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Calibration of Helical Orifice with Rectangular Cross-Section

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1. Introduction

Pressure is suddenly changed when a phase change occurs in the tube of a once-through steam generator during the heat exchange. It makes the flow interrupted and supplied repeatedly. This irregular flow causes the performance degradation of a steam generator. This flow instability in the tube could be prevented by the orifice inserted in the tube inlet. In this paper the pressure drop of a helical orifice with a rectangular cross-section is estimated analytically and experimentally.

2. Orifice Design and Test Conditions

2.1 Orifice design

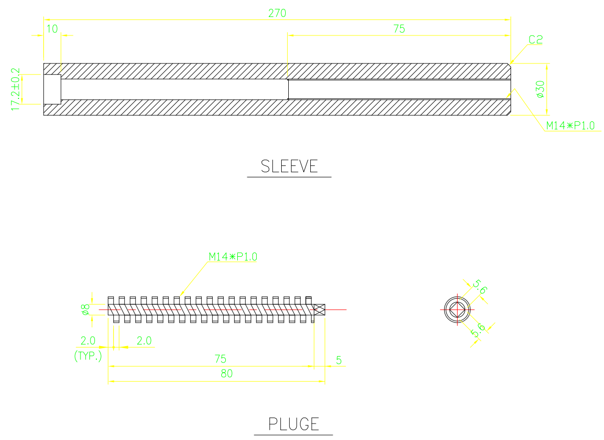

Fig. 1. Schematics of plug and sleeve of an orifice.

The helical orifice consists of a pair of plug and sleeve like a male and female screw. The pressure drop is caused by the wall friction along the helical path with the rectangular area in the plug. The length of the flow path is adjustable through the triangular screw in the outer surface of the plug and the inner surface of the sleeve. In this type orifice, the pressure drop decreases as the cross-sectional area increases, and it increases as the path length increases.

2.2 SKBK correlation for pressure drop estimation

The pressure drop in the helical tube can be estimated by the correlation [1] developed by SKBK Company for specific parameters like the geometry of the plug and sleeve as well as the property. It is as follows:

$$\Delta P = (\lambda \frac{L}{d} + \zeta) \times \frac{\rho W^2}{2} , \quad [Pa]$$

where,
$\lambda = 0.11\,(68/\,Re + \Delta/d)^{0.25}$: friction resistance factor
d : hydraulic diameter of orifice path
Δ : orifice wall roughness
$\zeta = 0.1 * L/\pi D$: correction factor to consider flow twisting (based on experimental data)
D : average axial diameter of plug

2.3 Test Condition

In this study the target pressure drop is 637 kPa for a specific mass flow rate of 0.06 kg/s under the atmospheric pressure of 1 bar and the normal temperature of 20°C. The calibration is conducted to determine the path length when the differential pressure is equivalent to the target pressure drop.

3. Calibration Results

3.1 Test Facility

In order to control the flowrate constantly, the pump with an inverter were installed in a single pipe line. Mass flow could be controlled by a mass flow meter and a pump inverter. Pressure drop in the orifice is measured by a pressure transmitter. The test section layout is illustrated in Fig. 2.

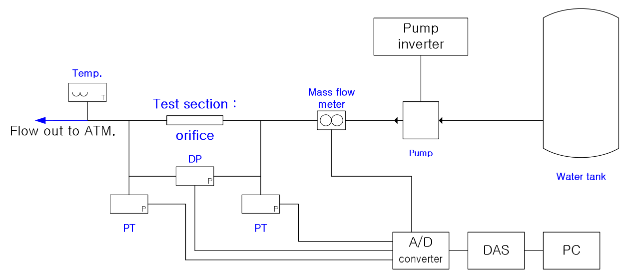

Fig. 2. Test section layout.

3.2 Pre-test

First of all, for the change of the orifice path length with two different areas the characteristics of the pressure drop were estimated by the SKBK correlation. The pressure drop was also measured with the test section and they were compared with the estimated value. For the orifice of the different area the pressure drop of the small area(2x2 mm^2) was greater than that of the other(2.3x2.3 mm^2) both SKBK correlation and experiment individually. For the orifice of the same area the flow path length increases as the differential pressure increases linearly. It is represented in Fig. 3. The analytic solution was greater than the experimental result for the equivalent orifice path length. The reason of their difference is caused by a machining tolerance of each orifice. That is It should be noted that the SKBK correlation was formulated by its own experimental measurement data.

