Natural Convection effects on Fluid Flow and Heat Transfer in Liquid Slag Layers of Continuous Casters

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Computational Domain with Mesh and Boundary Conditions

Adiabatic Wall
\( \frac{dT}{dx} = 0 \)
\( V_x = 0 \)
\( V_y = 0 \)

Wall Boundary
\( T = T_c \)
\( V_x = 0 \)
\( V_y = 0 \)

Moving Wall
\( T = T_h \)
\( V_x = U \)
\( V_y = 0 \)

Adiabatic Wall
\( \frac{dT}{dx} = 0 \)
\( V_x = 0 \)
\( V_y = 0 \)

Mesh (160x16), Aspect Ratio = 10
Pure Natural Convection

Fig 2. Velocity vector, Temperature contour, Nu and $V_y$ profiles for $U = 0$, $\mu = 0.51$ Pa·s, $k = 10.18$ W/m·K
Contours of Horizontal Density Gradients
(Calculated vs Experimental Interferogram)

Oertel measurement (1988)

FIDAP
Ra

1.0E+05

2

3

4

5

U = 0 mm/s

FIDAP [Pr 667]

FIDAP [Pr 100]

Koschmieder (1974) [Pr 50 - 1670]

Rossby (1969) [Pr 200]

Fig 4. Variation of $\text{Nu}_{\text{avg}}$ with Ra (comparison of FIDAP with experimental results)
Mixed Convection
(Sub-critical Interface Velocity)

Fig 5. Velocity vector, Temperature contour, Nu and $V_y$ profiles for $U = 1.25$ mm/s, $\mu = 0.51$ Pa-s, $k = 10.18$ W/mK
Forced Convection
(Post-critical Interface Velocity)

Fig 6. Velocity vector, Temperature contour, Nu and $V_y$ profiles for $U = 3$ mm/s, $\mu = 0.51$ Pa-s, $k = 10.18$ W/mK
Heat Flux vs Velocity, Viscosity & Conductivity

Fig 8. Heat Flux as a function of $\mu$, $k$ and $U$
Average Nusselt Number vs Shear velocity

Fig. 8 $\bar{Nu}$ as a function of Ra, Pr and $U/U_o$
Fig 9. Right Peak Nusselt number as a function of $\mu$, $k$ and $U$
Avg Cell Aspect Ratio vs Velocity, Viscosity & Conductivity

Fig 10. Average Cell Aspect Ratio as a function of $\mu$, $k$ and $U$
Fig 11. Relative unevenness of Nu profile as function of $U$, µ, and k
Profile of Horizontal Velocity Through Thickness

Fig 12. $V_x$ as a function of $(y/H)$ through the eye of the roll for different $U$
Eye Center Location Above Bottom vs Interface Velocity

Fig 13. Eye center location as a function of Interface velocity for $\mu = 0.51$ Pa-s, $k = 10.18$ W/mK
Fig 14. Maximum roll Speed as a function of Interface velocity for Ra = 2500, Pr = 100
Flux Bottom Velocity vs Average Interface Shear Stress

\[ \tau_0 = 4.35 \mu \frac{U}{H} \]

- a) \(Ra = 2500, Pr = 100\)
- b) \(Ra = 100000, Pr = 667\)
- c) \(Ra = 4613, Pr = 667\)
Average interface shear stress vs Steel surface velocity

\[ V_o = 0.0283 \sqrt{\tau_o} \ln(1+C \sqrt{\tau_o}) + 0.088 \sqrt{\tau_o} \]

\[ w = \text{Wideface width (mm)} = 1840 \]

- \( C = 972 \) (w/4)
- \( C = 486 \) (w/8)
Flux layer bottom velocity vs Steel bulk velocity
(Effect of flux layer thickness)

\[ \mu = 0.1 \text{ Pa-s} \]

- Solid line: \( h = 20 \text{ mm} \)
- Dashed line: \( h = 30 \text{ mm} \)
Flux layer bottom velocity vs Steel bulk velocity
(Effect of flux layer viscosity)

- Steel bulk velocity (m/s)
- Flux layer bottom velocity (mm/s)

- $h = 20$ mm
- $\mu = 0.1$ Pa·s
- $\mu = 1$ Pa·s
Fig 16. Heat Flux as a function of $U$ and $\Delta T$ for $\mu = 0.51$ Pa-s and $k = 10.18$ W/mK
Heat Flux vs Interface Velocity, Liquid Layer Thickness

Fig 17. Heat Flux as a function of U and H for $\mu = 0.51$ Pa-s and $k = 10.18$ W/mK
Heat Flux vs Interface Velocity, Liquid Layer Thickness

Fig 8. Heat Flux as a function of U and H for \( \eta = 1 \) Pa-s and \( k = 3 \) W/mK