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Eulerian Multiphase CFD Model Optimisation and Sensitivity Analysis for Nuclear Reactor Fuel Assembly Simulations

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Abstract

Attempting to simulate the flow around a nuclear reactor fuel assembly via an interface tracking CFD method is currently computationally impossible, owing to the multiscale nature of the problem. Solving it would require tracking an immense number of vapour bubbles in both the micrometre (after nucleation) and metre (when exiting) range. Instead, Vlček and Sato [1] proposed using a Eulerian model (PSI-CTU) that tracks the presence of bubbles via population balance equations rather than resolving the interfaces, showing good agreement with the DEBORA experiment for flow of freon-12 in a heated pipe [2].

The main disadvantage of the Eulerian model is a significant number of empirical parameters, which require tuning on a case-by-case basis. To reduce the time required for such tests, we propose the use of an inverse problem methodology to derive the empirical parameters of the CFD model while minimising the error to the experimental results. The optimisation tests multiple methods such as genetic algorithms and particle swarm in both single and multi-objective optimisation strategies to minimise the error. However, such methods require over 10^5 simulations which is prohibitive even using Eulerian methods. Therefore, a surrogate model to replicate the results of the Eulerian model using neural networks has been developed. Both feed-forward and cascade forward networks have been tested, with the latter currently showing improved results. Figure 1 shows results obtained by using the parameters derived through a single objective genetic algorithm optimisation using a cascade-forward network. Compared to the results of the original PSI-CTU parameters, the optimised simulation achieves lower errors compared to experimental results related to the vapour velocity and volume fraction at the exit of the pipe. A follow-up sensitivity analysis is also significantly accelerated using the surrogate model.

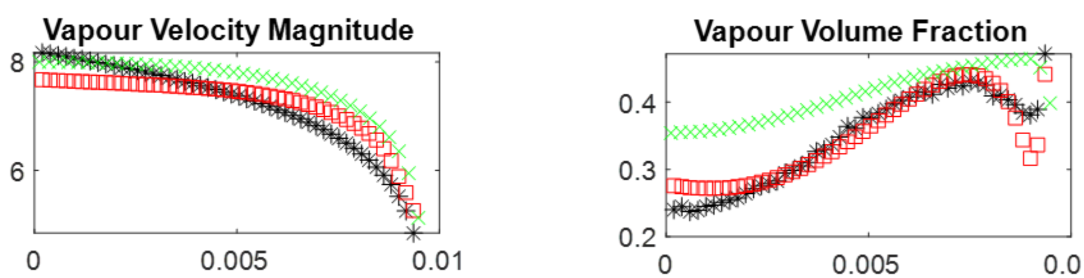

Figure 1: Neural network results using the empirical parameters derived by a single-objective genetic algorithm (red) compared to experimental results (black) and PSI-CTU simulations (green) [1]

[1] D. Vlček, Y. Sato, Sensitivity analysis for subcooled flow boiling using Eulerian CFD approach, Nuclear Engineering and Design, 405 (2023) 112194.

[2] J. Garnier, E. Manon, G. Cubizolles, Local measurements on flow boiling of refrigerant 12 in a vertical tube, 13 (2001) 111.

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