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# Experiments of Turbulent Thermal Mixing Phenomena Using Parallel Non-Isothermal Water Jets

**Y.K. Kim, J.M. Kim, Y.B. Lee, J.S. Hwang, and H.Y. Nam**
Korea Atomic Energy Research Institute

## ABSTRACT

Turbulent thermal mixing experiments by the injection of two parallel non-isothermal water jets have been performed. The turbulent velocities and fluctuations under the isothermal conditions have been measured using LDV system. The velocity vectors have been plotted in two dimensions from the data measured at $29 \times 16$ points. The thermal mixing experiments also have been conducted, where we used 45 K-type thermocouples with a sheath diameter of 0.020″ which were fixed with 5 mm distance in a line at a measured height. The measured heights were 5, 10, 20, 30, 40 cm from the upper end of rectangular nozzles. We measured the turbulent temperatures under the various flow velocity conditions with $12℃ \le \Delta T \le 40℃$. The sampling frequency and sampling time were about 420 Hz and 10 seconds, respectively. The measured results of equal velocity parallel jets were analyzed axially and radially to obtain the variation of temperature fluctuation.

## 1. Introduction

The clarification of thermal stripping phenomena, generated by the mixing of different temperature fluids, is important to evaluate thermal fatigue at the walls of immersed structures above the core regions in Advanced Liquid Metal Reactors(ALMRs). The characteristics of thermal stripping in ALMR have been generally estimated from model tests, using sodium as a working fluid, because of various uncertainties regarding the temperature fluctuation phenomena. It is, however, desirable to develop simple estimating methods, using alternative fluids, in order to consider the various experimental restrictions and also because of the expense involved in sodium tests.

The results of turbulent mixing experiments have been reported by Kasza et al.[1] in thermal mixing tee, Betts et al.[2] in PFR scale model, Wakamatsu et al.[3], Moriya et al.[4], and Ushijima et al.[5] in non-isothermal coaxial jets, comparing sodium tests with water or air tests.

In the present study, the turbulent velocities and fluctuations under the isothermal conditions have been measured using LDV system. And the thermal mixing experiment were conducted and analyzed in water parallel jets with the variation of the temperature difference between hot and cold water and with the variation of the mean velocity of water.

## 2. Experiments

We have fabricated a water thermo-hydraulic test facility for the turbulent thermal mixing experiment which mock up the Sodium Thermal Hydraulic Test Facility(THTF) developed by our team at KAERI[6]. The schematic diagram of the water facility is shown in Fig. 1. The water facility has two test sections which have same dimensions with the sodium loop as shown in Fig. 1. Test Section I is designed for the observation of the flow and temperature fluctuation phenomena. Test Section II is for the experiment of the local natural circulation.

Turbulent mixing experiments were performed using parallel water jets at Test Section I. The walls of test section were made with acryl for the penetration of laser beam. The parallel jets are formed in the rectangular nozzles with cross sections of 5mm × 50mm and then mixed in the test section tank. The top of nozzles are located 100mm above the bottom surface. The test section tank has two 1¼ inch outlet line pipes located 600mm above the bottom surface.

In the first step, the temperature was measured using K-type thermocouples with 0.020″ sheath diameter. The 45 thermocouples were located in the thermocouple comb at regular distances of 5 mm for the radial measurement of temperature. The thermocouple comb was moved up and down for the axial measurement. The turbulent velocities and fluctuations under the isothermal conditions have also been measured at 29 × 16 points using LDV system.

Table 1 shows the experimental conditions. Thermal mixing experiments were conducted under the equal velocity conditions. The ranges of the Reynolds number(Re) and the temperature differences between hot and cold water jets($\Delta T$) are $1.8 \times 10^4 \leq Re \leq 8.2 \times 10^4$ and $12℃ \leq \Delta T \leq 40℃$, respectively. The measured heights were 5, 10, 20, 30, 40 cm from the upper end of the nozzles. Therefore, we obtained 20 sets of LDV data and 100 sets of temperature fluctuation raw data at the above experimental conditions. The temperature and flow rate of the hot and cold water were kept constant with the power regulating system for the heater and cooler in the facility.

As a second step, we are now conducting the simultaneous measurement of velocity and temperature at the same point. It is the more detailed experiment than the present one. So we expect that it would produce more useful results.

