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EXPERIMENTAL STUDY ON PENETRATION LENGTH IN A SMALL SIZE BRANCH PIPE IN A NUCLEAR POWER PLANT

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Abstract

Penetration phenomena in a closed branch pipe connected to a high velocity and high temperature flow in a main pipe were investigated experimentally. The penetration length has been studied with a pipe of 43mm in I.D. where the damages due to the thermal fatigue were reported. The purpose of this study is to expand the data on the penetration length in the smaller pipes. It was found that the penetration length and the period of fluctuation increased with increasing the pipe diameter and the main flow velocity. An empirical non-dimensional correlation on the penetration length in a uniform temperature condition for the pipe inner diameter from 8mm to 43mm was proposed.

1. Introduction

Many pipes branch off from a main pipe in industrial plants. Hot water penetrates into the branch pipe with a cavity flow induced by the main flow when temperature of liquid in the main pipe is higher than that in the branch pipe. The penetration causes thermal stratification by the temperature difference when the branch pipe end is closed. The pipe may be damaged due to the thermal fatigue when the thermal stratification layer fluctuates. The pipe damage was already reported in the nuclear power plants. Therefore, the design evaluation of the branch pipe length should be examined from the viewpoint of safety.

The cavity flow induces a spiral flow with long period fluctuations. The thermal stratification layer fluctuates and causes the wall temperature fluctuation at an elbow of the branch pipe [1]-[4]. The thermal stratified layer doesn't fluctuate when the penetration doesn’t reach to the bent of the branch pipe. The penetration length with a pipe of 43mm in I.D. where the damage was reported before and larger diameter ones has been studied [5] [6].

The purpose of this study is to expand the data on the penetration length with the smaller pipes from 8mm to 43mm in I.D.. The inner diameters of the test sections were the same as those used in the pipe system of nuclear power plants in Japan.

2. Experimental apparatus and methods

Figure 1 shows the main pipe of a rectangular duct of 60mm in width and 10mm in height. The I.D. of the main pipe in the real plants was around 600mm, much larger than that of the branch pipe. The main pipe was simulated by a rectangular channel since the curvature of the real main pipe was very small. The rectangular duct was connected to the circular pipe 86mm in I.D. of the loop and the branch pipe was connected with the entrance region of 600mm in length that was about 35 times as long as the hydraulic equivalent diameter so that the flow was assumed to be developed. Figure 2 shows the test section made from acrylic resin. Six pipes with different inner diameter were tested. The nominal sizes and the inner diameters were shown in Table 1.

The main flow velocity was changed from 4m/s to 15 m/s for each branch pipe. The main flow temperature was controlled by a heat exchanger in the loop. It was kept at room temperature for the uniform temperature conditions experiments when the main and the branch pipe temperature were the same. The temperature in the main pipe was kept around 65 ^{o}C and that in the branch pipe was kept at room temperature for the non-uniform temperature condition experiments. Particles of formed polystyrene were used for tracers of flow visualization and the images were recorded by a video camera.

