Vessel Size Effect on the Characteristic Frequency of the Free Surface Fluctuations

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1. Introduction

Studies of the free surface fluctuations is one of the important topics in a liquid metal nuclear reactor using sodium as the coolant that has a free surface in the upper plenum of the reactor vessel. The main reasons for the study on the free surface fluctuations can be summarized as: 1. to secure the structural integrity of a reactor vessel by considering the thermal stress on the vessel wall induced by the fluctuations of the free surface between the hot sodium and cold cover gas, 2. to prevent the cover gas entrainment at the free surface of the sodium because the entrained gas causes a change in the reactivity and also reduces the heat removal capability in the core.

Some experimental studies on the free surface fluctuations have been reported [1-5]. However, most of them focus on the gas entrainment phenomena and only a few works concern the basic characteristics of the free surface fluctuations. Since the thermal stress on the wall is strongly dependent on the amplitude and frequency of the free surface fluctuations, studies on the amplitudes and frequencies should receive more attention.

In Nam [5], empirical formulae on the amplitudes and frequencies with respect to the geometric and hydraulic parameters were introduced. It is an interesting result, but the experiment was performed within the parameter range near the onset point of the fluctuations. In the real reactor condition, larger sized fluctuations may exist and the formula needs to be modified.

In this study, we performed experiments on the free surface fluctuations, especially on larger sized fluctuations and made an analysis of the amplitudes and frequencies. The main focus of this paper is the effect of the vessel size on the characteristic frequencies. It is thought to be helpful for finding the scaling laws, for example, designing a scale-down experiment.

2. Experiment

The experimental apparatus consists of a closed water flow loop. The water is circulated by a pump through a regulator, flow meters, a cylindrical test section, and a storage tank. A schematic diagram of the test section is shown in Fig. 1. The water is injected into the test section at the bottom and flows out though 4 outlets on the wall. The diameter of the test section, mean water level, inlet nozzle diameter and flow rate are represented by D, H, d, and Q, respectively.

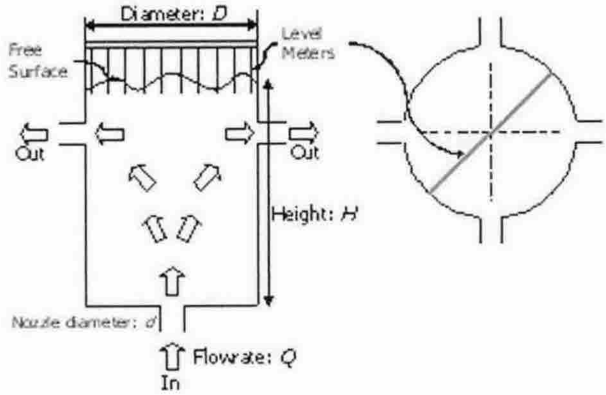

Figure 1. Test Section

The free surface fluctuations were measured by conductivity type level meters with different test section diameters, 380mm, 480mm, 680mm, 780mm, and 1000mm. The mean level was varied to 890mm, 1090mm, 1290mm, and 1490mm and the nozzle diameter was also varied to 38mm, 48mm, 58mm, 78mm, and 100mm. With fixed geometrical conditions (D, H, d), the flow rate was varied and the free surface fluctuations were recorded for several minutes at 10 different measuring positions including the near-wall-position and the center-position.

3. Analysis

To obtain the characteristic frequency, the Fourier transformation was used. The coefficients were obtained by averaging 13 results with the moving window technique. The window size was 4096 samples and the overlap between the windows was 75%. To prevent the aliasing and truncation error, the Hanning window was used. And a 0.1Hz high pass filter and 4Hz low pass filter were used to cut off the DC bias and high frequency noise. And the characteristic frequencies were calculated by averaging the Fourier coefficients.

4. Results and Discussions

To present the characteristic frequencies more generally, we introduced a normalized frequency, which is defined as follows:

$$f_{ndu} = \frac{f}{f_0} = \frac{f}{\sqrt{\frac{g}{2\pi D}}} = \sqrt{\frac{2\pi}{g}}\sqrt{D}f \qquad (1)$$

where, g is the gravity. This normalization is based on the free surface wave theory [6].

At a fixed mean water level and inlet nozzle diameter, the relation between the characteristic frequencies and the other parameters is shown in Fig. 2. In fig. 2, instead of the normalized frequency, $f\ D^{1/2}$ is used, which has the same meaning as the normalized frequency. The units are in a SI (mks) unit system.

In Fig. 2, the normalized frequencies are found to be correlated with the flow rate Q and the diameter D with a power of 3/2. At the other conditions, the relations are similar (not shown here).

The normalized frequency seems to be proportional to the abscissa $Q\ D^{3/2}$ at a small flow rate, but the slope is lowered at the large flow rate. The exact empirical relation is now being studied and will be found elsewhere.

5. Summary and Conclusions

In this paper, we performed experiments to study the characteristics of the free surface fluctuations. Especially, the vessel size effect on the frequencies of the free surface fluctuations was the main issue.

As for the results, we found that the normalized frequency $f\ D^{1/2}$ near wall is correlated with $Q\ D^{3/2}$. Similar relations could also be found at different conditions and different measuring positions.

The exact empirical relation is now being studied and will be found elsewhere. In addition, studies on the effect of the mean water level and nozzle diameter and the spatial frequency profiles are underway.

Ackowledgement

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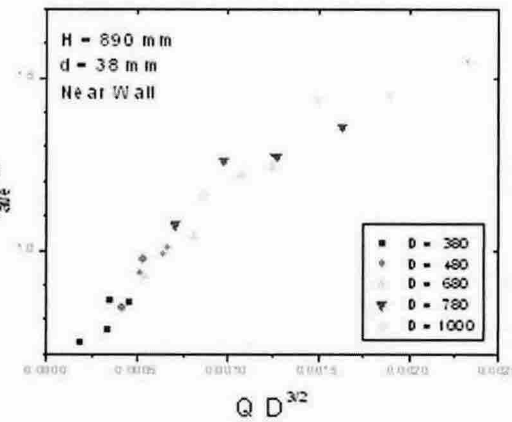

Figure 2. Effect of Test Section Size on the Characteristic Frequency