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Effect of the Geometry on a Free Surface Fluctuation in a Vessel

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1. Introduction

In a liquid metal reactor there exists a free surface in the upper plenum of the reactor vessel where the sodium coolant contacts with the cover gas. Fluctuation of this free surface causes two important phenomena. One is to secure the structural integrity of the reactor vessel due to a thermal striping. Another is the gas entrainment at the free surface. An experimental study has been performed to measure the fluctuation phenomena in a vessel. The effects of the vessel diameter and water level on a free surface fluctuation are studied. And a geometry factor is developed and compared with the experimental data.

2. Experiment

Figure 1 shows the test section used in the experiment. The water enters from the bottom of the tank and flows out at the side nozzles. Five types of vessels with different diameters (d_V), 0.38m, 0.48m, 0.68m, 0.78m, and 1.0m were prepared. Also five types of inlet nozzles with different diameters (d_N), 0.038m, 0.048m, 0.058m, 0.078m, and 0.1m were prepared. Mean water level (H) was varied for four cases, 0.87m, 1.07m, 1.27m, and 1.47m from the inlet nozzle. Four outlet nozzles were located at a 0.74m elevation from the bottom with a 90 degree, whose diameter was 0.046m. The range of the flow rate was 1×10^{-3}~15×10^{-3} m^3/sec in the experiment. The free surface fluctuation was measured by a wire level sensor at ten different locations. The calibrations of these were performed in a practical condition. Temperature of the water was controlled by a cooler to within 20±0.5℃.

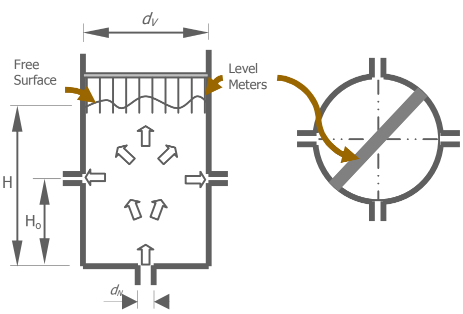

Figure 1 Test section for the free surface fluctuation experiment

3. Result and Discussion

The standard sampling deviation (σ) of a signal is defined as follows;

$$\sigma = \sqrt{\sum_i^N (H_i - H)^2 / (N-1)} \tag{1}$$

where N is the number of data. In the case of analyzing a free surface fluctuation, the Froude number (Fr) is the most adequate dimensionless number, which is developed as a new formulate related to the central velocity of a circular jet in this study as follows;

$$Fr = \sqrt{\frac{d_N}{H}}\sqrt{\frac{d_N}{\lambda}}\frac{V_N}{\sqrt{gH}} \tag{2}$$

where g is the gravitational constant, V_N is the velocity at an inlet nozzle, and λ is a length scale.

The fluctuation amplitude is linearly proportional to the square of the Froude number according to a parameter study. In order to obtain the geometrical effect, the tendency of the fixed Froude numbers (Fr^2_{fix}) obtained by using an equal fluctuation amplitude is examined for each condition of a vessel diameter and a water level as shown in Fig. 2.

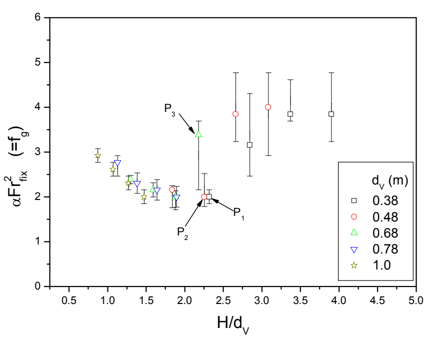

Figure 2 Scaled fixed Fr versus H/d_V

The Fr^2_{fix} with a scaling factor α is designated as a geometry factor f_g. When H/d_V is smaller than 2, f_g decreases with an increase of the value. This means that a surface fluctuation increases with an increase of H/d_V.

