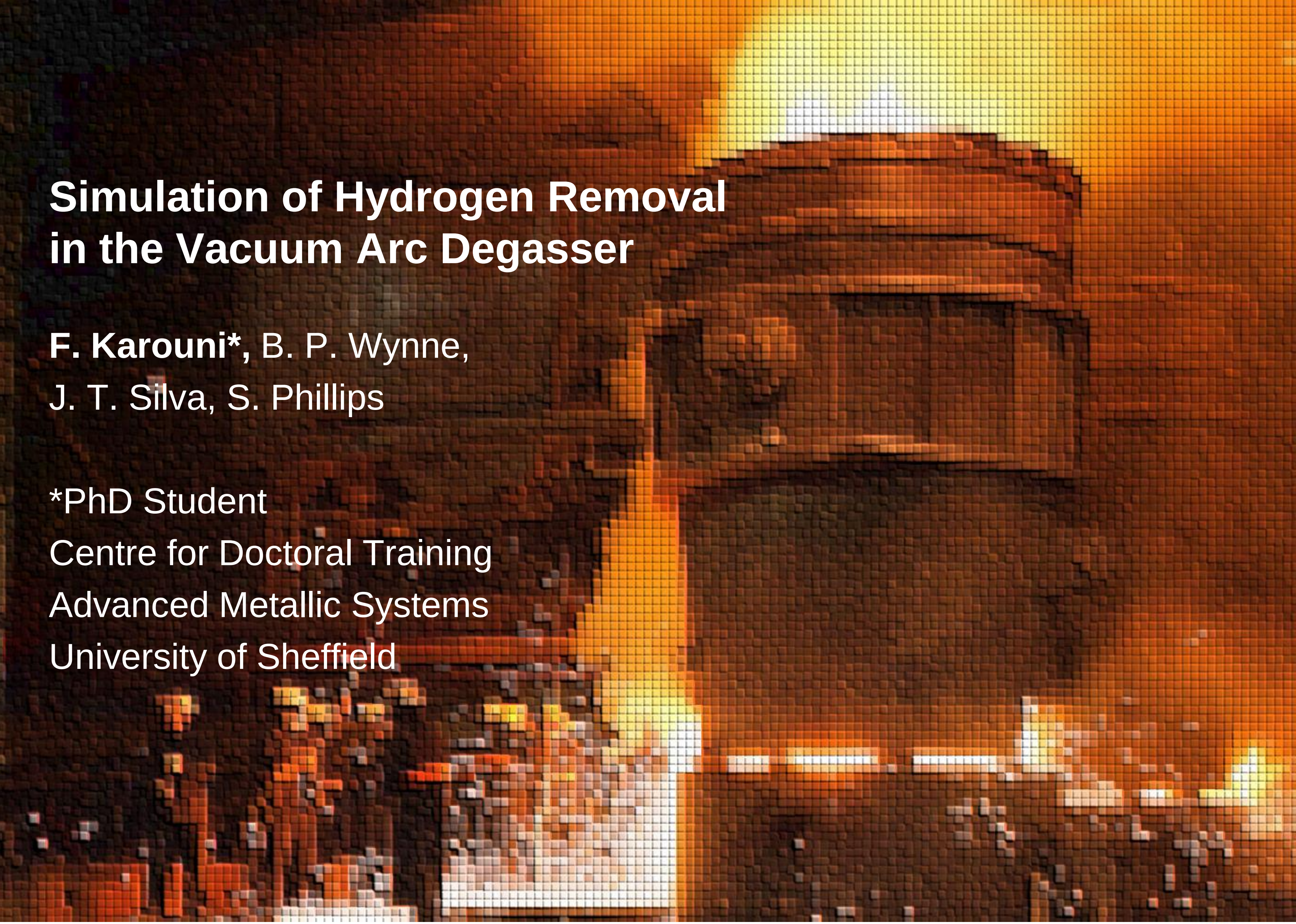

Simulation of Hydrogen Removal in the Vacuum Arc Degasser

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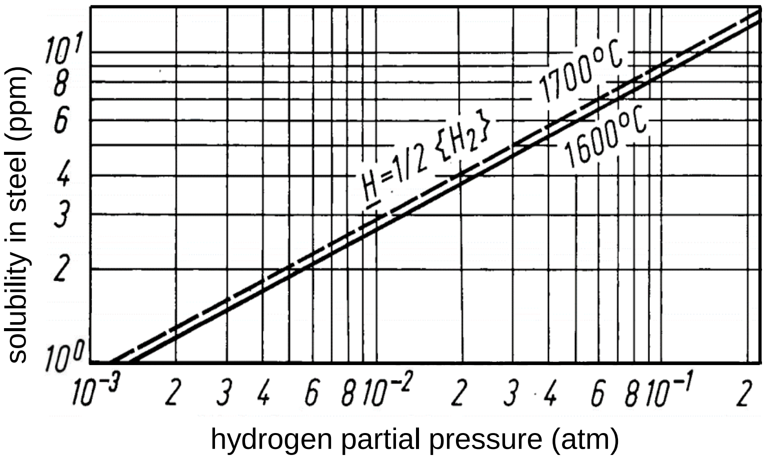
tapping from electric arc furnace into ladle