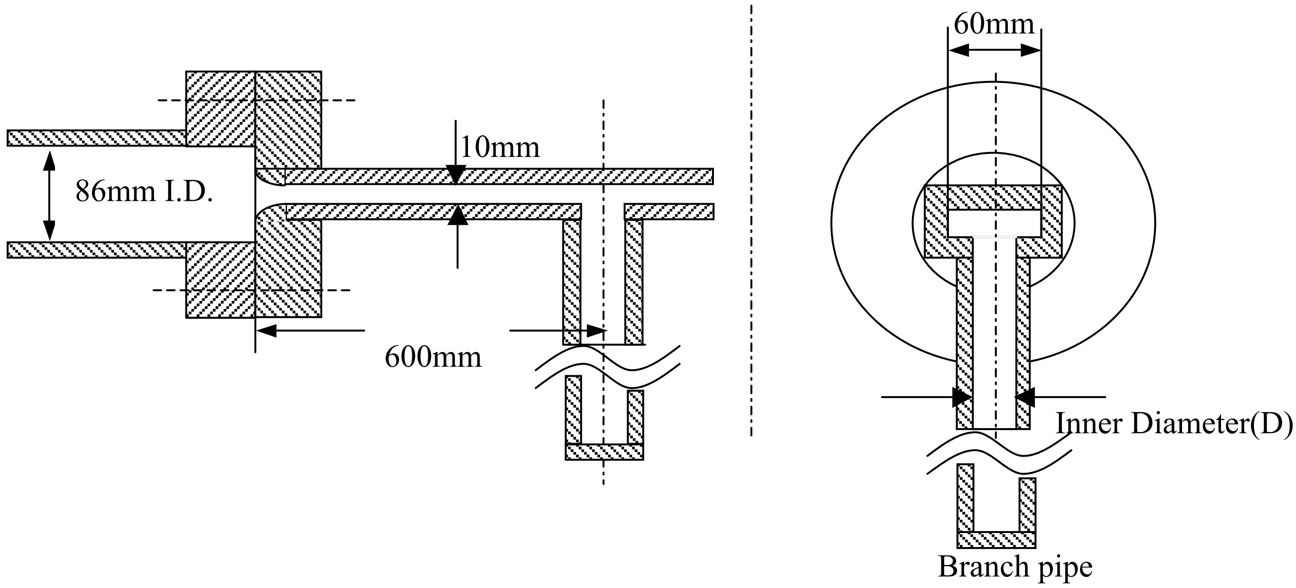
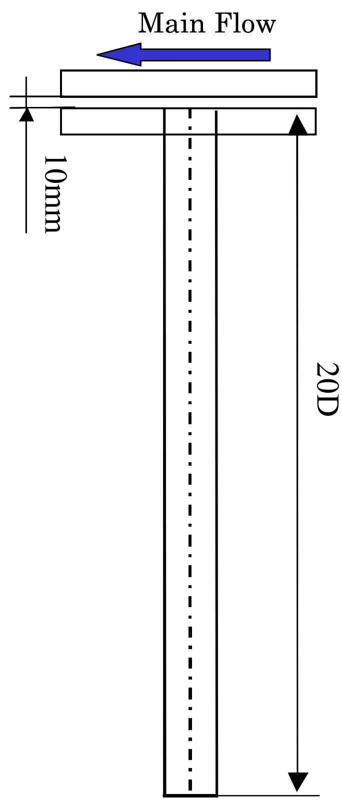


Fig.1 The shape of main pipe section



D=Inner Diameter

Fig.2 Test section

Table 1

Nominal Size	Inner Diameter [mm]
JIS 2B	43
JIS 3/2B	34
JIS 1B	21
JIS 3/4B	16
JIS 1/2B	12
JIS 1/4B	8

3. Experimental results and discussion

3.1 Visualization

The flow pattern was observed by the tracer method. Flow patterns observed in the straight branch pipe are illustrated in Figure 3. The flow patterns were divided into 3 Regions in all sizes of pipes for both uniform and non-uniform temperature experiments from the flow visualization by using the tracer method. A cavity flow was initiated and unsteady vortices were observed in Region 1. In Region 2, the flow was much disturbed and no typical flow pattern could be identified by the observation. A disturbed spiral flow near the wall and an upward flow in the center were observed in Region 3. Fluctuations with long periods of the spiral flow velocity were observed. The boundary between the Regions 2 and 3 was not so clear. The lengths from the main flow channel to the flow pattern boundaries were measured by L_1, L_2 and L_3 as shown in Figure 3, respectively. The spiral flow was fluctuated vertically. The penetration depth was defined by the maximum L_3, and its fluctuation width was indicated by ΔL_3.

