SIMULATION OF GAS INJECTION INTO LIQUID WITH SIMMER

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ABSTRACT

This paper deals with numerical simulations of the air-injection-into-water experiment by Castillejos [1] with the SIMMER-III code [2]. Because of complexity of the problem, we need to confirm that the code can predict the two-phase flow behaviours before we apply it for simulation of helium bubbling in molten salt reactors. Numerical simulations are performed with the original and improved versions of the model for momentum exchange between gas and liquid. Simulation results are presented and compared with experimental ones. It is shown that, although the radial distribution of the void fraction (gas volume fraction) cannot be predicted well by the numerical simulation, the volume-averaged values can be well predicted. The reason for the discrepancy in the radial void fraction distribution is that the 2D code with relatively fine meshes can hardly simulate the large bubble break-up, which plays an important role in this case. How to extend this simulation to helium bubbling for removal of fission products in molten salt reactors is discussed in this paper as well.

1. INTRODUCTION

In the SAMOSAFER project (an EU molten salt reactor project) it is proposed to inject helium gas into the molten salt pool from the bottom to remove fission products. Before doing numerical simulations of such a complicated phenomenon, we would like to check the SIMMER-III code, which we will apply for an existing gas injection experiment described by Castillejos [1]. The SIMMER code (including 2D SIMMER-III and 3D SIMMER-IV) possesses advanced fluid-dynamics of multiphase-flow and neutronics models [2, 3]. The code is applied for simulation of hypothetical severe accidents in sodium fast reactors and other systems with focus on core behaviour after core melting. The equation-of-state (EOS) models for various material have been developed. In particular, they are available for several molten salts, water and air.

The experiments of air injection from the bottom into water was carried out by Castillejos and described in 1986 in [1]. The information about bubble sizes, gas velocities and gas volume fractions is available. In particular, for the gas volume fraction the author provided a quite good correlation for its spatial distribution which is valid for various parameters. In this experimental study, the water depth, the air injection flow rate, and the diameter of the nozzle can vary. However, we focus on a test with two gas flow rates. The initial water depth in the pool is 40 cm, the internal radius of the tank is 25 cm, and the injection diameter 6.35mm. The two gas flow rates chosen are 371 and 876 cm^3/s. The corresponding average gas injection velocity values are 11.71 and 27.66 m/s, respectively.

In the past, the Castillejos experiment was one of SIMMER validation experiments for two-phase flow. Pigny in 1999 [4] performed simulations of the experiment with SIMMER-III and later in 2011 [5] with SIMMER-IV. Meantime Suzuki et al. (2003) [6] simulated gas-liquid-metal two-phase flow with SIMMER-III, where the momentum exchange model was assessed and improved, so that a more accurate average gas volume fraction was computed.

In this paper we follow the main route of the above-mentioned investigations and do assessments of the following model options:

— Mesh size variations, using of two meshes for the central injection region;
— Original modelling options:
  - Navier-Stokes equations;
  - Turbulence model.
— Improved modelling options:
  - Large Interface Simulation (LIS);
  - Improved momentum exchange function MXF95 (Suzuki 2003) [6].

2. SIMMER-III GEOMETRY MODEL

The initial experimental flow set-up is axisymmetric about the water tank centreline. Therefore, the 2-D RZ axisymmetric approach of the SIMMER-III code is suitable for the geometric modelling. A preliminary discretization of the whole flow domain is done by 25x50 meshes in radial and axial directions with one central cell for the gas injection at the bottom. Finally the meshes are refined by 50x100 with two cells for the gas injection, as shown in Fig. 1.