Vacuum Arc Degassing (VAD)

$$C_{H,\mathrm{steel}} = \frac{\exp\left(-\Delta G^0/RT\right)}{\xi_H}\sqrt{p_{H_2}}$$



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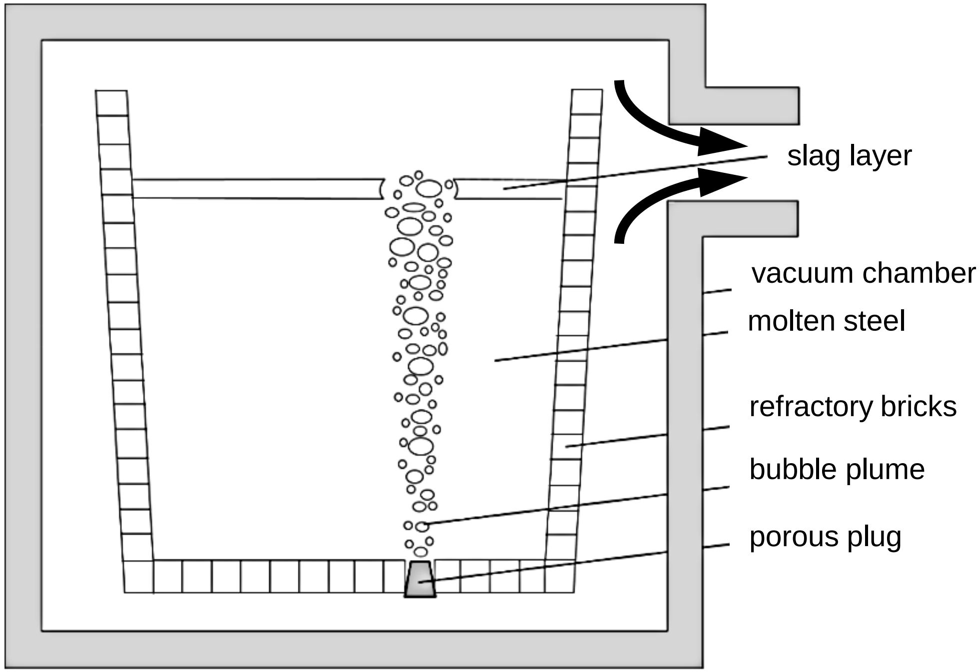
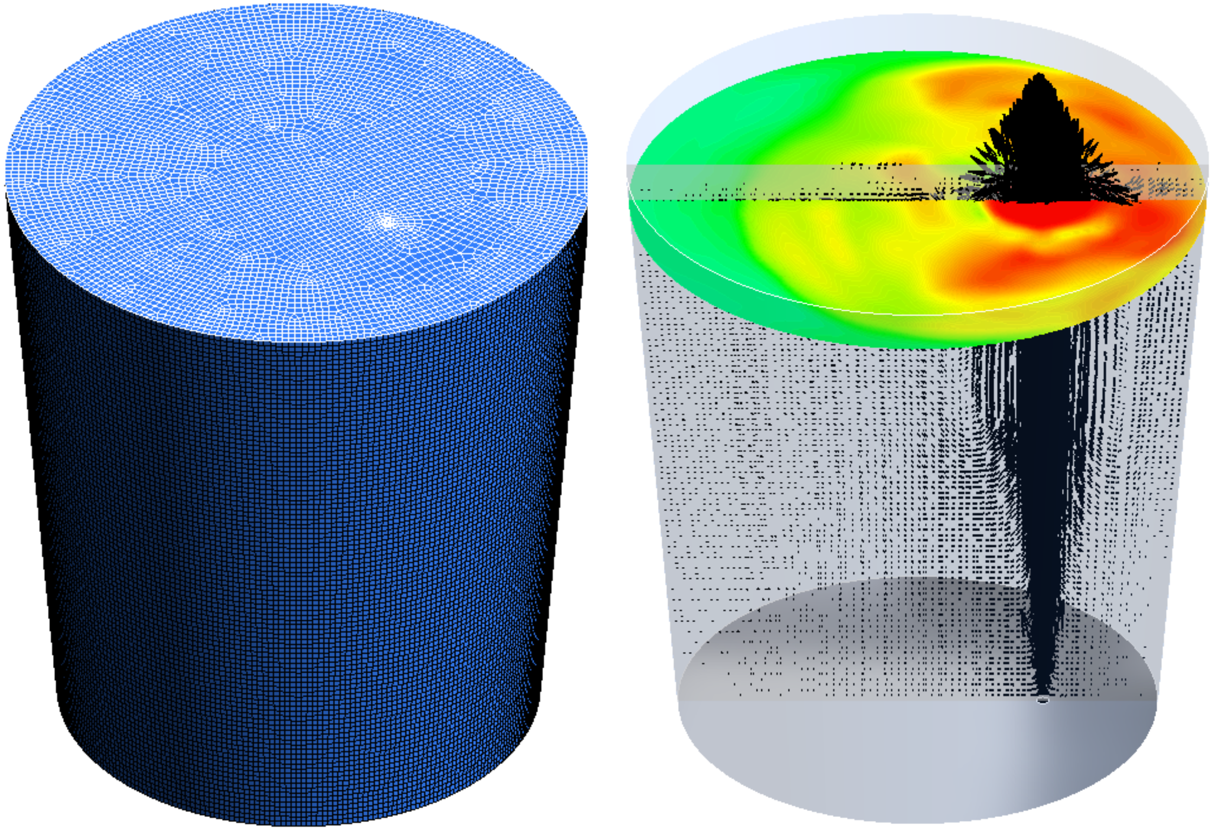


ξ_H = activity coefficient, $\Delta G^0 = 36485 + 30.46T$, p_{H_2} = partial pressure of hydrogen in bubble, T = temperature, R = ideal gas constant

Computational Fluid Dynamics (CFD) Approach



1. Meshing of geometry into cells.
2. Specification of boundary conditions .
3. Solving transport equations at each cell.
4. Extraction of data (flow field, hydrogen concentration over time).

