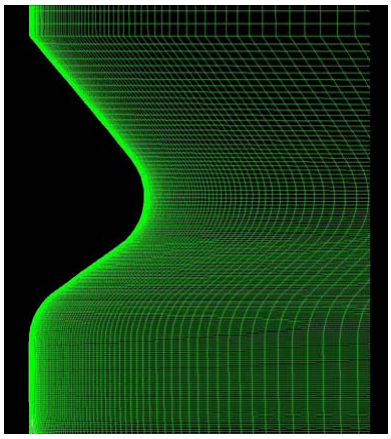
Heat Flux and Melting Rate

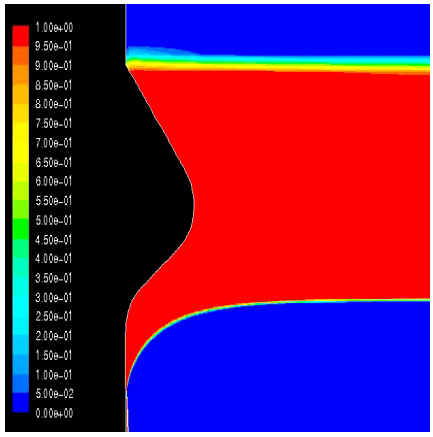


Heat Flux and Melting Rate

- Lower part of the solid slag rim <u>remelting</u>
  - Maximum heat flux and maximum melting rate 11mm above the steel shell tip, -0.75MW/m^2, -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 <u>solidification</u> in case of level fluctuations.

CFD + VOF + Dynamic Mesh





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.**

Acknowledgments

- FUNDACION LABEIN
- CONTINUOUS CASTING CONSORTIUM
- All my Lab. & Office colleagues