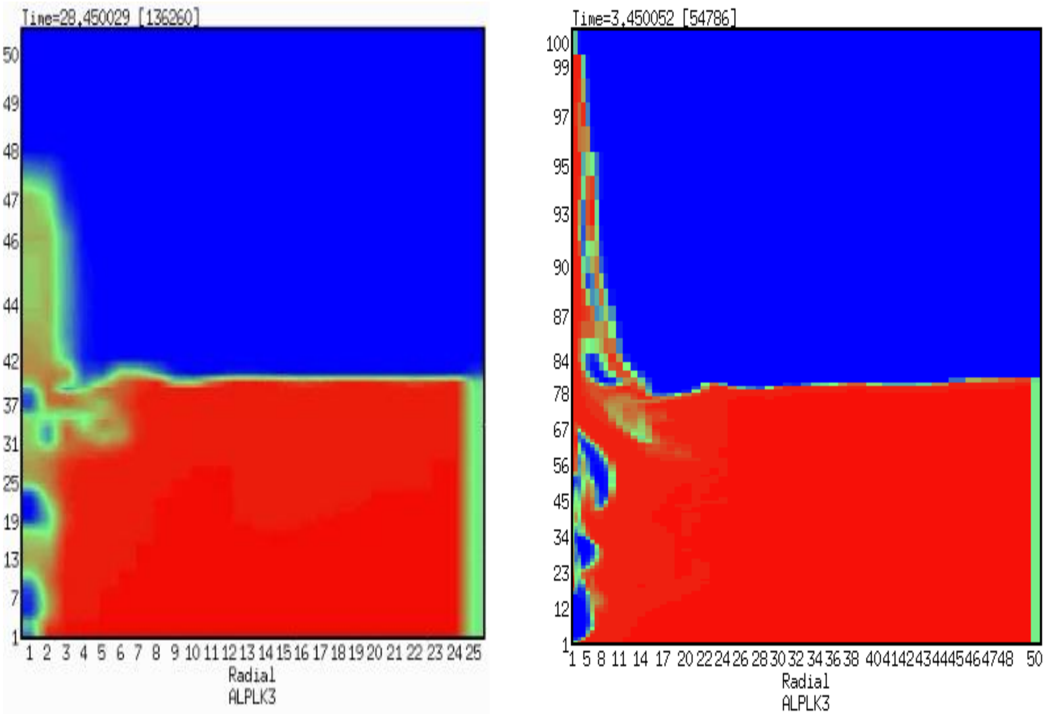

FIG. 1. SIMMER geometric model with two mesh setups of 25x50 and 50x100.

3. SIMMER-III SIMULATION RESULTS

First of all, use of the refined meshes leads to marginally better results, where the gas plume expands better than for the coarse meshes. But the use of even finer meshes leads to a numerical instability. In the following we focus on other model variations, i.e. LIS and MXF95.

We evaluate our results for the radial distributions of gas volume fraction (void fraction) by comparing them with experimental ones and then we compare the axial ones and volume averaged ones. Fig. 2 and Fig. 3 show the radial distributions of time averaged void fractions at two axial positions, with the heights z above the gas inlet of 6.5 cm and 19.25 cm, for two gas flow rates Q = 371 and 876 cm^3/s, which are denoted as cases of Q371 and Q876. In general, SIMMER overestimates significantly the void fraction in the central region and underestimates it in the peripheral region of the gas plume. The LIS model does not improve the results, but the momentum exchange modification (MXF95) improves them slightly. The reason for the discrepancy, we believe, is that the large bubble break-up process cannot be well simulated by the 2D code, so that the gas plume in the numerical simulation does not spread so widely as in the experiment at higher axial locations.