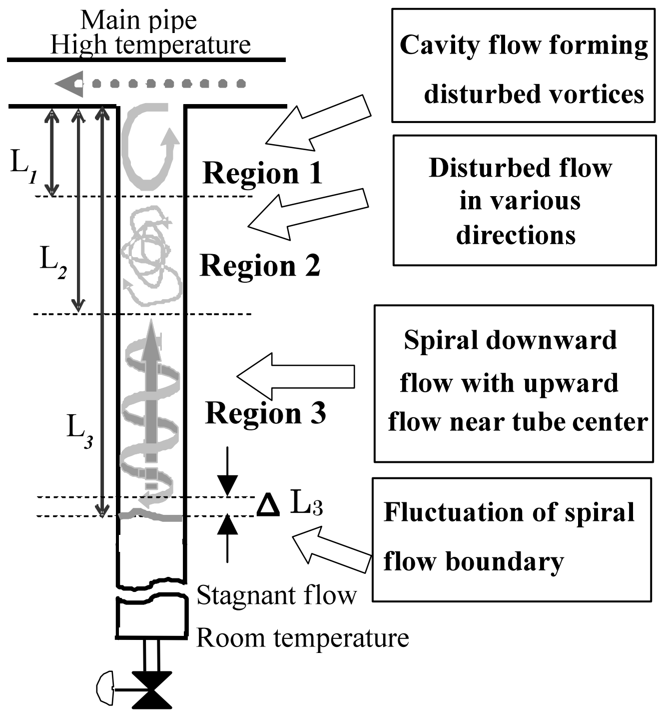


Fig. 3 Flow regime in a vertical branch pipe

3.2 Experimental results in uniform and non-uniform temperature conditions

Figures 4,5 and 6 show L_1/D, L_2/D and L_3/D against the main flow velocity, respectively in the uniform temperature conditions. It was shown that neither the pipe diameter nor the flow velocity of the main flow affects in the Region 1. The values of L_1/D were almost constant and about 3. The values of L/D were larger by increasing the main flow velocity and the pipe diameter for both L_2/D and L_3/D of the penetration length. It is estimated that the amount of kinetic energy transmission to the branch pipe increases with increasing of the I.D. of the pipe.

Figure 7 shows that the relationship between the periods of the fluctuation of the spiral flow velocity and the main flow velocity. The periods were from ten to several tens seconds. It was found that the period was longer when the main flow velocity was higher and the I.D. of the pipe was larger. It was estimated that the phenomena occurred because the L/D was larger with increasing the pipe diameter.

Figure 8 shows the relationship between the fluctuation width and the main flow velocity. It was found that the width in the pipes from 1/4B to 1B was larger for higher main flow velocity but the effects of the main flow velocity were small for the pipe of 2B and 3/2B. The values of $\Delta L_3/D$ were less than 2 and was small comparing to the penetration length. The values of $\Delta L_3/D$ increased from 1/4B to 1B and decreased from 1B to 2B with increasing the branch pipe I.D. as shown in Figure 9 where $\Delta L_3/D$ were plotted against the pipe diameter D.

Figures 10, 11 and 12 show L_1/D, L_2/D and L_3/D against the main flow velocity, respectively in the non-uniform temperature condition. Tendencies of the values of L/D, the period and the width in the non-uniform temperature condition were qualitatively similar to those in the uniform temperature conditions.

Figures 13 and 14 also show the period and width of the spiral fluctuation in the non-uniform temperature condition. The difference by the temperature condition was not seen in the length of Region 1 and L_1/D was about 3 in both conditions. The lengths of Region 2 and the penetration length for the uniform temperature conditions were a little deeper than those for non-uniform ones. It was estimated that the thermal stratified layer suppressed the penetration in the non-uniform conditions. Clear difference was not seen on the influence of the pipe diameter in the both conditions. The values of $\Delta L_3/D$ also increased with increasing the branch pipe I.D. from 1/4B to 1B and decreased with decreasing from 1B to 2B as sown in Figure15. The reason why such tendency was observed in both the uniform and the non-uniform temperature conditions will be examined in more detail. $\Delta L_3/D$ in the non-uniform temperature conditions were a little smaller than that in the uniform ones. It is estimated that the thermal stratification layer may suppress the fluctuation.

