Visualizing the complex flows in the reactors for steel sector digitization

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At the Sustainable Metallurgy and Industrial Technologies (SMITH) Research Lab, we blend engineering insight with practical innovation to tackle real-world challenges in process metallurgy. One of our primary strengths lies in the physical/cold/water modelling of metallurgical processes. This powerful technique uses scaled-down models made up of Perspex or acrylic material to simulate and study industrial metallurgical processes in a safe, cost-effective, industrially relevant, and highly controlled environment. Using similitude techniques, we replicate the complex behavior of molten metals, gas–fluid interactions, and liquid-liquid interactions found in full-scale industrial reactors. These models are usually guided by the dimensionless numbers, such as Reynolds, Froude, and Weber numbers, ensuring that the flow dynamics in our experiments faithfully mirror those in real systems. By doing so, at the SMITH lab, we are committed to pushing the boundaries of process metallurgy, where academic rigor meets industrial relevance.

SMITH lab houses a gas-stirred ladle with a top lance (Refer to Fig 1) to simulate the hot metal desulphurization industry process, in which different process parameters, such as gas flow rate, lance diameter, and immersion depth, can be varied to understand their effects on the jet penetration depth, bubble size, rise velocity, mixing time, etc. Figure 2 depicts the dynamics of bubbles that leave the top lance, thus helping us to visualise, understand, and improve the process effectively.

Similarly, Electric Arc Furnaces (EAFs) are crucial in steel production, utilizing steel scrap and Direct Reduced Iron (DRI) as key inputs. However, slag carryover control during tapping, primarily driven by vortex and drain sink formation, remains a significant challenge. Despite the widespread use of Eccentric Bottom Tapping (EBT) in EAFs, limited research has explored slag carryover mechanisms. We at the SMITH lab conduct experiments using a scaled-down Perspex model presented in Fig. 3 of an industrial EAF, incorporating a bottom purging system to analyze its impact on slag entrainment. The study investigates the factors such as filling flow rates, dwell time, nozzle diameter, initial liquid, purging flow rates, purging duration, etc, that influence vortex and drain sink formation. Critical heights for vortex and drain sink formation were recorded under varying conditions, and dimensional analysis was employed to derive predictive mathematical models. Further, the mathematical formulation of the EAF tapping process, considering the reactor's complex shape, accurately predicts the critical time for vortex formation, offering potential industrial applications to minimize slag carryover and enhance steel quality in EAF operations. In addition to the EAF cold model, SMITH also houses the Basic Oxygen Furnace (BOF) model. We will be exploring ways to decarbonize the BOF process using this model in the near future in association with the steel sector. In addition to the EAF cold model, SMITH also houses the Basic Oxygen Furnace (BOF) model. We will be exploring ways to decarbonize the BOF process using this model in the near future in association with the steel sector.

It should be noted that physical modelling offers a unique advantage and allows us to understand critical process phenomena such as mixing, vortex formation, bubble dynamics, mass transfer rates, etc, without engaging hazards and costly high-temperature experimentations. This approach determines the optimum process conditions for industrial operations, making them more efficient, economical, and environmentally sustainable.

Our lab also collaborates with industries such as M/s. Jamipol Limited, Jamshedpur, to design better top lance configurations, optimize gas-powder delivery systems, and improve reaction kinetics inside a metallurgical vessel, i.e., hot metal desulphurization unit. From enhancing hot metal quality to liquid steel refining & tapping, our research contributes directly to digitizing the steel sector.

Figure 1. A scaled down Water model setup of an Industrial Desulphurization unit.

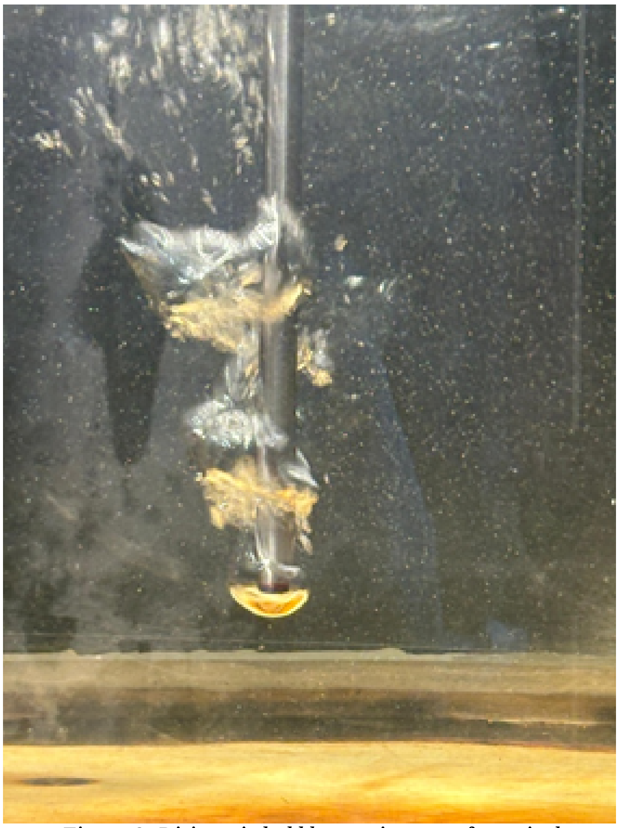
Figure 2. Rising air bubbles coming out of a typical T-shaped lance.