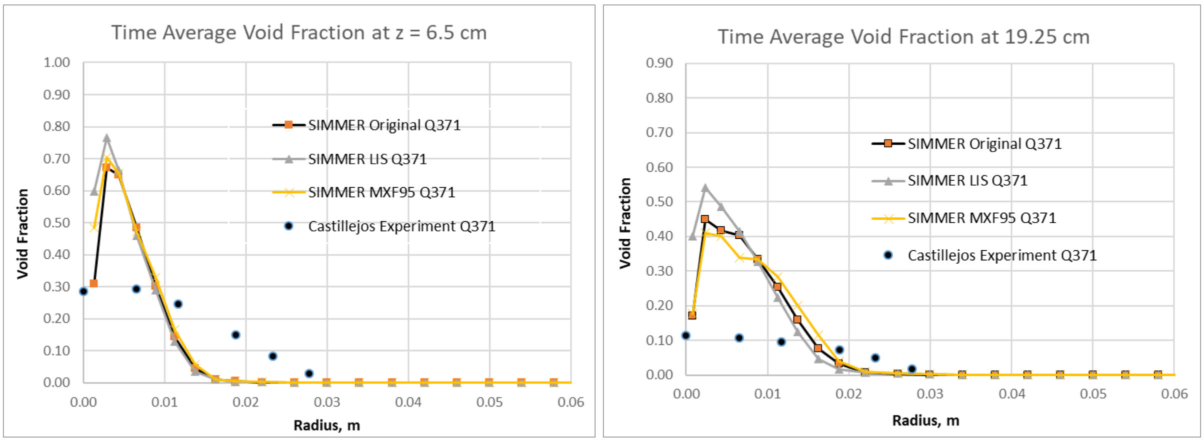

FIG. 2. The radial distribution of time average gas volume fraction at two heights of 6.5 cm and 19.25 cm in the case of Q371.

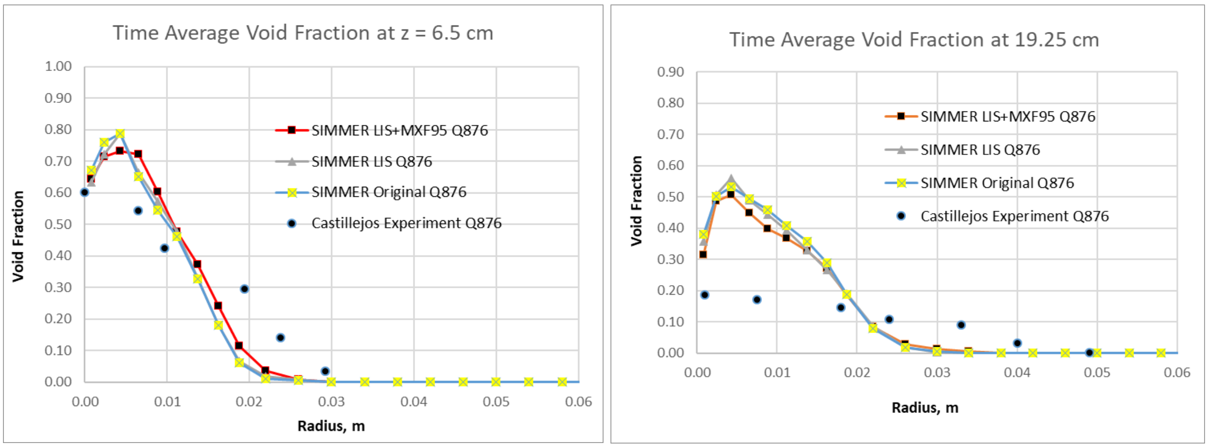

FIG. 3. The radial distribution of time averaged gas volume fraction at two heights of 6.5 cm and 19.25 cm in the case of Q876.

