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Geometry Effect on the Frequency Generated by a Jet in a Vessel

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1. Introduction

In a fast 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, which are a thermal striping on a vessel wall and a gas entrainment at a free surface. An experimental study has been performed to investigate the frequency of a free surface fluctuation in a vessel. There are two dominant frequency regions which are generated by a standing wave and a jet. In this paper, the effect of the geometry on the frequency generated by a jet is described by a dimensionless number based on the central velocity of a jet.

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 $1\text{x}10^{-3}$~$15\text{x}10^{-3}\text{m}^3$/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.

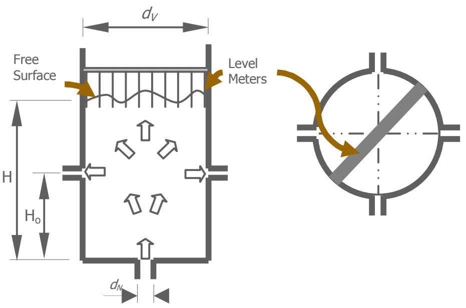

Figure 1 Test section for the free surface fluctuation experiment

3. Data treatment for a frequency analysis

The experimental data was obtained at 556 conditions in the experiment, besides the data was measured at ten different locations. The frequency characteristics of the data were extracted by the FFT method and statistically analyzed by a program in this study. Figure 2 shows the typical power spectral density for the FFT analysis of the data with a 200Hz sampling rate. A dominant frequency regularly appears below 7Hz, and appears irregularly in the range of 10~50Hz with a very low power spectral density. For this region, the data was collected with a 25Hz sampling rate.

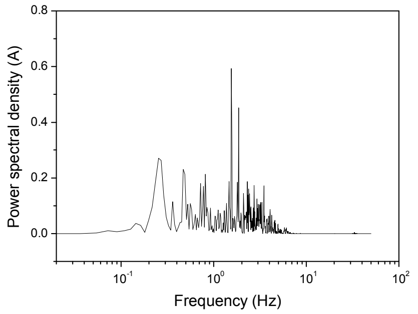

Figure 2 Typical power spectral density of the FFT analysis in the experiment

According to a detailed examination of the tendency of the data, the dominant frequency by a standing wave appears above about 0.75Hz. When the frequency is less than 0.75Hz, the frequency is independent of the vessel diameter, and the data is more scattered according to the condition of the jet. As shown in Fig. 2 and in most of the data, the power spectral density shows a skewed distribution below about 0.75Hz. An averaged frequency weighted by a power spectral density is used as the following formula;

$$f_{p,avg} = \frac{\sum f_j A_j^2}{\sum A_j^2} \tag{1}$$

where j is an index of a frequency in the region for each location p. Finally the averaged frequency is obtained by averaging the frequencies of ten locations.

4. Result and Discussion

Figure 3 shows the averaged frequency with respect to a dimensionless number which has a frequency dimension. The fluctuation of a free surface increases stably with an increase of the vessel diameter to water level ratio, when the ratio is greater than a certain value, the fluctuation becomes scattered and suddenly falls into the unstable region.

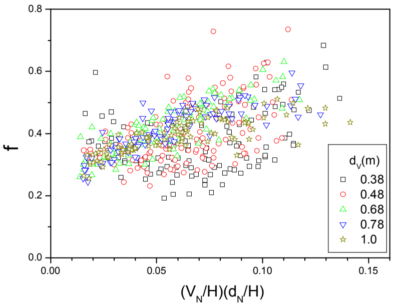

Figure 3 Frequency versus a value with a frequency dimension

A dimensionless value (H^*) which is enough to properly separate the regions is defined in the analysis as follows;

$$H^* = \sqrt{\frac{1}{4}\frac{H}{d_V} + \frac{3}{4}\frac{H - H_o}{d_V}} \tag{2}$$

When analyzing the frequency (f) of a free surface fluctuation generated by a jet, there are two adequate dimensionless numbers. One is the value $f(d_N^3 \rho / \tau)^{1/2}$, where τ is the surface tension. When it is applied to the present experimental data, it increases sharply with an increase of the nozzle diameter. The other is the Strouhal number ($St = fd_N/V_N$) defined based on the nozzle diameter and a velocity at that. Since the Strouhal number also sharply increases with an increase of the nozzle diameter, we assumed that a surface fluctuation is proportional to the central velocity (V_S) of a circular jet instead of the velocity at a nozzle. The central velocity of a circular jet is described as $V_S \sim d_N V_N / H$. Then a new Strouhal number based on the central velocity of a jet is defined such as $St = fH/V_N$. Since the period (T) of a fluctuation is the inverse of a frequency, a new dimensionless fluctuation period is defined by using the Strouhal number as follows;

$$T^* = \frac{TV_N}{H} \tag{3}$$

The dimensionless number has a constitution where a fluctuation period is divided by the time for a jet to reach a free surface. In the region for $H^* \le 1.1$, the dimensionless fluctuation period is related to the Froude number based on the inlet nozzle diameter, and it is not affected by the vessel diameter in that region. The relation can be described as follows;

$$T^* = 3.2\left(\frac{V_N}{\sqrt{gd_N}}\right)^{4/5}\left(\frac{d_N}{H}\right)^{1/5} \tag{4}$$

For another meaning of this equation, the frequency is proportional to $(d_N V_N)^{1/5}$, and is inversely proportional to $H^{4/5}$. In the region for $H^* > 1.1$, the fluctuation becomes unstable and the dimensionless period is proportional to the Froude number based on the vessel diameter, and the relation is given by;

$$T^* = 4.8\frac{V_N}{\sqrt{gd_V}} \tag{5}$$

where g is the gravitational constant. Figure 4 shows the comparison between the experimental data and the value calculated by Eqs. (4) and (5).

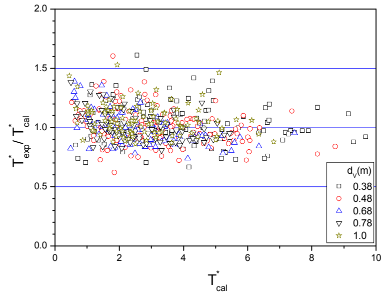

Figure 4 Comparison between the experimental data and the value calculated

5. Conclusion

A frequency is generated by a jet in a lower frequency region, but there are two kinds of phenomena according to its fluctuation stability. When the fluctuation is stable at $H^* \le 1.1$, the frequency increases with an increase of the velocity and the inlet nozzle diameter, but it decreases with an increase of the surface level. When the fluctuation is unstable at $H^* > 1.1$, the fluctuation becomes scattered and unstable, and it is nearly independent of the velocity. The frequency generated by a jet is well described by the dimensionless period and a certain Froude number according to the fluctuation stability.

Acknowledgement

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