NUMERICAL ANALYSIS ON POOL BOILING USING USER DEFINED FUNCTION

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1. Introduction

The boiling phenomena in a water tank are widely seen in many applications. PAFS (passive auxiliary feedwater system) adopted in the APR+ (Advanced Power Reactor Plus) of Korea is one such application. When PAFS is activated with an actuation signal, steam from the steam generator passes through heat exchanger tubes submerged in a water tank of the PAFS. [1, 2, 3] Outside these heat exchanger tubes, nucleate boiling phenomena appears. In the present work, a numerical study is reported on three-dimensional transient state pool boiling of water having an immersed heat source. The velocity vector fields during the decrease in the water level are numerically investigated in a pool, and the accuracy of the results is checked by comparing the experimental results conducted using the PIV techniques by Kim et al. [3, 4]. These numerical results can be used as basic research data for an analysis and prediction of the natural circulation phenomena in the cooling tank of the passive safety system in a nuclear power plant.

2. Methods and Results

2.1 Method

The domain for a numerical analysis is a rectangular vessel with a cylindrical rod inserted near the bottom. The vessel is filled with liquid water and open at the top side, forming a pool. Therefore, the top boundary represents the free surface of the liquid. The initial level of the liquid is 400 mm. The rod is heated with a power of 600 W, driving the liquid to the saturation temperature and leading to boiling, which will start when the temperature on the surface of the rod is over the saturation temperature. The heat input is modeled as a constant volume heat source in a solid. A polyhedral mesh around the heated rod ensures interface conformity. The characteristic cell sizes are 3.5 mm and 8 mm near the heated rod and in the remaining area, respectively.

In a real situation, a free surface moves down as the liquid vaporizes and vapor escapes the pool. Therefore, it is important to model the free surface reasonably for accurate numerical results. In the present analysis, two different possibilities are under analysis in order to implement movement of the top boundary. One method is to model the top boundary as a wall permeable only to vapor that moves down as the vapor volume leaves the domain. The movement of the top wall is included using a mesh morpher and calculated from the volume balance considerations, as shown in the following Eqs.

$$\dot{V}_{domain} = \dot{V}_{lq} + \dot{V}_{vap} \quad (1)$$

$$\dot{V}_{vap} = \frac{\dot{m}_v^{wall}}{\rho_v} + \frac{\dot{m}_v^{bulk}}{\rho_v} - \frac{\dot{m}_v^{top}}{\rho_v} \quad (2)$$

$$\dot{V}_{lq} = -\frac{\dot{m}_v^{wall}}{\rho_l} - \frac{\dot{m}_v^{bulk}}{\rho_l} \quad (3)$$

$$\rightarrow v_{top} = \dot{V}_{domain} / A_{top} \quad (4)$$

The other method is to capture the separation between the liquid and vapor using an Eulerian multiphase model. Even if the Eulerian multiphase model was not designed to capture this, it may provide a reasonable result. The suitable drag model needs to be included to capture the phase inversion in the interphase between liquid and vapor. The drag force between phases is calculated as follows:

$$F_{ij}^D = A_{ij}^D (v_j - v_i) \quad (5)$$

where A_{ij}^D is the linearized drag coefficient.

In the described phase inversion drag model,

$$A_{ij}^D = C_{ij}^D \frac{1}{2} \rho_M \left| v_j - v_i \right| \left(\frac{a_{ij}}{4}\right) \quad (6)$$

where C_{ij}^D and ρ_M are calculated as a mixture, employing a blending function:

$$\rho_M = \beta_l \rho_l + \beta_v \rho_v \quad (7)$$

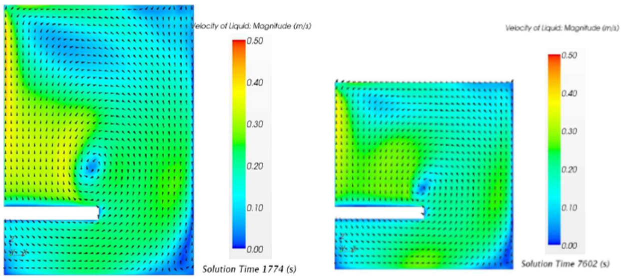
$$C_{ij}^D = \beta_l C_{Tomiyama}^D + \beta_v C_{SN}^D \quad (8)$$