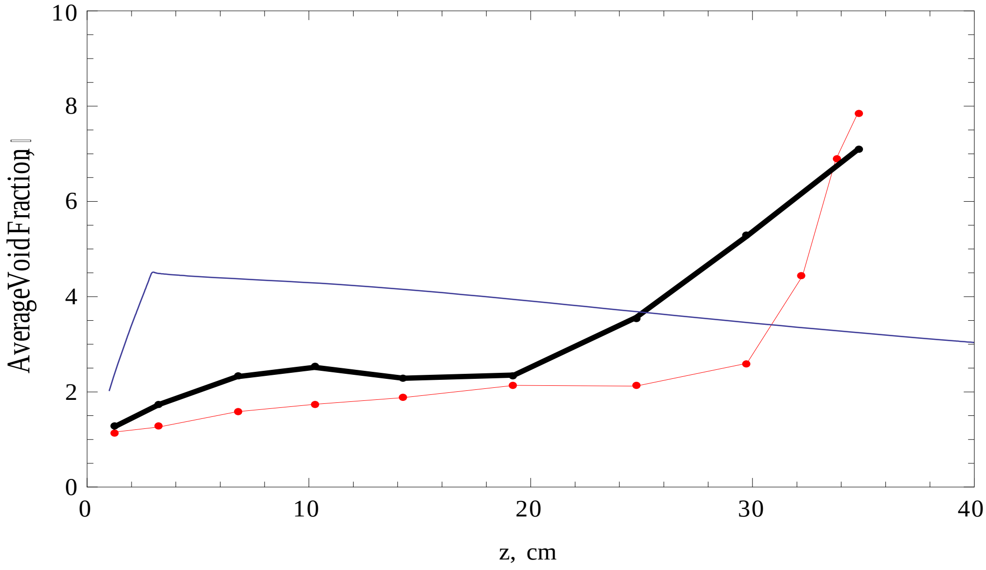

FIG. 4. The axial distribution of cross-sectional-area (r from 0 to 6 cm) averaged gas volume fraction in the case of Q371, where the thin blue line stands for experimental result, the thin red line for SIMMER original one and the thick black line for SIMMER improved one.

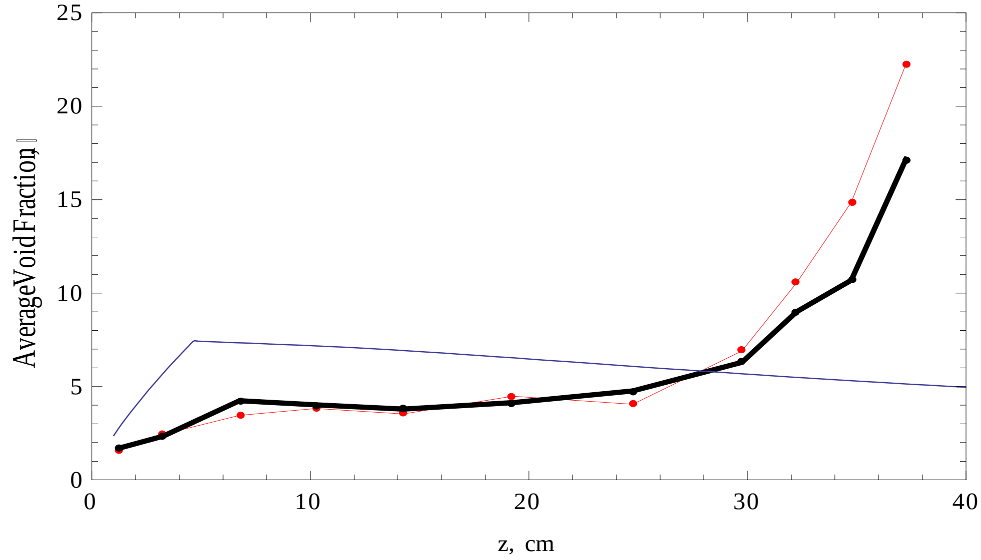

FIG. 5. The axial distribution of cross-sectional-area (r from 0 to 6 cm) averaged gas volume fraction in the case of Q876, where the thin blue line stands for experimental result, the thin red line for SIMMER original one and the thick black line for SIMMER improved one.

Since the experimental void fraction has been described by a correlation using analytic functions, its cross-sectional area and volume averaged values can be easily obtained. Fig. 4 and Fig. 5 show the axial distributions of the radially averaged void fractions for cases Q371 and Q876, respectively. The results show that the improvement leads to more significant effects in the lower gas flow rate case Q371 than in the case of Q876. Finally, Table 1 shows the volume averaged void fractions. The simulation values agree quite well with the experimental ones.

TABLE 1. VOLUME AVERAGED VOID FRACTIONS

Case	Q371	Q876
Experiment, %	3.90	6.33
SIMMER Original	2.24	4.69
SIMMER Improved	**3.17**	**4.56**

4. CONCLUSIVE REMARKS AND DISCUSSIONS

Air-injection-into-water cases were successfully simulated with SIMMER-III. Although the radial void distribution cannot be well represented by the numerical simulation, the volume averaged values agree well with experimental ones. We plan to apply the code for more uniform gas injection in molten salt reactor applications. Therefore one may avoid the mentioned issues in simulation of the void distribution. We also consider to choose the dimensionless numbers, such as Reynolds, Eötvos and Morton numbers, in the same range as considered in this paper, so that a similarity can be achieved in the simulations.

ACKNOWLEDGEMENTS

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