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Frequency Characteristics of Thermal Fluctuations Induced by Triple Jets

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1. Introduction

Thermal fluctuations are very important because the thermal fluctuations affect the lifetime and stability of the reactor, especially in liquid metal reactors where the operation temperature is so high and the temperature difference between the hot region and cold region is large. This phenomenon is usually called a thermal stripping because cold and hot stripes appear at plumes and jets. There are a large amount of experimental studies about thermal stripping [1-6]. But the frequency characteristics of the thermal fluctuations have not been studied much.

In this paper, we study the thermal fluctuations induced by triple jets that simulate the flow at the exit of a fuel assembly where the temperature difference between the hot tubes and cold tubes is large (about 150℃). We performed experiments and analysis of the thermal fluctuations induced by triple jets, especially on the frequency characteristics.

2. Experiment

The experimental facility consists of a test section and two loops, a cold loop and a hot loop. As the working fluid, we used air instead of sodium because the previous studies[1,4] reported that the thermal mixing phenomena of air and sodium is similar for $Re > 2\times10^4$.

The air enters the test section through the nozzles as shown in Figure 1. The gaps between the nozzles are 52.5mm. The velocities of the cold/hot/cold jets are 10/10/10, 10/20/10, and 10/30/10m/s, respectively. The temperature of the hot jet is varied as 80℃ and 60℃ and the temperature of the cold jets is 40℃.

For the temperature measurement, we used cold wires made by TSI to detect the fast temperature fluctuations. The diameter of the cold wire is 1.27 ㎛ and the time constant is 0.17ms when the velocity is 30m/s. The sampling rate is 4 kHz. We measured the temperatures at 23 different horizontal positions and 12 different vertical positions, a total of 276 positions.

3. Analysis

To analysis the frequency characteristics, Fourier transformation was used. The coefficients were obtained by averaging 200 results with the moving window

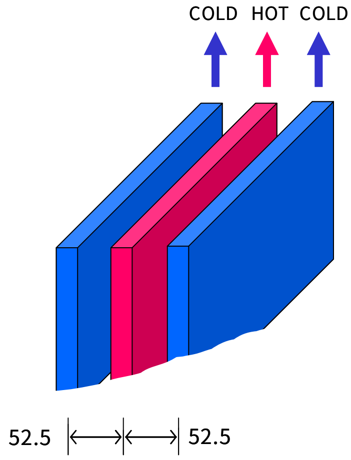

Figure 1. The shape of the triple jet nozzles

technique. The window size was 1024 samples and the overlap between the windows was 50%. To prevent the aliasing and truncation error, the Hanning window was implemented. And a 10Hz high pass filter and 2 kHz low pass filter were applied to cut off the DC bias and high frequency noise. The frequencies were calculated by averaging the Fourier coefficients. We introduce a ratio between the temperature signal and background noise. With the maximum ratio, we defined the dominant frequency of the temperature fluctuations and we also introduced the strength of the dominant frequency as the ratio.

4. Results and Discussions

In Figure 2, we plotted the dominant frequencies and their strengths with respect to the positions as contour plots. The spatial positions are normalized with the distance between the nozzles. We do not show the results of the $\Delta T = 20$ case in the paper but the results are similar to those of the $\Delta T = 40$ case shown in Fig. 2.

We can first see that high frequency fluctuations are activated near the nozzles and the high frequency fluctuations dampen out faster at the side nozzles ($x/D = 1$) and dampens out slower at the center ($x/D = 0$). As the velocity of the center jet increases, the high frequency fluctuations at the center last longer.

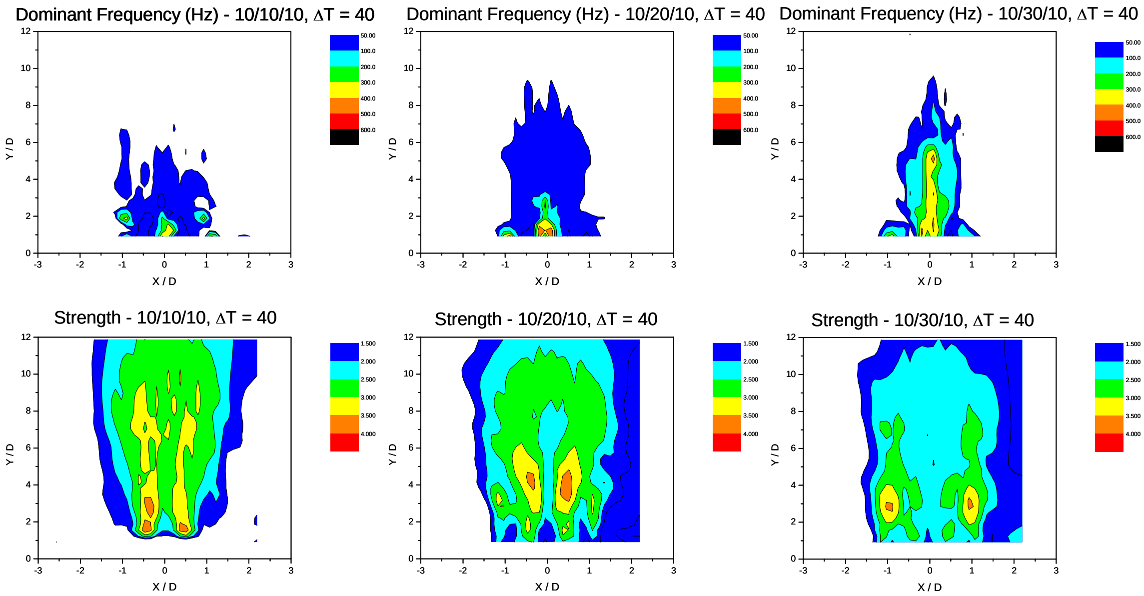

Figure 2. Dominant frequency and its strength

In the figure of strengths, we found that strong fluctuations are formed between the jets, near x/D = +0.5 and x/D = -0.5. As the center velocity increases (10/20/10), the strongest positions move out from the inlet nozzle, but when the center velocity grows more (10/30/10), the strength decreases overall.

Considering the two results above together, we can conclude an interesting result. The results for dominant frequencies and the results for the strengths are complementary. Between the strong positions, there are high frequency regions, and vice versa. Because the high strength means an existence of a stable structure, we can introduce a hypothesis that the stable structures which appear between the jets and high frequency fluctuations are formed between the stable structures. Comparing this hypothesis and the results of Tokuhiro [6], there is a possibility that the stable structure represents the thermal mixing structure.

5. Summary and Conclusions

In this paper, we performed experiments to study the characteristics of the thermal fluctuations induced by triple jets. Especially, the frequency characteristics of the thermal fluctuations are the main issues.

As for the results, we found that high frequency fluctuations appear near the nozzles and strong fluctuations appear between the nozzles. Comparing the results with previous results, we can introduce a hypothesis that stable thermal mixing structures are formed between jets and at the interfaces between the structures there is high frequency fluctuations. For the proof of the hypothesis, more careful investigations on the thermal structures including studies on velocity the profiles are required.

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