2.2 Results and Discussion

As shown in Figs. 1 and 2, numerical results from a morphing method were compared with the experimental results at different instants. It can be seen that there is a good similarity between the observed flow patterns and the experimental results conducted by Kim et al [4]. There is one big recirculation loop of the liquid flow in the domain and the highest velocities are achieved over the rod. Most of the vapor rises over the rod, also expanding horizontally as it goes up.

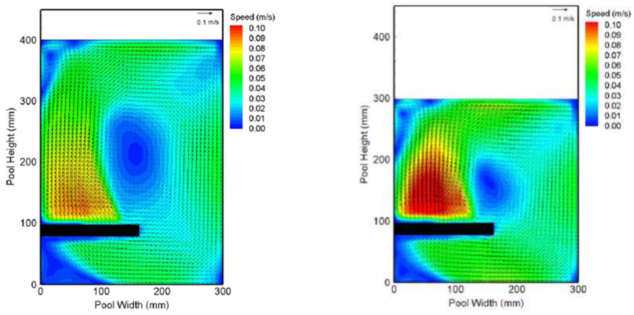
In Fig. 3, the liquid flow pattern and vapor volume fraction obtained by the Eulerian multiphase method are shown at different instants. The results are very similar with those by the previous method. The drawback is that it is less robust and much more time consuming.

Also, it can be seen that some numerical glitches are present close to the free surface. The behavior of the free surface also presents some degree of irregularity on its movement. The top moving boundary approach presents a number of advantages that makes it seem a superior option to consider.



(a) pool height 400 mm (b) pool height 300 mm

FIGURE 1. VELOCITY VECTOR FIELD (NUNERICAL RESULTS BY MORPHING METHOD)

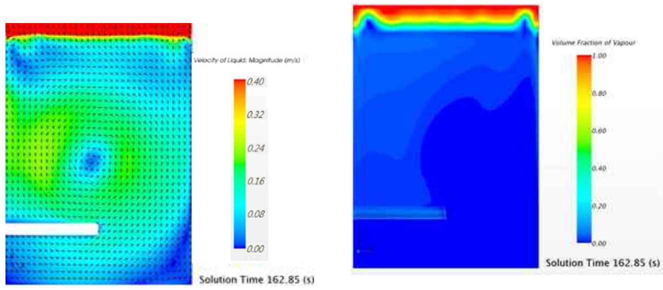


(a) pool height 400 mm (b) pool height 300 mm

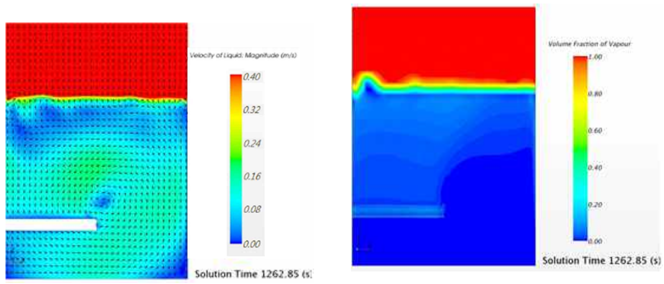
FIGURE 2. VELOCITY VECTOR FIELD (EXPERIMENTAL RESULTS CONDUCTED BY KIM et al. [4])

3. Future Work

A sensitivity analysis on several boiling sub-models, such as the bubble departure diameter and frequency and active nucleation site number density, was not conducted. Therefore, the effect of boiling sub-models on the thermal hydraulic characteristics in the pool boiling may be studied for a numerical aspect as future work.



(a) pool height 400 mm



(b) pool height 300 mm

FIGURE 3. VELOCITY VECTOR FIELD & VAPOR VOLUME FRACTION (NUNERICAL RESULTS BY EULERIAN MULTIPHASE METHOD)

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