MODELING OF MULTIPHASE FLOW AND BUBBLE DISTRIBUTION IN STEEL CONTINUOUS CASTING

(THE 7TH BAOSTEEL BIENNIAL ACADEMIC CONFERENCE)

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Keywords: *argon bubbles, turbulent flow, submerged entry nozzles, computational models*

1 General Introduction

During continuous casting of steel, argon gas is often injected to avoid nozzle clogging and to help control flow in the mold. However, if the bubbles cannot escape through the slag layers on the surface in the mold, and are entrapped into the solidifying steel shell, then they can lead to slivers during rolling and ultimately defects in the final product, owing to their associated inclusions. Understanding gas behavior is challenging because, in addition to the multiphase turbulent flow, the volume fraction and size distribution of the bubbles is difficult to predict. The argon flow rate into the molten steel is often less than measured, due to leakage, or is greater, due to passive aspiration, as gas may be fed into negative pressure regions, such as joints between the slide-gate plates. After their initial formation where gas is injected at the refractory surface, the bubbles evolve as they move within the highly-turbulent flowing steel in the nozzle, sometimes coalescing into large gas pockets, and elsewhere shearing apart to form smaller bubbles. Once in the mold cavity, they move with and change the flow pattern, and may be captured into the dendritic interface. Previous computational models of these complex phenomena are reviewed elsewhere [1].

2 Model Formulation

A system of models has been developed to better predict the behavior of gas bubbles during continuous casting, including their size distribution and capture into the final product. The first step is a three-dimensional model of porous gas flow through the refractory nozzle walls, combined with an analytical model of gas injection, to quantify the initial size distribution entering the nozzle, including a methodology to predict leakage [2]. Next, passive gas aspiration is predicted using a pressure-energy balance model [2]. Thirdly, a new hybrid EE-DPM model combines an Eulerian-Eulerian finite-difference model of multiphase gas/liquid flow with a model to track the transport of each individual bubble using a Discrete Particle Method [2-5]. This new model predicts the location of gas pockets, shearing off of those gas pockets to form bubbles, and evolution of the bubble size distribution in space and time due to both coalescence and breakup. Finally, the transport of bubbles through the turbulent flow field in the liquid pool, and their capture into the solidifying shell is tracked using a transient model with an advanced capture criterion [6].

3 Model Validation and Application

To validate the model system, each of the individual component models is evaluated against experimental measurements. The new hybrid model can match measured velocity, gas fraction, and size distribution profiles across the diameter of upward vertical pipe flow of water-air mixtures [3]. Recently, bubble size evolution has been measured in the downward flow of a stopper-rod system, where significant breakup is observed in the thin gap of the flow-control region, and coalescence is observed down the nozzle [7]. Figure 1 compares the EE-DPM model predictions of gas pocket formation with benchmark experiments [8] in a low-melting liquid metal / argon flow system. Bubbles forming at the stopper tip coalesce into gas pockets, which are sheared off, to send smaller bubbles down the nozzle. Figure 2 shows that the resulting size distribution matches reasonably well with measurements.

Finally, the model system is being applied to simulate real casters under conditions of practical interest. Figure 3 shows a snapshot of an example simulation of a commercial slide-gate nozzle. A large gas pocket can be seen beneath the slide gate for these conditions. The bubbles are smaller in the most turbulent region near the gate opening, while larger bubbles are observed near the gas pocket. Further models predict the transport and capture of the bubbles into the slab [6]. The complete model system is being applied to predict the entrapment of bubbles in the final slab for different casting conditions, to find ways to minimize the associated defects.

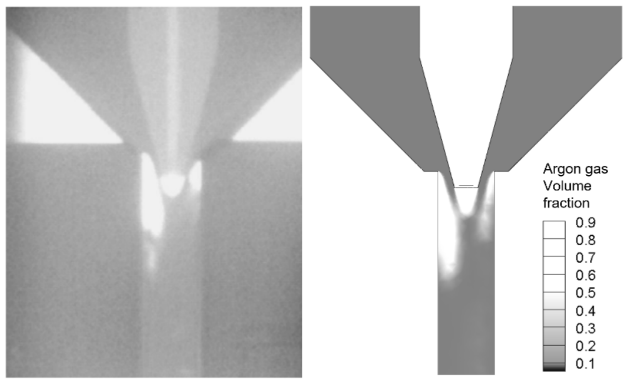

Fig. 1. Gas pockets observed from X-rays of liquid metal (left) [8] compared with model simulation (right) [2].

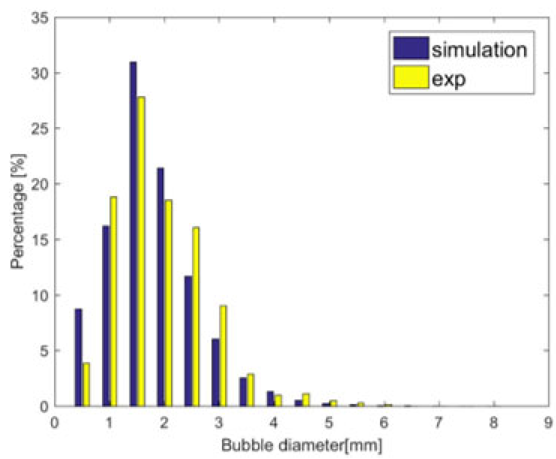

Fig. 2. Bubble size distribution in the lower mold, comparing predictions and measurements [4].

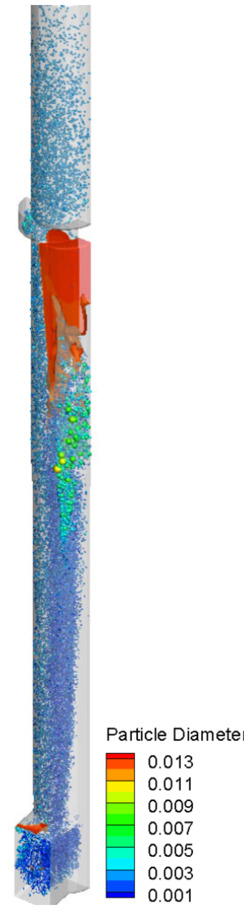

Fig. 3. Model prediction of turbulent flow in a commercial slide-gate nozzle showing argon gas pocket and bubble distribution (mm) [2].

4 Acknowledgements

The sponsors of the Continuous Casting Center at the Colorado School of Mines, and the Continuous Casting Consortium at the University of Illinois are gratefully acknowledged. The authors also thank the National Science Foundation Grant CMMI 18-08731 for support that enabled this research.

5 References

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