Objectives

1. Develop three phase model (slag-argon-steel) for full scale vacuum arc degasser (VAD).

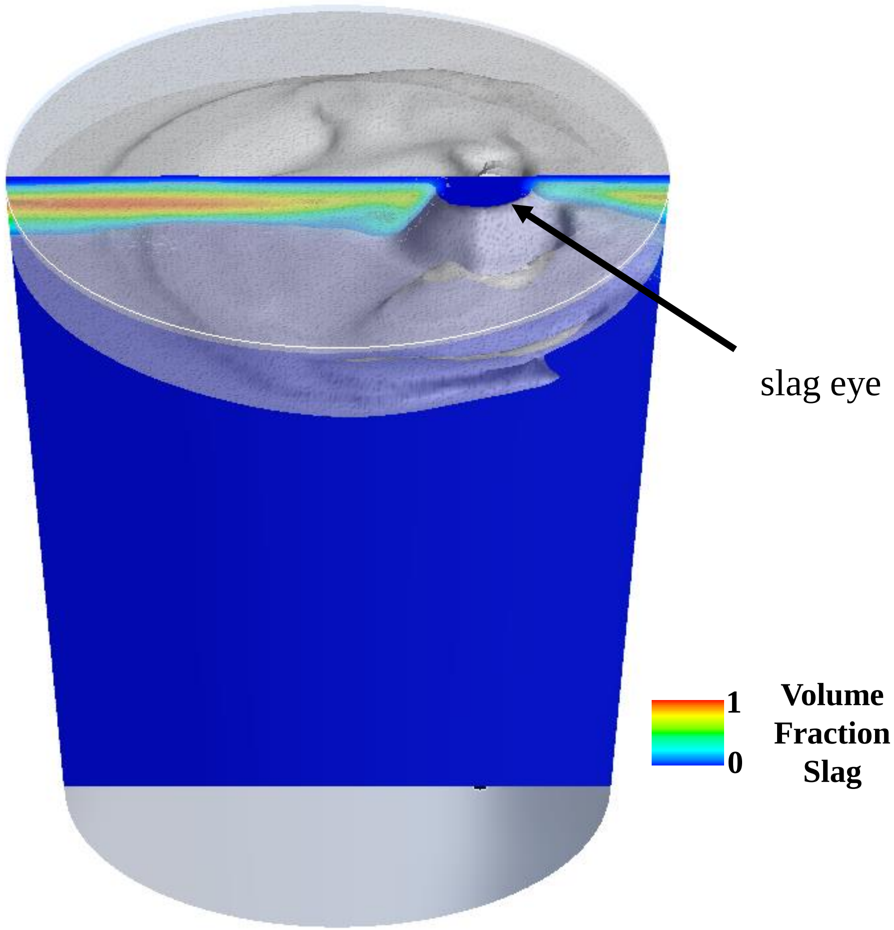
2. Test predictions against hydrogen measurements from Sheffield Forgemasters International Ltd (SFIL) for a series of melts in 100 ton VAD unit.

3. Apply model to range of process and design setups in order to identify optimum conditions for hydrogen degassing in a VAD.