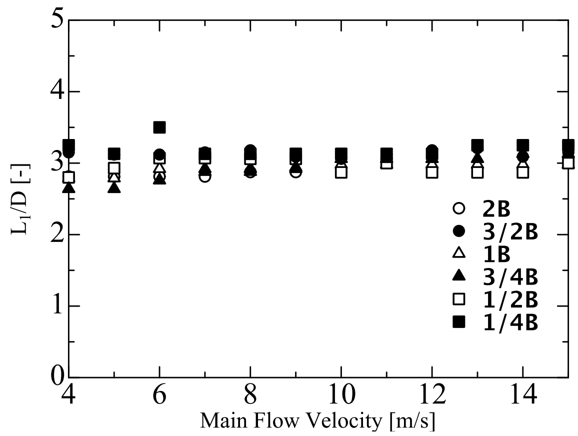


Fig.4 Relationship between L_1/D and main flow velocity (Uniform)

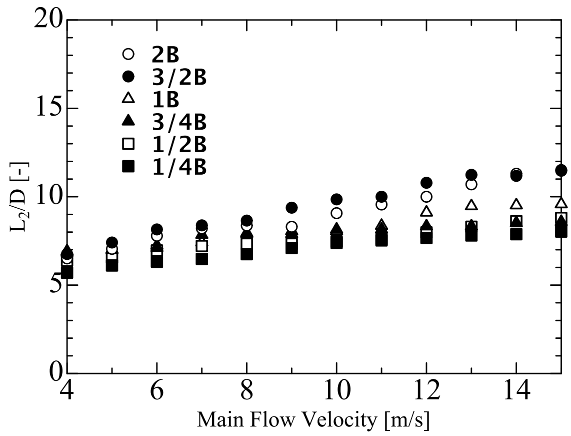


Fig.5 Relationship between L_2/D and main flow velocity (Uniform)

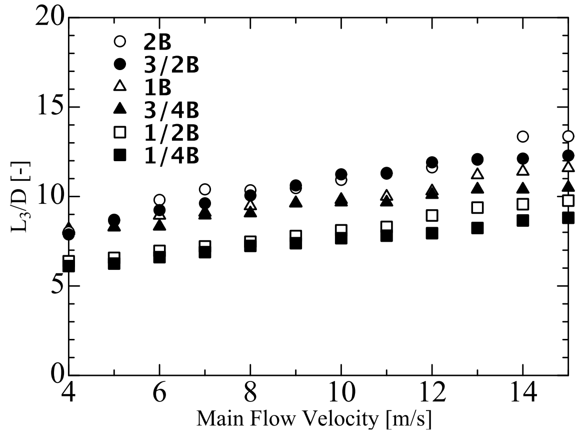


Fig.6 Relationship between L_3/D and main flow velocity (Uniform)

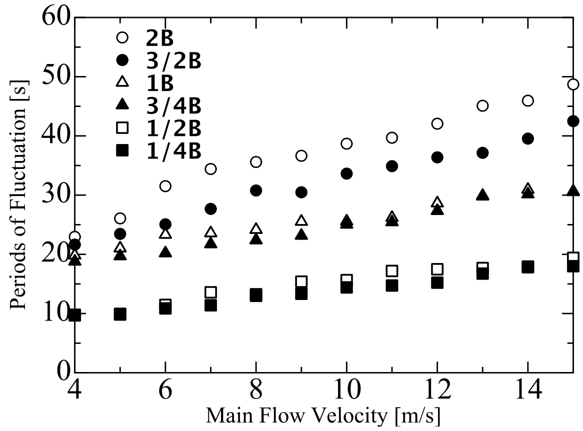


Fig.7 Relationship between period of fluctuation at Region3 and main flow velocity (Uniform)

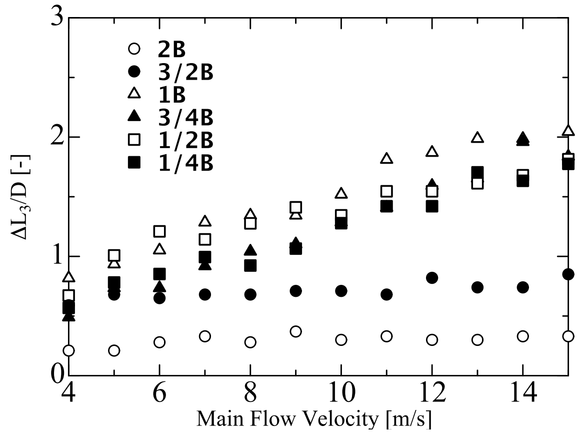


Fig.8 Relationship between fluctuation band and main flow velocity (Uniform)