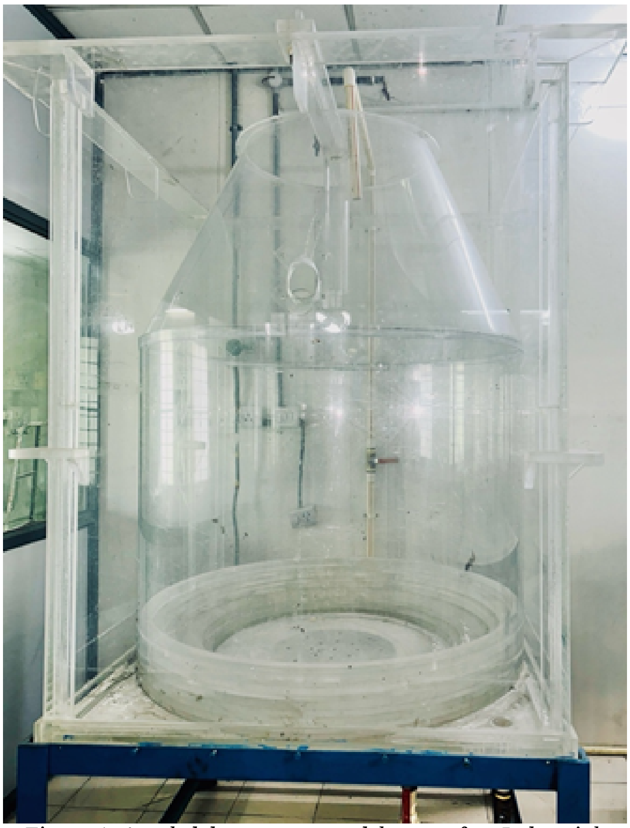
Figure 4. A scaled down water model setup of an Industrial DeS ladle

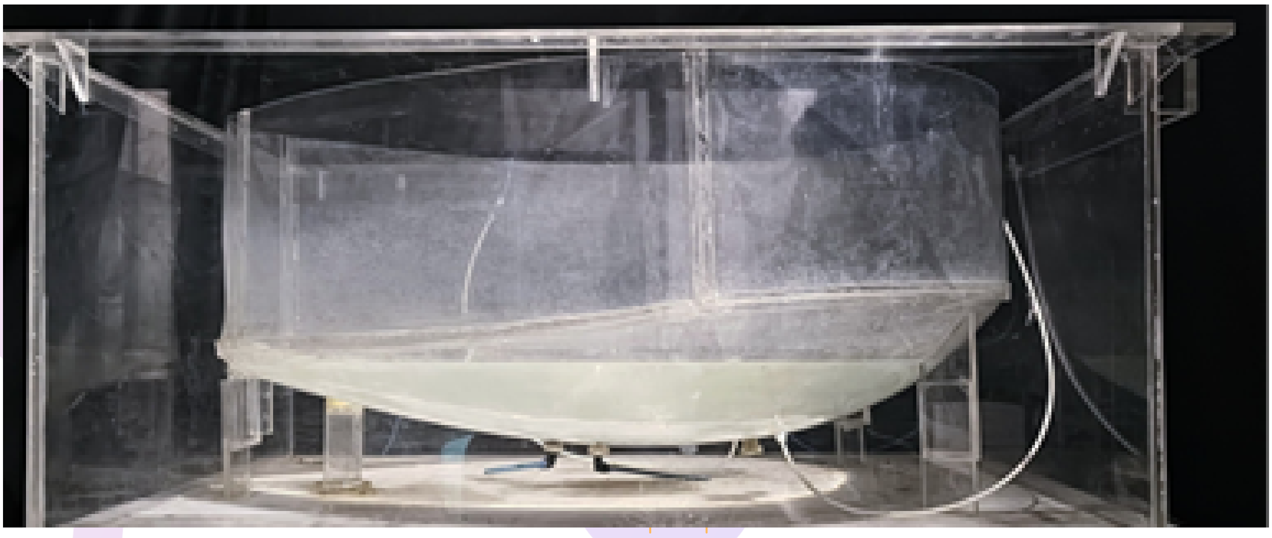
Figure 3. A scaled down cold model setup of an Industrial Electric Arc Furnace.

[1] **Dr Ashok kamaraj**
Assistant professor
[2] **Mr Syed Furqan Bukhari**
Research Scholar
[3] **Mr Abdul Rohid**
MTech Student
[4] **Mr Uppaluru Guru Srikanth Reddy**
MTech Student
Department of Materials Science And Metallurgical Engineering