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Mixing in Bubbly Flows: Secondary Stage Steel Refining

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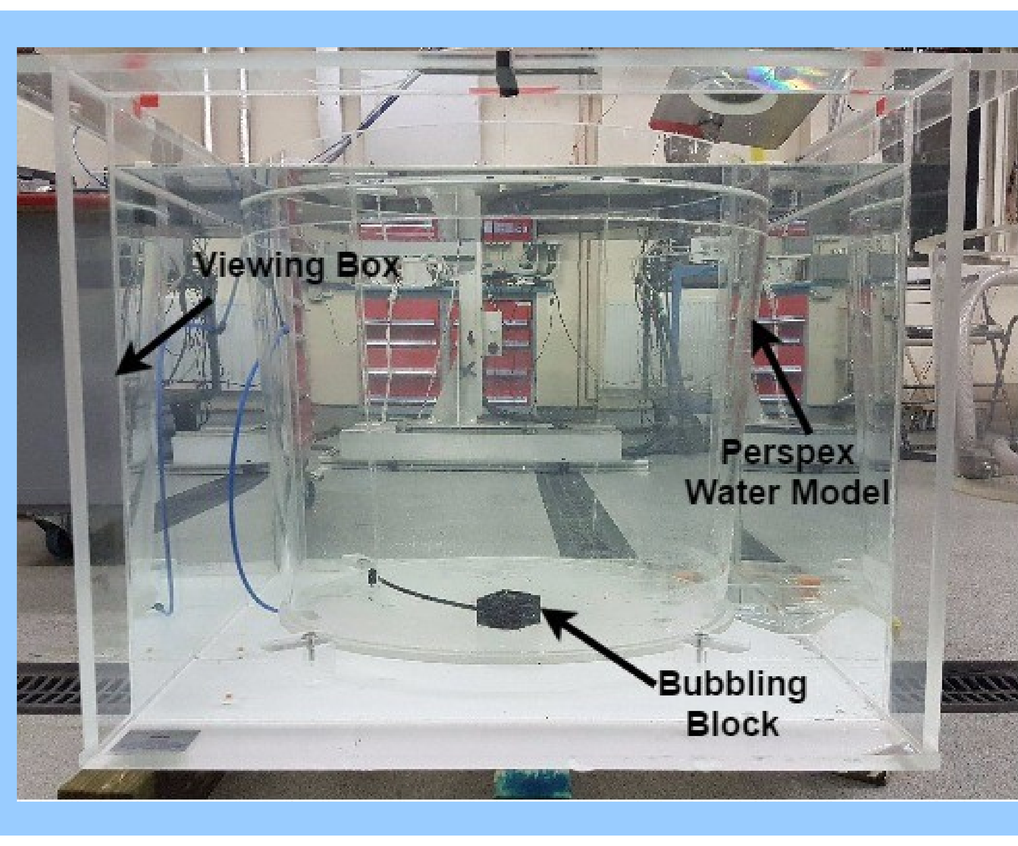
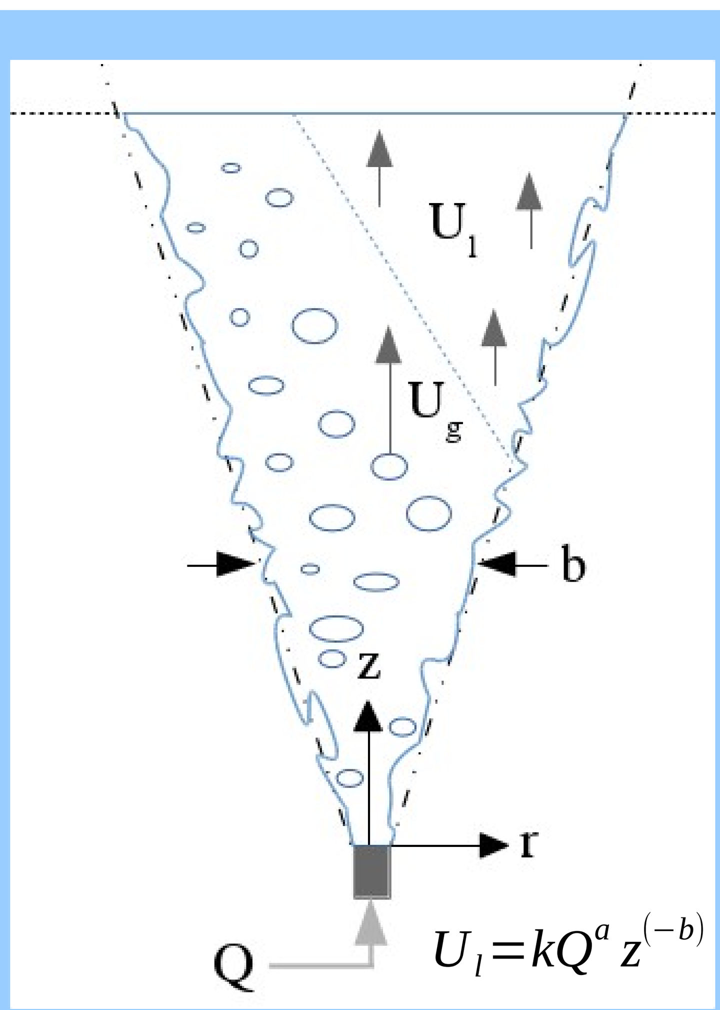
Introduction