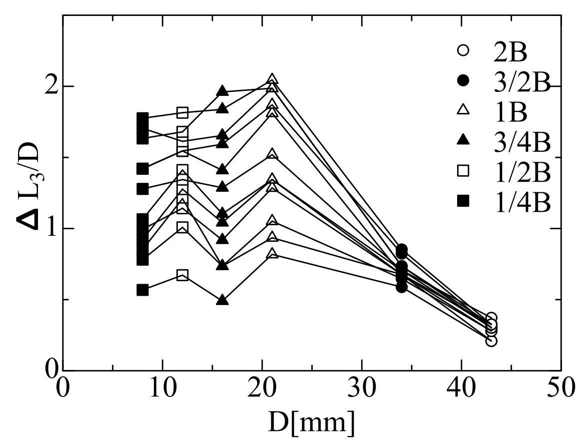


Fig.9 Relationship between fluctuation band and I.D. (Uniform)

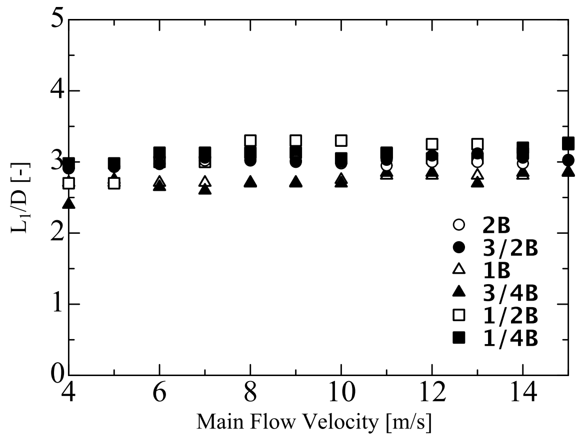


Fig.10 Relationship between L_1/D and main flow velocity (Non-uniform)

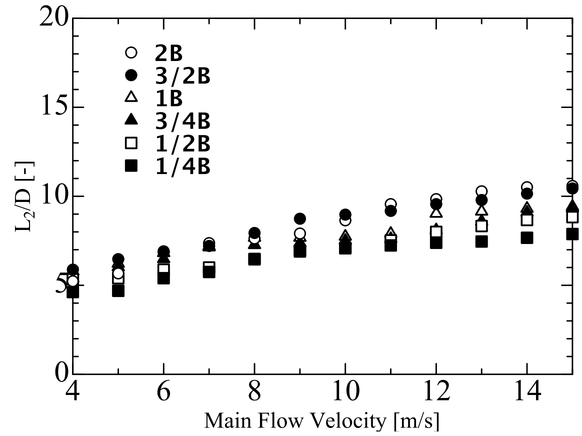


Fig.11 Relationship between L_2/D and main flow velocity (Non-uniform)

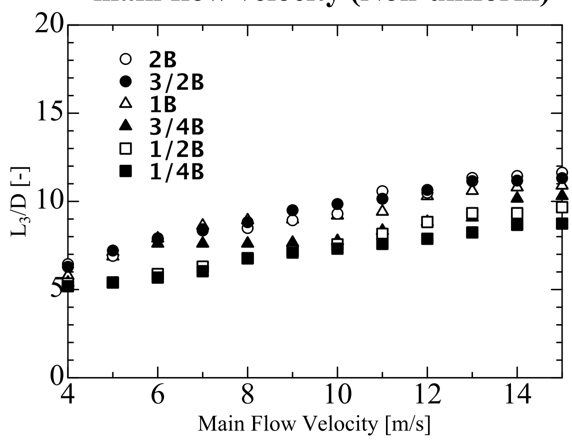


Fig.12 Relationship between L_3/D and main flow velocity (Non-uniform)