When H/d_V is greater than 2, f_g suddenly increases with an increase of the value, and the degree of a dispersion of the data also increases. After the transient region, the increment of f_g reduces when H/d_V is greater than about 2.6. Since stable data of P_1 appears after the transient data at P_2 and P_3, the value of H/d_V is not enough to properly separate the regions. In order to avoid this problem, a dimensionless number is introduced according to the analysis of the data. It is defined as follows;

$$H^* = \sqrt{\frac{1}{4}\frac{H}{d_V} + \frac{3}{4}\frac{H - H_o}{d_V}} \qquad (3)$$

where H_o is the elevation of the outlet nozzle. Figure 3 shows the distribution of f_g obtained from all of the experiments, where f_P is a factor which means the effect of the radial distance on a fluctuation.

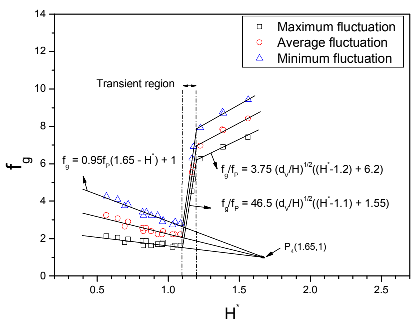

Figure 3 Geometry factor f_g versus H^* in the experiment

Transient region is well defined with H^*, and the transient region exists in the range of $1.1<H^*<1.2$. In the steady state region the lines of the three inclinations of f_g come together at one point which is considered as an ideal critical value. Figures 4 and 5 show the distributions of the average standard deviation when $H^*<1.1$ and $H^*>1.2$, respectively. R^* is the ratio of the vessel radius to the radial distance from the center of the vessel.

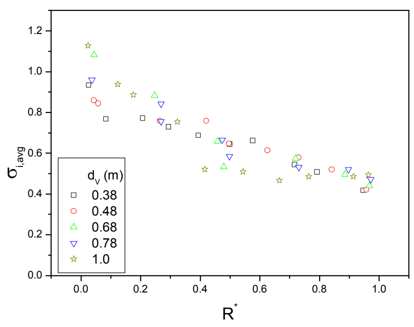

Figure 4 Distribution of σ in the steady state region ($H^*<1.1$)

The fluctuation decreases exponentially with an increase of the radial distance in the steady state region. In the unsteady state region the distribution of the fluctuation is nearly uniform, strictly speaking, the fluctuation at the position of $R^*=0.5$ is higher than that of the center.

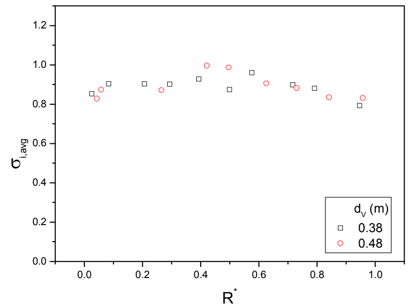

Figure 5 Distribution of σ in the unsteady state region ($H^*>1.2$)

A geometrical factor is developed by using the above analogy, and it is compared with the experimental geometry factor as shown in Fig. 6. The averaged data is fitted well by the calculated geometry factor to within ±10%, but the scattered data escapes from the error range.

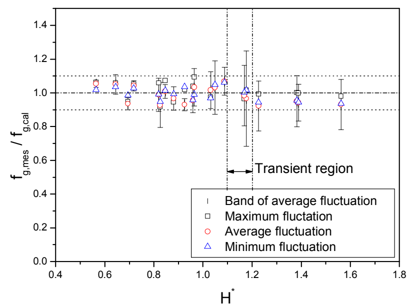

Figure 6 Comparison of the calculated f_g versus the measured f_g

4. Conclusion

A dimensionless number (H^*) concerning the ratio of a vessel diameter to a water level is introduced to present the effect of a geometry on a free surface fluctuation in a vessel. When the dimensionless number is smaller than 1.1, the surface fluctuation increases stably with an increase of the number. But when the number is greater than 1.1, the surface fluctuation suddenly decreases with an increase of the number and it becomes unstable. And then the decrement of the surface fluctuation reduces when the number is greater than 1.2.

In the stable region, the maximum fluctuation occurs at the center of a vessel and the fluctuation amplitude decays exponentially according to the radial direction. In the unstable region, the fluctuation is nearly uniform.

Acknowledgement

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