

MULTI-OBJECTIVE CFD-BASED DESIGN OPTIMISATION OF TOP BLOWING ARGON STIRRED MOLTEN STEEL LADLE

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Abstract

High-quality, cost-effective mixing is essential for achieving full thermal and compositional homogenisation in steel refining. The stirring of a molten steel ladle with argon injection through a top submerged lance nozzle is investigated through a Computational Fluid dynamics (CFD)-based multi-objective optimisation framework. The present work employs a multi-fidelity approach which combines single and multi-phase CFD and residence time distribution (RTD) analyses. This framework aims to identify optimal combinations of design features which maximise desirable characteristics such as mixing index and pressure drop. A surrogate modelling approach, using a 30-Design of Experiment (DOE) points is generated through Optimal Latin Hypercubes Sampling (OLHS) and a permutation genetic algorithm, was employed to determine optimal process parameters. The ladle design is formulated in terms of one geometric and one operating design variables: the lance depth and argon inlet velocity. Four data-driven modelling approaches are compared, namely Random Forest, XGBoost, LightGBM, and a Multilayer Perceptron are considered. It is shown the LightGBM-based surrogate modelling approach to be the most effective within the operating conditions and geometric under investigations. A Pareto front is then built using LightGBM coupled with the multi-objective genetic algorithm (MOGA) approach NSGA-II, allowing designers to balance compromises between designs with maximum mixing index and those with minimal pressure drop. Results suggest that the best compromise design is with a lance height of 2.4m and injection velocity of 0.96 m/s. This configuration provides a high mixing index of 0.942, whilst maintaining a low-pressure drop of 1.6MPa. While deeper lance submersion can improve the mixing index by up to 3.3%, this leads to a 22% increase in pressure drop. Conversely, pressure drop can be reduced by around 17%, which comes at the cost of a 20% decrease in mixing index compared to the compromise point. Overall, the proposed optimisation methodology demonstrates strong capability in guiding the design of complex industrial applications towards more efficient operation.