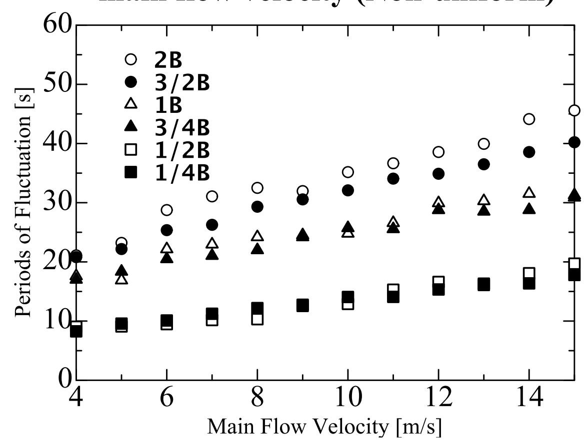


Fig.13 Relationship between period of fluctuation at Region3 and main flow velocity (Non-uniform)

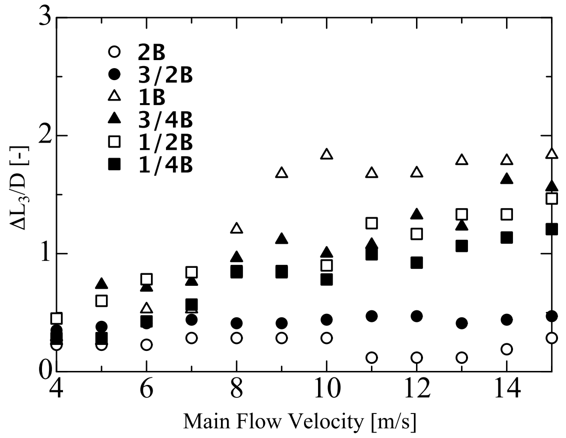


Fig.14 Relationship between fluctuation band and main flow velocity (Non-uniform)

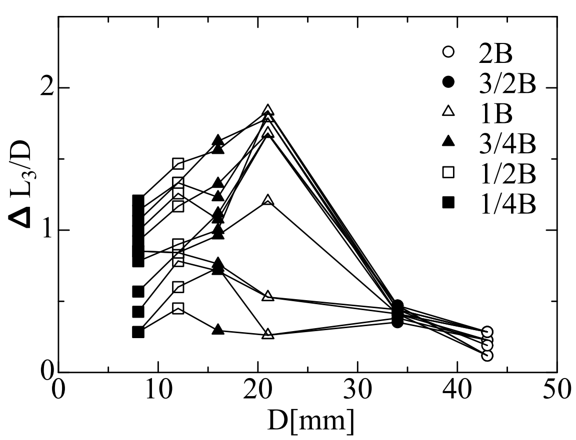


Fig.15 Relationship between fluctuation band and I.D. (Non-uniform)

3.3 Influence of pipe diameter on penetration length of main pipe

Figures 16 and 17 show the relationship between the non-dimensional penetration length to the Reynolds number of the main pipe,

$$\mathrm{Re} = \frac{U_m D}{\nu} \tag{3.1}$$

where U_m ,D and ν are the main flow velocity, the inner diameter and the dynamic viscosity, respectively.

It was found that the penetration lengths in the uniform temperature conditions were well correlated by the Reynolds number of the main pipe as shown in Figure 16 and non-dimensional correlation

$$\frac{L_3}{D} = 0.21\mathrm{Re}^{0.31} \tag{3.2}$$

was obtained, which was applied to the pipe diameter from 8mm to 43mm. The penetration lengths in each pipe diameter in the non-uniform temperature conditions were smaller than the values predicted by the Eq. (3.2) as shown in Figure 17. The influence of the pipe diameter on the values of L_3/D can be seen. It was shown that the buoyancy at the thermal stratified layer affects the penetration length and its affects could not be correlated only by Reynolds number. The other non-dimensional number is required for the correlation in the non-uniform temperature condition.