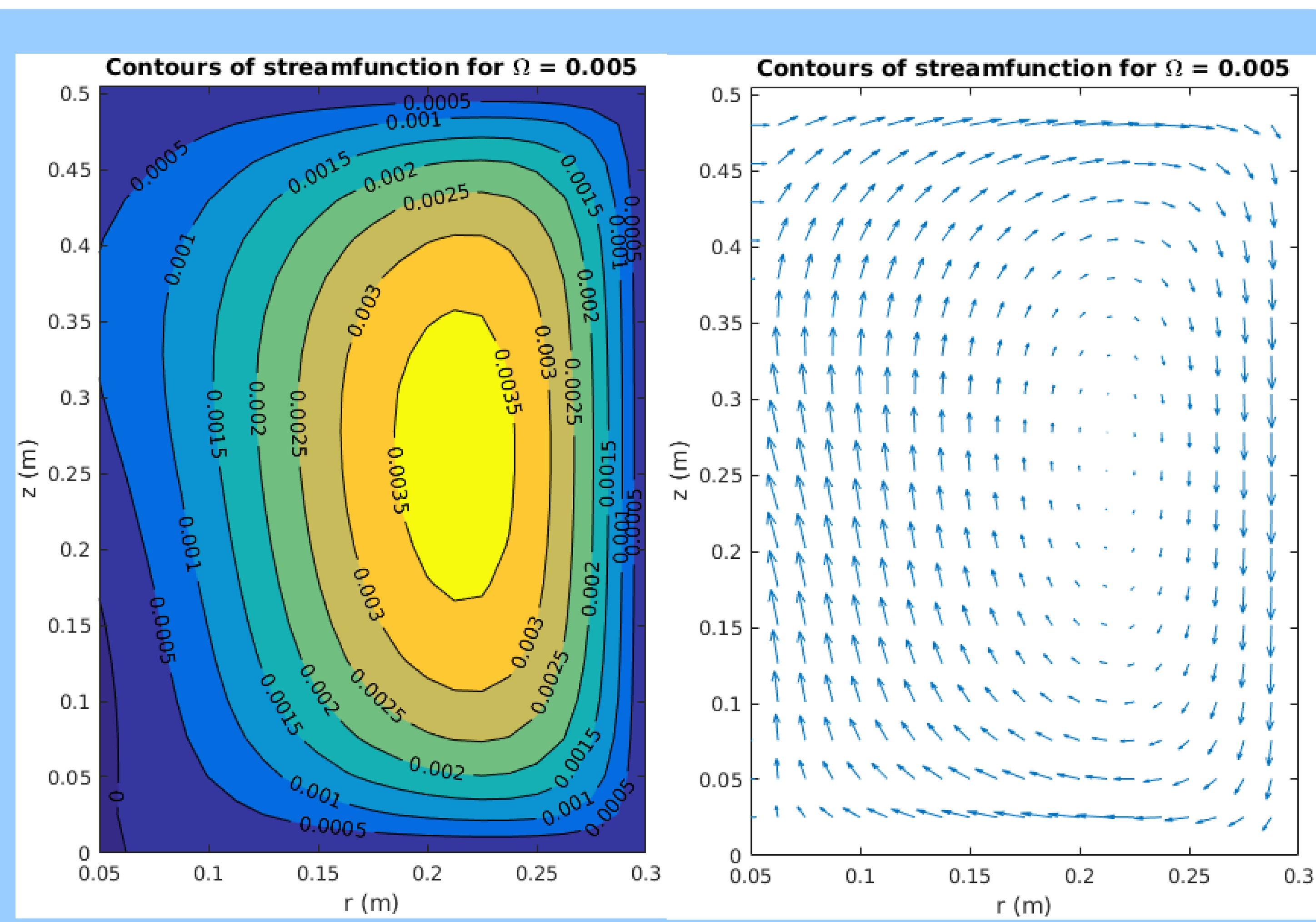
- Steel is a crucial material worldwide; infrastructure, automotive and aircraft industries, commercial metal products and machinery are just some of the examples.
- The steel making process involves multiple complex stages; we are interested in the Ladle furnace in the secondary refining stage.
- During this stage, alloy compositions are added to the molten steel to produce the required “grade” of steel in a massive steel Ladle.
- The molten steel mixture needs to be homogenised; to do this argon is bubbled through a plug at the bottom, the bubbles induce turbulence in the molten steel which helps with mixing as well as removing unwanted compounds or “inclusions”.
- The mixing is fluid dynamically driven and better understanding of the dynamics has previously lead to improved design and efficiency.