## 3. Results and Discussion

### 3.1 Velocity Distribution and Average Temperature

In Fig. 2, the velocity vectors have been plotted in two dimensions from the data measured at 29×16 points using the LDV system. Two jets with different velocities can be discriminated near the end of nozzle. But the velocity distribution at 3cm above the nozzle end shows only one peak.

In the case of Q = 15 ℓ/min and $\Delta T$ = 40℃, the average temperature($T_{mean}$) distribution is shown in Fig. 3. The absolute maximum and minimum values of $T_{mean}$ decrease with increasing axial height. From the figure the $T_{mean}$ distribution seems to be flatten in the range of $h \geq 30$cm.

### 3.2 Temperature Fluctuation

The temperature fluctuations at the center line of the water parallel jets have been analyzed using the same method with sodium experiments[7]. Fig. 4 shows the variation of the temperature fluctuations in rms values($T_{rms}$) at Q = 5 ℓ/min and $\Delta T$ = 40℃. As shown in the figure, the maximum values of $T_{rms}$ appear at the center line.

In order to estimate the thermal fatigue damage due to thermal stripping, it is necessary to examine the characteristics of the peak amplitudes and periods of temperature fluctuation. Following the recipe of Moriya et al.[4], the wave-form characteristics are discussed in regard to the peak-to-peak amplitudes and periods using the zero-up-crossing method. When $\Delta T$ = 30℃ and 40℃, the peak amplitudes and periods of temperature fluctuation at the center line are calculated and analyzed.

Fig. 5a and Fig. 5b show the variation of the peak amplitudes of temperature fluctuation. Generally the peak amplitude increases at first and then decreases with increasing the axial height. The maximum values occur at h ~ 10cm and further precise measurements are required to determine the correlation of maximum positions and experimental conditions. The peak amplitude also increases with increasing $\Delta T$ and slightly with increasing the flow rate.

## 4. Conclusion

In the present study, velocity and temperature measurements have been performed and analyzed in non-isothermal water parallel jets. Two parallel jets with different velocities mix rapidly and the velocity distribution at 3 cm above the end of nozzle shows one peak.

The maximum temperature fluctuation in rms value occur at the center line as expected. The peak-to-peak amplitude at the center line has been analyzed using the zero-up-crossing method. The peak amplitude increases at first and then decreases with increasing the axial height. The maximum values occur at h ~ 10cm.

## References


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Table 1. Experimental Conditions

| Q(ℓ/min) | $T_{hot}$(℃). | $T_{cold}$(℃). | $\Delta T$(℃). | Re | h(cm) |
|---|---|---|---|---|---|
| 5 | 70 | 30 | 40 | $1.8\times10^4$ | 5 |
| 10 | 55 | 25 | 30 | $3.6\times10^4$ | 10 |
| 15 | 52 | 28 | 24 | $5.4\times10^4$ | 20 |
| 20 | 49 | 31 | 18 | $8.2\times10^4$ | 30 |
| | 46 | 34 | 12 | | 40 |

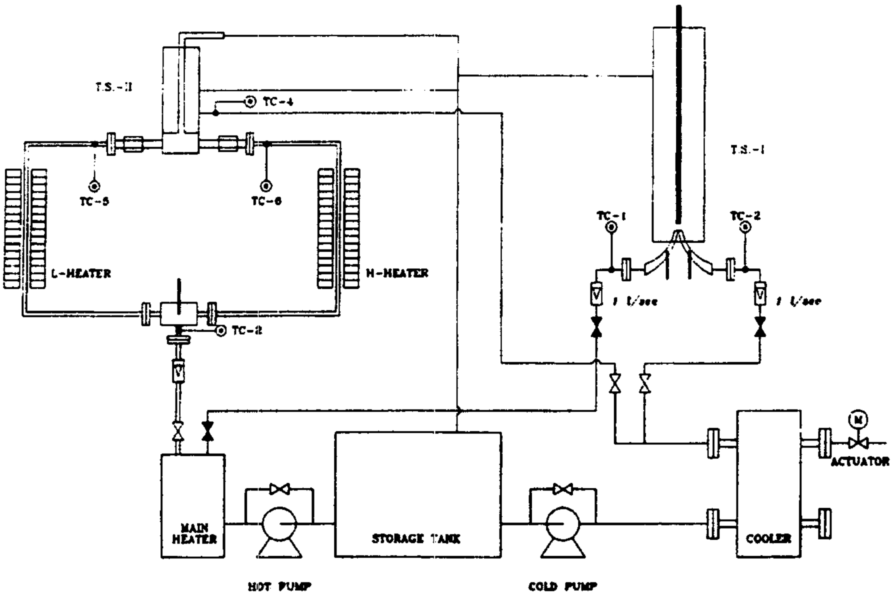


Fig. 1. Schematic Diagram of Water Test Facility.