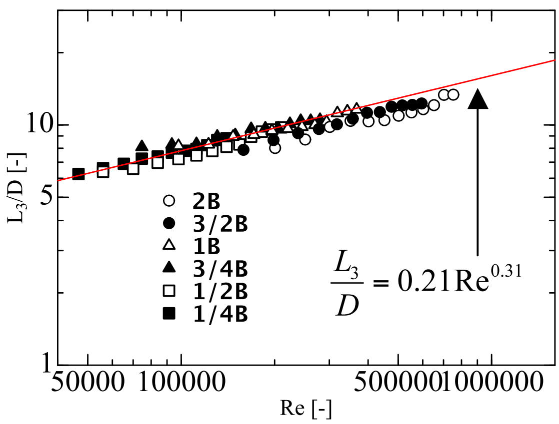


Fig.16 Relationship between L_3/D and Reynolds number (Uniform)

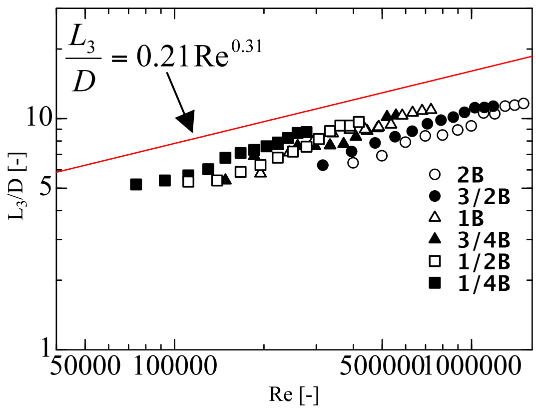


Fig.17 Relationship between L_3/D and Reynolds number (Non-uniform)

4. Conclusions

The flow pattern visualization in the branch pipe was carried out for the pipes from 1/4B to 2B.

1. The flow patterns in the branch pipe of the small diameter were similar to those in 2B pipe and classified it into three regions.
2. L/D of Region1 was about 3 in all conditions in the present experiment.
3. The period of fluctuation of the spiral flow increased with increasing the main flow velocity and the pipe diameter.
4. The values of ΔL_3/D increased from 1/4B to 1B and decreased from 1B to 2B with increasing the branch pipe I.D.
5. Non-dimensional correlation on the penetration length in uniform temperature condition was proposed.

5. References

[1] Nakamori, N., Suzuta, T., Ueno, T., Kasahara, J., Hanzawa, K., Oketani, K., and Ukai, O., Thermal Stratification in Branch Pipe, Proceedings of 30th National Heat Transfer Symposium, D252 (1993), pp.646-648.

[2] Kim, J. H., Roidt, R. M., and Deardorff, A. F., Thermal stratification and reactor piping integrity, Nuclear Engineering and Design, Vol.139, No.1 (1993), pp.83-95.

[3] Keller, J. D., Bilanin, A. J., Kaufman, A. E., and Carey, J., Thermal Cycling Screening and Evaluation Methodology and Application to Pressurized Water Reactor Branch Line Piping, Third International Conference Fatigue of Reactor Components (2004)

[4] Takenaka, N., Hosokawa, S., Hamatani, D., Hase, M., Onojima, D., Yamamoto, Y.,

Saito, A., Oumaya, T., Nakamura, A., and Miyoshi, K., Experimental Study On Temperature Fluctuation Phenomena in a Closed Branch Pipe Connecting to High Velocity and High Temperature Flow in a Main Pipe, Proc.14th Int. Heat Transfer Conf., IHTC14-23190.

[5] Tanimoto, K., Shiraishi, T., Suzuki, S., Oguma, K., Shiina, K., Fukuda, T., Minami, Y and Moriya, S., Study on Thermal Stratification by Cavity Flow in a Branch Pipe with a Closed End, Bult.of JSME Ser.B vol.70, No.02-1253 (2004), pp.176-183, in Japanese.

[6] Kondo, Y., Tanimoto, K., Shiraishi, T., Suzuki, S., Ogura, K., Shiina, K., Fukuda, T., Chigusa, N and Moriya, S., Study on Thermal Stratification by Cavity Flow in a Branch Pipe with a Closed End , Bult. of JSME Ser.B vol.70, No.03-0178 (2004),pp.184-191, in Japanese.