Macroscopic Modelling

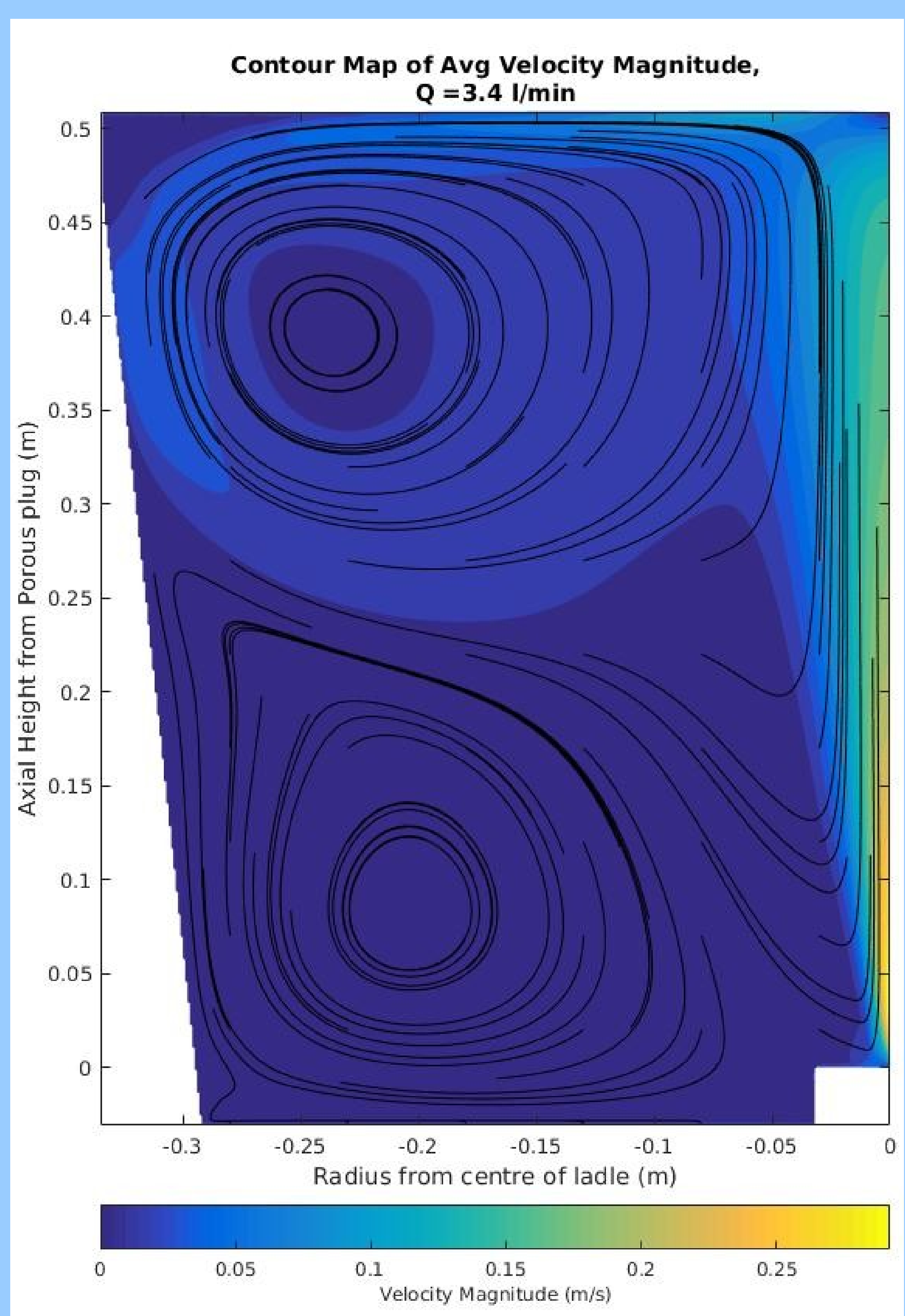


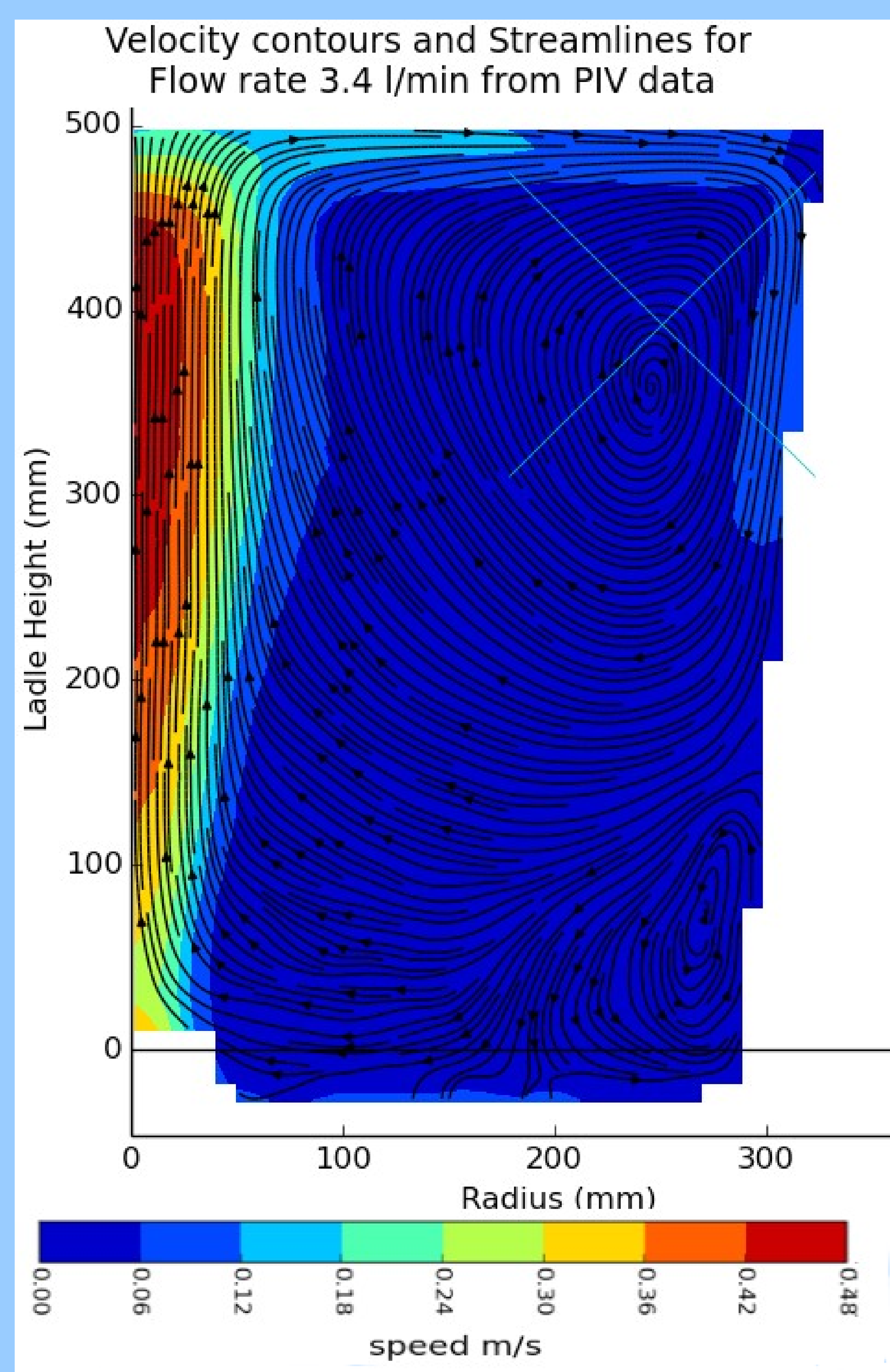
- Buoyant action on the flow by bubbles form a plume of rising liquid and bubbles (see left), expanding linearly via entrainment of the ambient liquid.
- Numerous correlations between liquid velocity 'U_l', gas flow rate 'Q' and height from the plume origin 'z' of simple form (see left), as well as more involved expressions, have been proposed.
- While simple macroscopic treatments of buoyant gas plumes are abundant, the same is not so for the bulk flow induced by the plume in a ladle.
- To study the bulk ladle flow, the axisymmetric, high Re flow in a simple cylinder-shaped ladle was described via a simplified Navier-Stokes equation for conserved potential vorticity (see right).



Computational Fluid Dynamics (CFD)

