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Film Boiling Heat Transfer on an Oscillating Surface

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1.Introduction

Recently, nuclear safety under the earthquake circumstance has received great attention. Film boiling occurs when the wall temperature is so high that the vapor layer exists between the heating wall and liquid. Many authors have studied film boiling o n the stationary heating surface[1-6].

The objective of this study is to numerically investigate the effect of the wall oscillation on the film boiling heat transfer. Toward this end, we performed volume-of-fluid simulations.

2.Numerical method

Figure 1 shows two-dimensional saturated film boiling on a vertically oscillating plate. Since the whole system oscillates vertically, it is not the flow boiling. In this study, numerical simulation is performed in the moving coordinates.

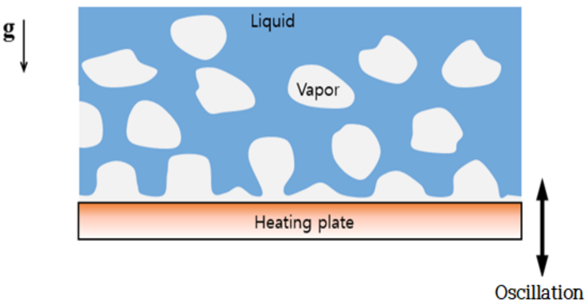

Fig. 1. Film boiling on an oscillating plate

The momentum equation in the moving coordinate is given as follows:

$$\frac{\partial}{\partial t}(\rho \mathbf{u}) + \nabla \cdot (\rho \mathbf{u}\mathbf{u}) = -\nabla p + \nabla \cdot [\mu(\nabla \mathbf{u} + (\nabla \mathbf{u})^T] + \rho \mathbf{g} + \sigma \kappa \mathbf{n} \delta_s - \rho \ddot{\mathbf{R}} \quad (1)$$

where $\ddot{\mathbf{R}}$ is the linear acceleration of the heating wall when viewed from the absolute coordinate. The term $\sigma \kappa \mathbf{n} \delta_s$ accounts for the surface tension force, which appears only in the gas-liquid interface region.

ANSYS FLUENT was used to perform numerical simulation in the moving coordinate. The last term in Eq. (1) was implemented by the help of user-defined function(UDF).

We used Sun's phase-change model to compute the mass transfer rate [7]:

$$\dot{m}_g = -\frac{2\lambda_g (\nabla \alpha \cdot \nabla T)}{L}, \quad (2)$$

where $\dot{m}_g$ is the vapor generation rate, L is the latent heat, λ_g is the vapor thermal conductivity, α is the vapor volume fraction, and T is the temperature.

Figure 2 shows the variation of the space-averaged Nusselt number with time for the stationary heating wall. The wall temperature is 5 K higher than the saturation temperature. The present result agrees well with Sun`s result in terms of the time-space averaged Nusselt number.

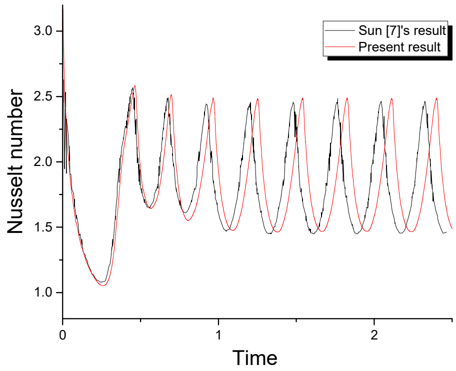

Fig.2. Simulation result for the stationary wall

3.Results

According to Fig. 2, the bubble departure period is about 0.28 s. So, there would be a remarkable change in heat transfer if the oscillating period is close to 0.28 s.

In the meantime, the Seismic design criteria of power plants in Korea is 0.3g, where g=9.81 m/s^2. Therefore, the following equation is used as the momentum source caused by vertical oscillation:

$$\ddot{\mathbf{R}} = 0.3g = A\Omega^2 \sin(\Omega t), \quad (3)$$

$$\Omega = 2\pi / T, \quad (4)$$

where T is the oscillation period, t is the time, A is the amplitude. For example, if the oscillation period is 0.28 s, and A is 0.0058 m. Figure 3 compares the heat transfer between the stationary and oscillating walls. For the oscillating wall, the time-space averaged Nusselt number is about 1.85, while for the stationary wall it is about 1.81. It is interesting to note that the wall oscillation increases the heat transfer even though the only gravity varies with time.

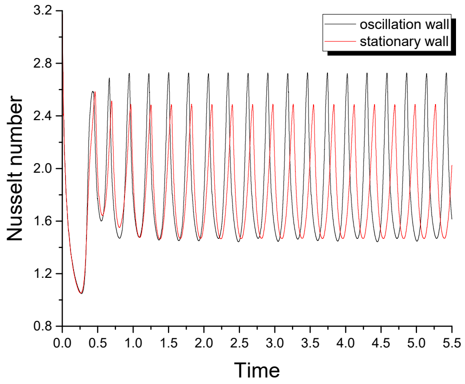

Fig.3. Variation of the spaced-averaged Nusselt number with time

Table 1. Result under the design criteria of 0.3g

Case No.	Period T(s)	Amplitude A(m)	Time-space averaged Nu
1	0.24	0.004294	1.828512
2	0.26	0.00504	1.838718
3	0.28	0.0058	1.852222
4	0.30	0.00671	1.840279
5	0.32	0.007634	1.832334

Table 2. Result as a function of the amplitude

Case No.	Amplitude A (m)	Time-space averaged Nu
1	0.002	1.82873
2	0.004	1.836383
3	0.006	1.853373
4	0.008	1.869398
5	0.010	1.878693
6	0.012	1.885915

Table 3. Result as function of the oscillation period

Case No.	Period T (s)	Time-space averaged Nu
1	0.24	1.829334
2	0.26	1.841966
3	0.28	1.853373
4	0.30	1.840279
5	0.32	1.810049

We simulated five cases under conditions that meet the seismic design criteria of power plants in Korea. Table 1 shows the result. The heat transfer is the largest for T=0.28 s.

We simulated additional cases while fixing T=0.28s or A=0.006m. Table 2 shows the result as a function of the amplitude while fixing T=0.28 s. The heat transfer increases monotonically with increasing the amplitude. outside of the seismic design criteria. Table 3 shows the result as a function of the period while fixing A=0.006 m. Case 3 shows the largest heat transfer. Nusselt number.

4. Summary

This paper deals with the effect of the wall oscillation on the film boiling heat transfer. Our simulation can be summarized as follows:

1. The heat transfer is enhanced when the oscillation period is close the bubble departure period.
2. The oscillation amplitude increases the heat transfer

This study will be extended to multi-mode simulation. In addition, the effect of horizontal oscillation will be investigated.

Acknowledgement

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