Features of Model

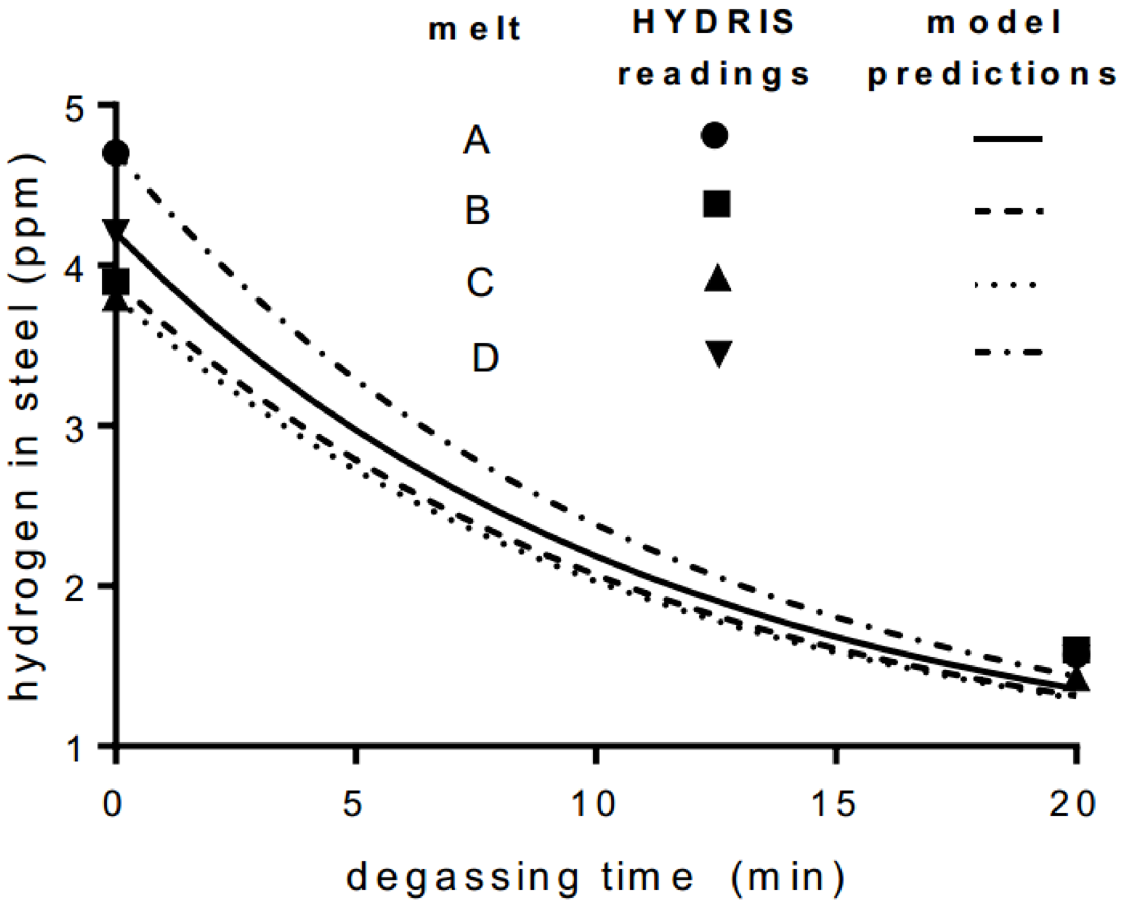
- Eulerian method for multiphase flow equations.
- The slag and steel are treated as incompressible fluids.
- Argon is treated as a compressible ideal gas with its density specified according to the ideal gas law.
- The temperature is assumed to remain constant at 1598^{o}C (1871K) across all simulations.
- Bubble size calculated using number density formulation with discrete population balance modelling.

Deformation of Slag Layer



- Slag layer illustrated with volume fraction isosurface.
- Formation of eye occurs due to molten steel-induced deformation.
- Layer and eye exhibit dynamic motion and shape due to swirling of bubble plume.

Comparison with Industrial Data



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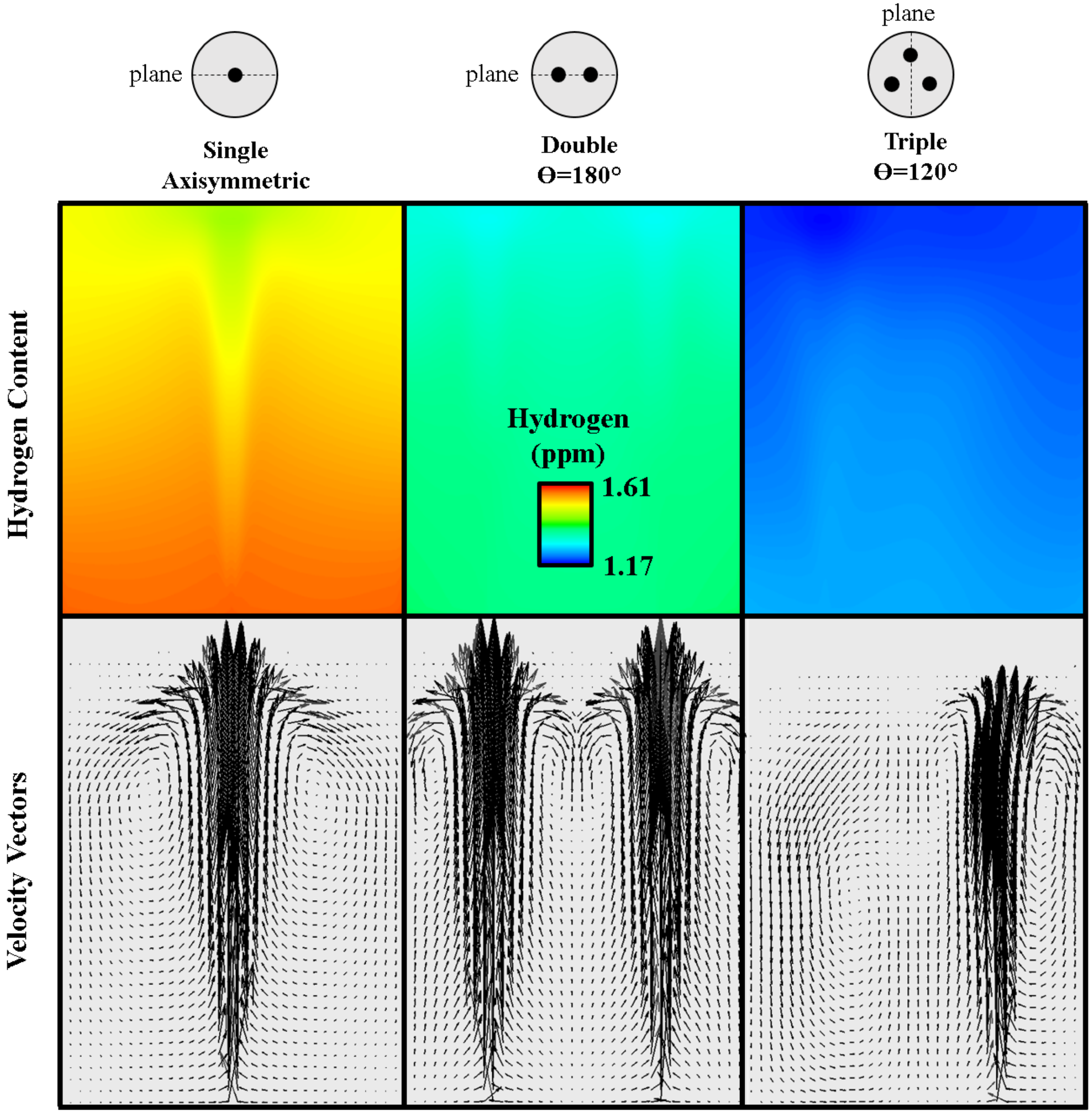
Features of Model