- A 2D half slice domain is used to model the centre-bubbling axis-symmetric problem.
- The full 3D geometry is used to model the off-centre bubbling problem.
- A Lagrangian Multiphase model is used to simulate the bubble plume, where each particle simulated a bubble.
- The bubbles were modelled as spheres with constant diameter 3.5mm.
- Compared different RANS turbulence models results: KE model derived by Launder and Sharma and SSG Reynolds Stress model by Speziale, Sarkar and Gatski.





Particle Image Velocimetry

- Two images taken with a 0.012 s gap.
- Software tracks laser illuminated seeding particles from one image to the the next, over the entire domain.
- Full 2D vector field is found for each image pair
- Sample rate 6 Hz.
- Average flow over 1 minute
- Bulk flow field is around 0.05 m/s.
- One main recirculation, which does not fill the entire domain, causing a very slow secondary recirculation at the bottom of the ladle.
- Used paraffin liquid wax to simulate effect of slag layer.
- Off-centered plug position and range of flow rates studied.

Future Work

- Modify the CFD model to incorporate both a free surface and a slag layer and validate it against the PIV data.
- Run the 3D CFD model with the RANS Reynolds Stress model to compare the turbulence models and validate it with the PIV results.
- Adjust CFD model to match steel ladle conditions, and model mixing in the ladle.
- Application of additional plume models and further development of macroscopic analysis of the bulk flow.
- Final validation of macroscopic and CFD against the water/air scale model PIV results and evaluation of the modelling approaches used for ladle design work.

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