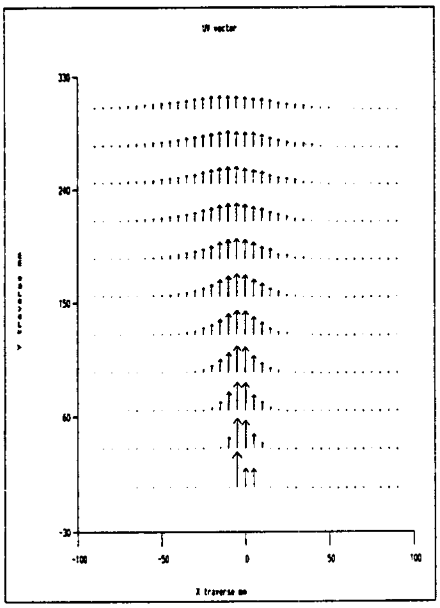

Fig. 2. Velocity Distributions as 2-D vector plot.

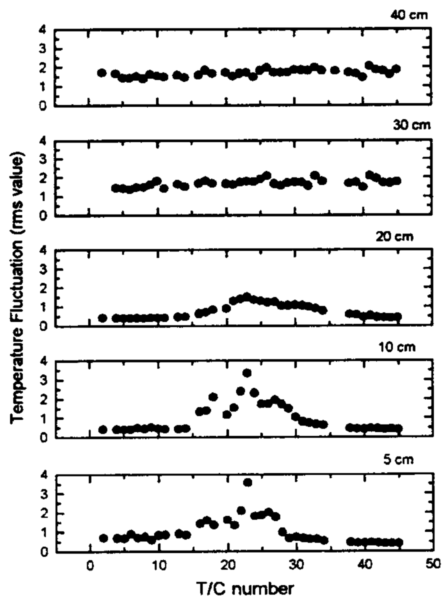


Fig. 4. Variations of Temperature Fluctuation

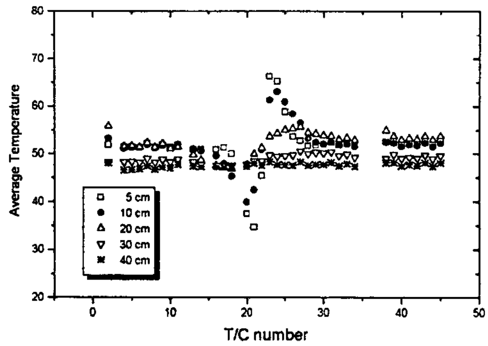


Fig. 3. Average Temperature Distribution.

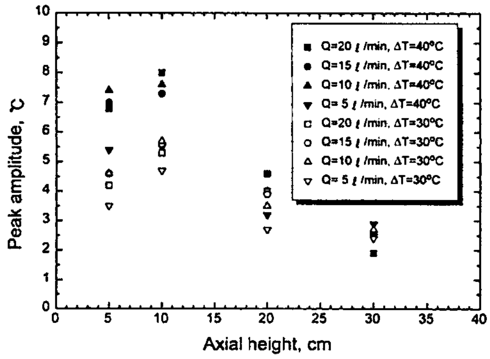


Fig. 5a. Variation of Peak Amplitude with Axial Height

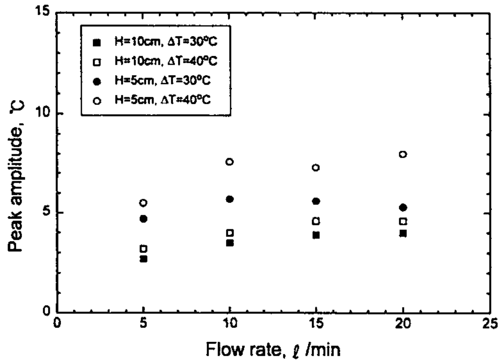


Fig. 5b. Variation of Peak Amplitude with Flow Rate.