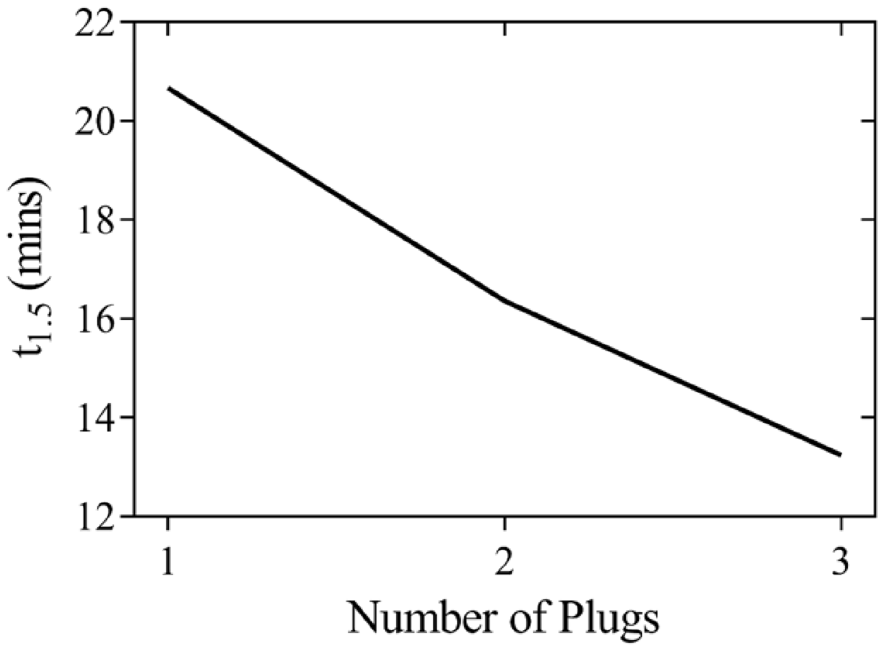
- The following design conditions were investigated: number of plugs, ladle aspect ratio (H/D) and plug positions.

- Performance indicators:
  - $\mathbf{t_{1.5}}$ = time taken to reach 1.5ppm from initial value of 5ppm.
  - Melt velocity vector profile.