3.3 Calibration

For the design verification, the calibration was carried out for all the orifices. The orifice depth was adjusted to provide the required mass flowrate, and the target pressure drop could be found also. The same measurement was repeated after a spot welding between the plug and the sleeve for sixty orifices. All of the pressure drops are represented in Fig. 4.

For the evaluation of this calibration results a bulk friction resistance coefficient (K_{bulk}) which divides a measured pressure drop by the square of the mass flow is used. The standard K_{bulk} is calculated by the target pressure drop and the required mass flow rate. This value is an index to determine the path length of the orifice. All of the K_{bulk} are located within the ±2% of the standard value.

For several orifices the pressure drops were additionally measured for increased the mass flow rates. Each curve of the pressure drop is proportional to the square of the mass flow rate and almost coincident each other as shown in Fig. 5. That is, individual differential pressure distributions are equivalent for a specific mass flow rate. These orifices will be established in the middle of a tube sheet. One side is connected with the common header as an inlet and the other side with individual tubes as an outlet. The flow characteristics in the tube depend on the differential pressure of individual orifice when the fluid in the common header flows out the individual tube through the orifice. Individual differential pressure distributions of the orifices are equivalent for a specific mass flow rate. It means that the flow rates of individual tubes are equivalently stable.

3. Conclusions

1. The pressure drop of a helical orifice was estimated both analytically and experimentally.
2. For the orifice with the machining tolerance several calibration tests were carried out.
3. The optimal orifice depth which satisfies the target pressure drop was found to provide the required mass flow rate.
4. All of the bulk friction resistance coefficients (K_{bulk}) were satisfied within the ±2% of the standard value.
5. Individual differential pressure distributions were equivalent for a specific mass flow rate.

REFERENCES

[1] SKBK, "Steam generator with helically coiled heat transfer area, Analytical Method (IZHER.500609.001)," SKBK internal report, 1984.

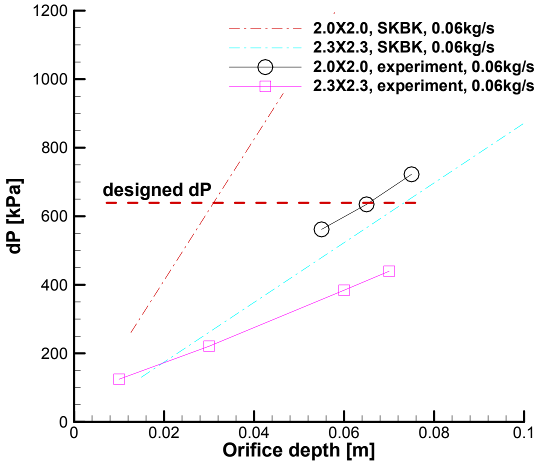

Fig. 3. Differential pressure versus the orifice depth.

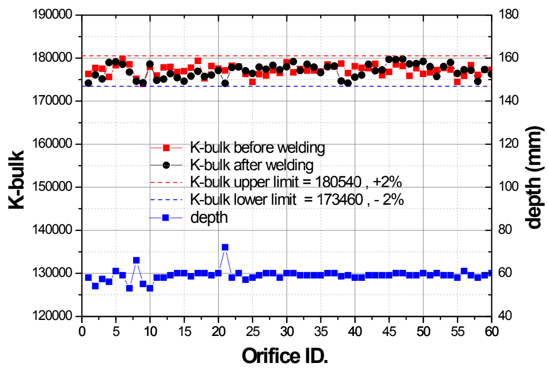

Fig. 4. K-bulk and orifice depth distribution for a required mass flow rate.

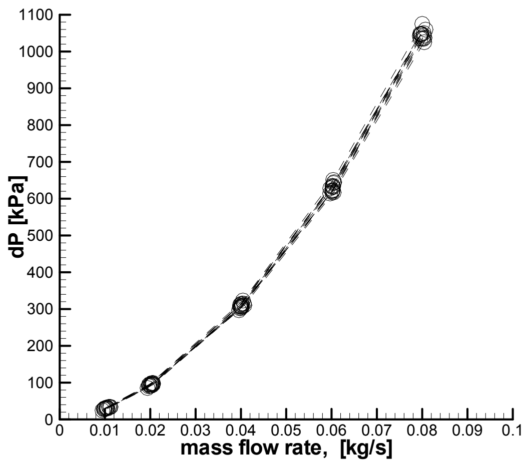

Fig. 5. Differential pressure versus mass flow rate.