Number of Bubble Injector Plugs

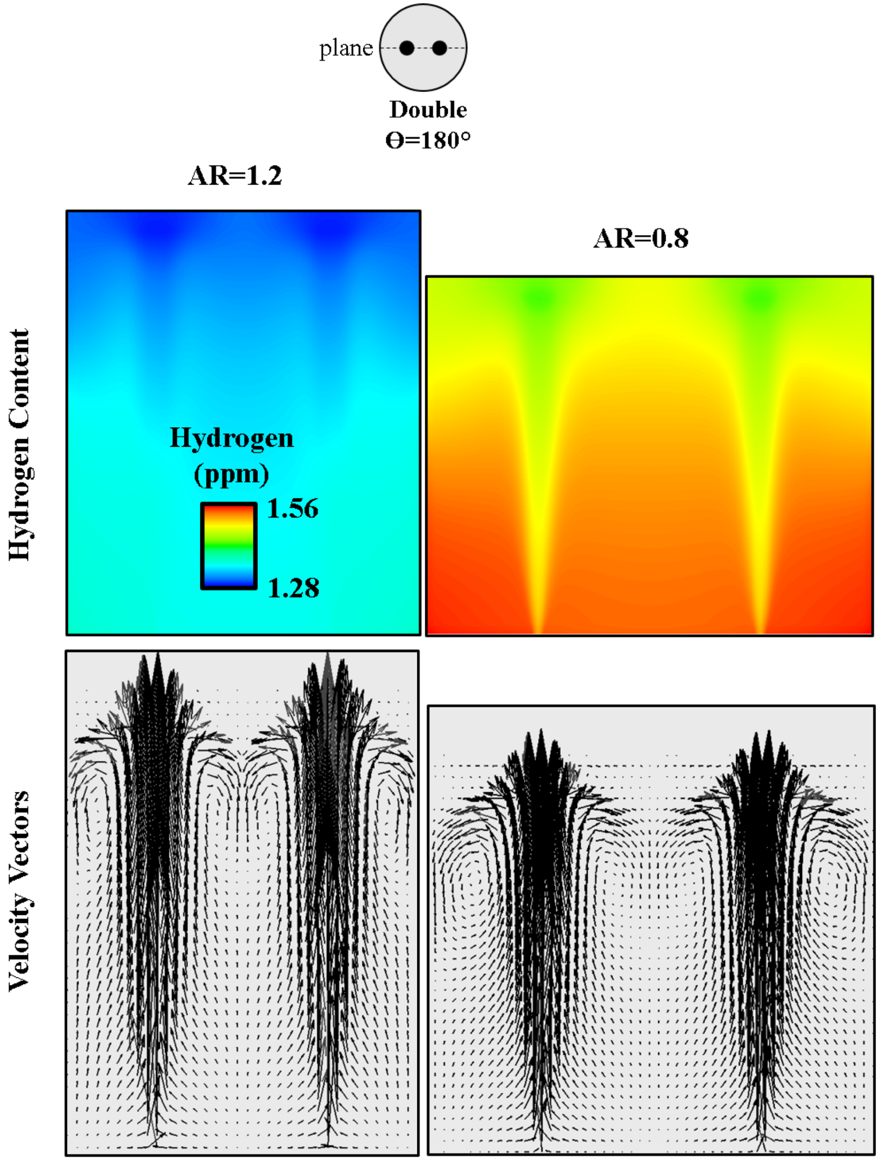


Number of Bubble Injector Plugs

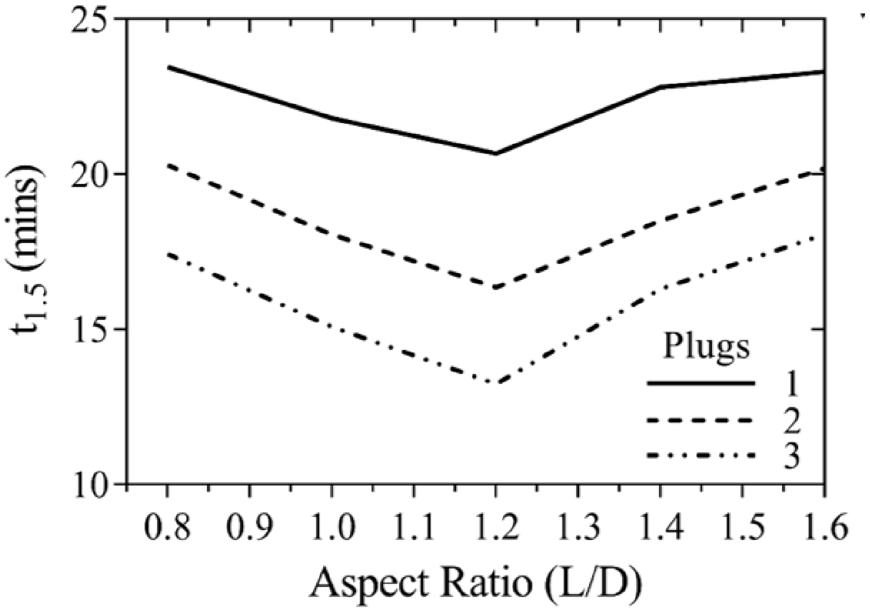


- Double and triple plug ladles reduce the time taken to degas a 100 tonne melt of molten steel from 5 to 1.5ppm ($t_{1.5}$) by 21% and 36% respectively when compared to a single axisymmetric plug.

Aspect Ratio (height/diameter)



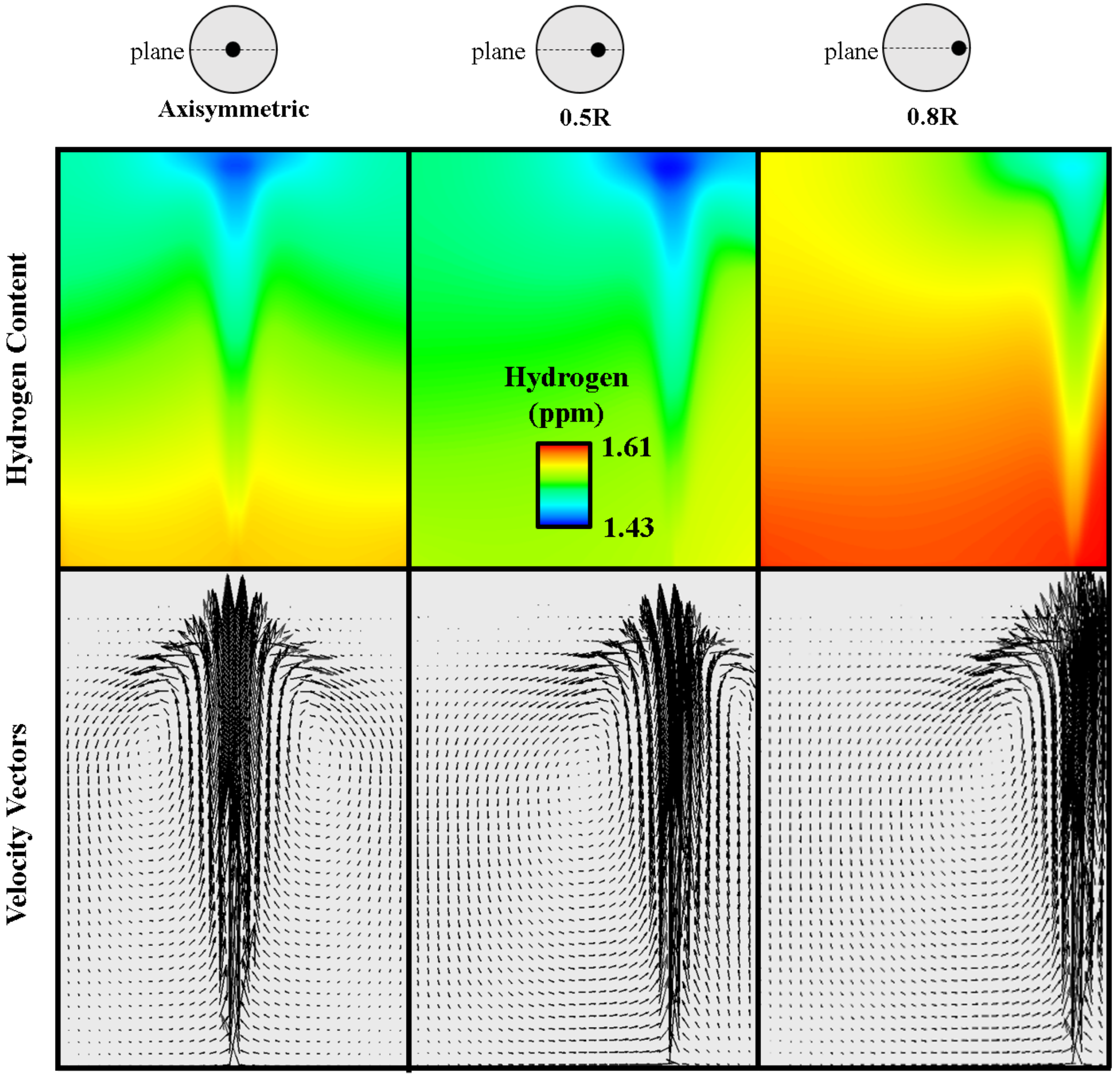
Aspect Ratio (height/diameter)



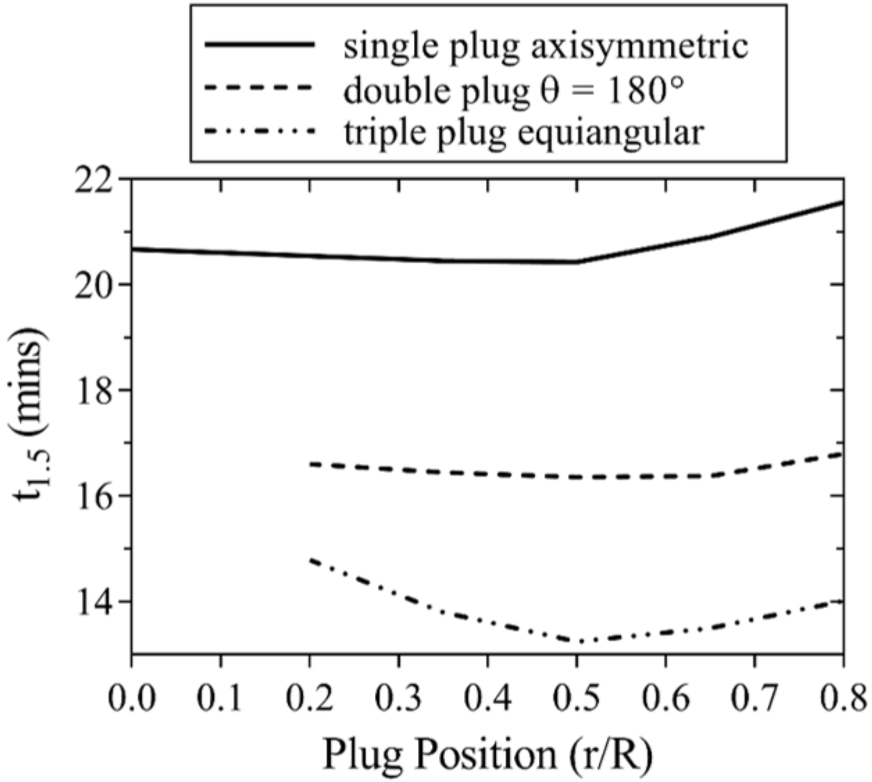
- Increasing the ladle AR for single, double and triple plug systems leads to a reduction in $t_{1.5}$ between AR=0.8-1.2, followed by an increase in $t_{1.5}$ between AR=1.2-1.6.

- While the flow field generally strengthens with AR, beyond AR=1.2 the increased solubility of hydrogen arising from the depth-dependent hydrostatic pressure limits the hydrogen removal rate.

Plug Radial Position



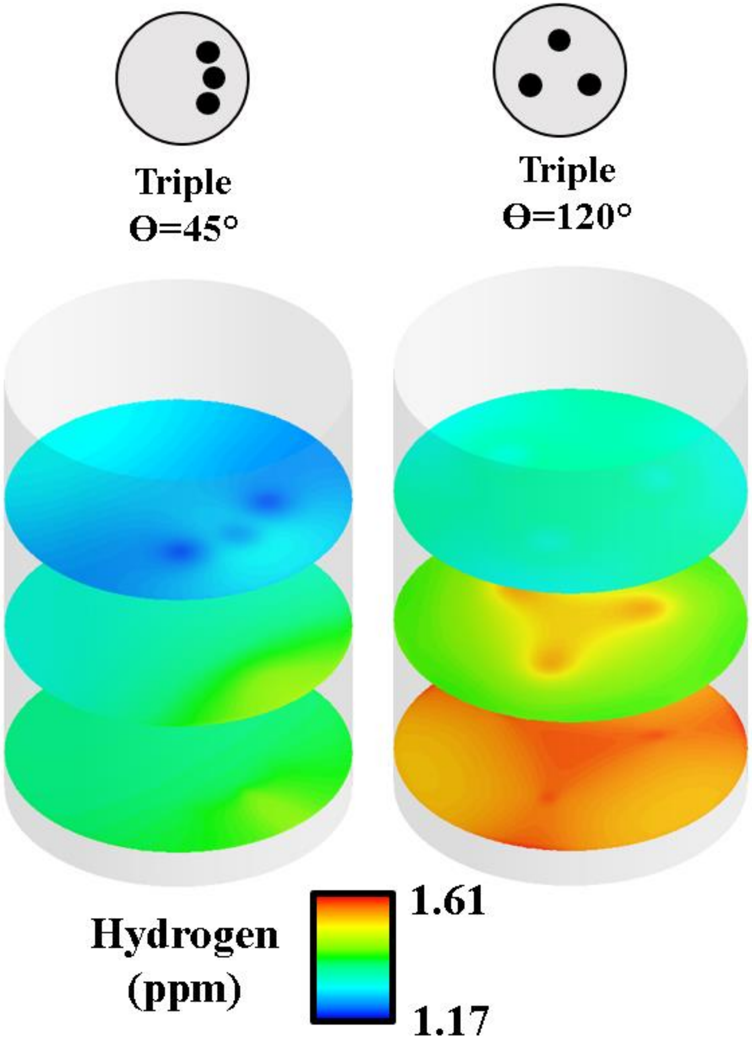
Plug Radial Position



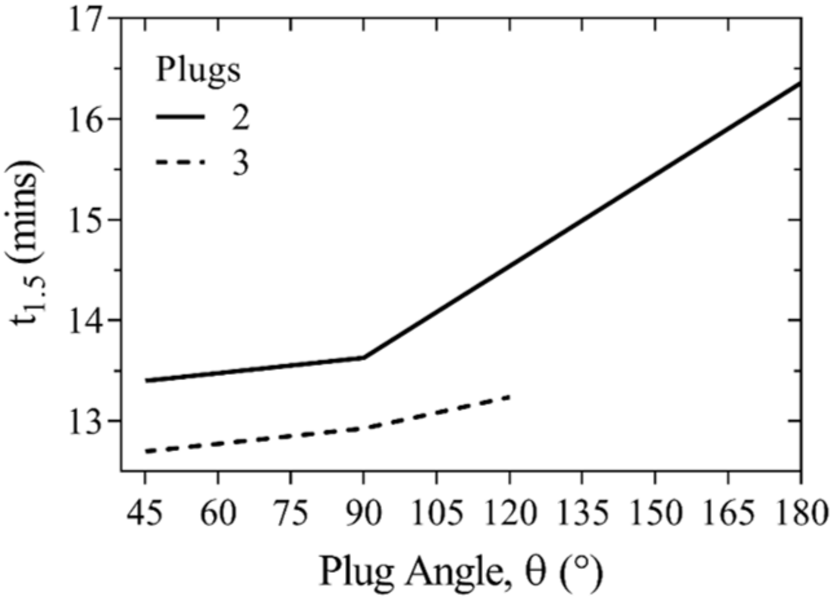
- The mid-radial plug position produces the lowest degassing time and greatest distribution of hydrogen throughout the melt for single, double and triple plug systems.

- When the plug position is more centralised, the flow is weakened in the region between the gas plume and the ladle walls, while if it is too far from the centre (r>0.5R) radial distribution of bubbles is limited due to their interaction with the ladle walls.

Inter-Plug Angle



Inter-Plug Angle



- For the dual and triple plug (0.5R) ladles, a plug angle of θ=45° produces the optimal hydrogen removal rate, reducing $t_{1.5}$ by 18% and 3.8% in comparison to plug angles of θ=180° and θ=120° for each respective layout.

Summary

- Three-phase mathematical model for hydrogen removal has been fully validated with industrial measurements.
- Multiple plugs are preferable for process efficiency.
- Higher aspect ratio ladles produce faster rates of hydrogen removal, below threshold value of 1.2.
- Off-centred plug position is optimal, as dead zones are avoided.
- In multi plug systems, closer plug angle spacing acts to spread bubbles more effectively around melt.

Thank you

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Further information:

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http://onlinelibrary.wiley.com/doi/10.1002/srin.201700551/abstract