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Effect of the Thermocouple Junction Type on Gas Temperature Measurement through Reduced Radiation Error

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1. Introduction

Gas temperature measurement has a larger bias than liquid temperature measurement because of the sources such as the sources shown in Fig. 1. The sources include the low heat transfer coefficient from gas flow, a non-uniform flow velocity and temperature profiles, large radiation effect, and thermal conduction through the thermocouple tube. In the case of liquid, there is no problem such as the above sources due to the large heat capacity, the high heat transfer coefficient and no radiation effect.

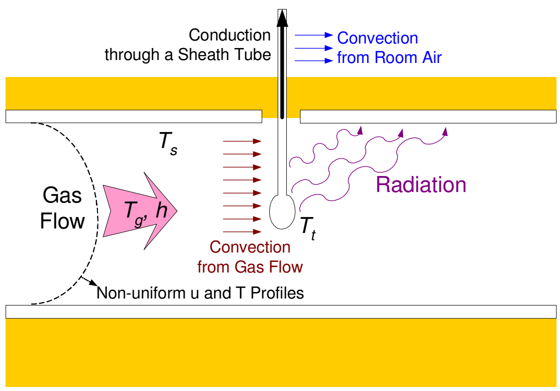

Fig. 1. Sources of Bias in Gas Temperature Measurement

Korea Atomic Energy Research Institute is developing the temperature measurement methodology to correct the radiation effect which is the main bias source for very high temperature gas [1]. The methodology is the usage of two thermocouples of unequal diameters called the Reduced Radiation Error (RRE). But the test results at the atmospheric pressure and the moderate temperature condition show that the conduction loss through the sheath tube is not negligible for the gas temperature measurement. In this study, the thermocouples with grounded junction were used to minimize the effects of the sheath conduction loss and the response time, and the test results were compared with the previous results [2] from thermocouples with grounded junction.

2. Methods and Results

2.1 Experimental Results

The tests in this paper were performed in the RRE test loop [2]. As the loop was always opened, the pressure of the gas flow was always 1.0 atm. The volumetric flow rate was maintained at 30 and 50 lpm by the Mass Flow Controller (MFC). The regulator decreased the pressure of the MFC inlet to about 2 bar. The working fluid was the high purity nitrogen. The heaters designed by Hong et al. [3] were used for heating the gas flow. Test section was a stainless steel pipe whose outer diameter and length were 1.5 inch and 3 m, respectively. The pipe was thermally insulated to minimize the temperature gradient at the cross section. The thermocouples were also thermally insulated to minimize the conduction loss through the thermocouple sheath tube. Two thermocouples with unequal diameters of 1/16 inch and 1/8 inch at the same measured position were installed to test the RRE effect at the outlet of the liner in Fig. 2. The flow-directional gap size between two thermocouples at the outlet of the liner is 1 cm to neglect the gas temperature difference between the measured positions of the thermocouples. The wall temperature is obtained from the average temperature at the top and bottom thermocouples in the thermal insulator in Fig. 2. The thermocouple close to the carbon composite heaters is an ungrounded junction thermocouple with diameter of 1/16 inch.

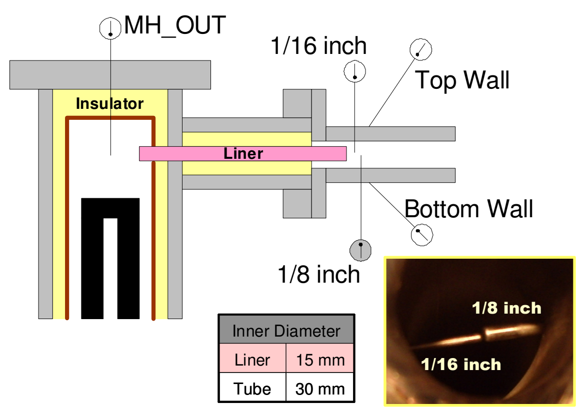

Fig. 2. Thermocouple Positions in the Experimental Loop

Generally, it is known that the time constant of the ungrounded junction thermocouple is about 2 times that of the grounded junction thermocouple [4]. So, the long time constants of the installed thermocouples require enough long observation times to be certain that the measured temperature. In this paper, there are two cases for the ungrounded junction thermocouples and the grounded junction thermocouples of the outlet of the liner to estimate the effect of the junction type for the possibly similar thermo-hydraulic conditions with the same mass flow rate and the heated power.

Table 2 summarizes the measured and calculated temperature values at the quasi-steady state in these tests. When it is assumed that the corrected temperature by RRE [1] is a true gas temperature, the effective radiation temperature of the surroundings can be obtained from the energy balance between the convective heat transfer and the radiation heat transfer on the sheath tube. However, the calculated temperature cannot be calculated from the energy balance on the sheath tube. It results from the overestimated gas temperature by RRE because of the energy dissipation by the conduction heat transfer in the sheath tube.

The grounded junction decreases the energy dissipation effect, so the measured temperatures from the grounded junction thermocouple are higher than those from the ungrounded junction thermocouples. But there is little effect on the temperature difference between the 1/16 inch and 1/8 inch thermocouples. The differences at the grounded junction and the ungrounded junction are 15.8℃ and 16.9℃, respectively.

In addition, radiation from heated surfaces results in overestimation of gas temperature through MH_OUT temperature.

Table 1. Temperature at Quasi-steady State

Case	Ungrounded	Grounded
Δ T	16.9 ℃	15.8
MH_OUT T	610.5 ℃	602.2 ℃
1/16 inch T	336.4 ℃	350.9 ℃
1/8 inch T	319.5 ℃	335.1 ℃
RRE Value	2.69	2.71
RRE corrected T	381.9 ℃	393.7 ℃
Measured Wall T	280.1 ℃	281.2 ℃
Calculated Wall T	-	-

2.2 CFD analysis

The computation fluid dynamics analysis was performed to show no temperature difference between the installed positions of 1/16 inch and 1/8 inch. The used code is ANSYS CFX 11.0. The boundary condition of the tube is an isothermal condition of 280℃, the working fluid is nitrogen at 1 atm, the inlet temperature is 400℃, and the mass flow rate is 9.46e-4 kg/s which is the experimental condition. Fig. 3 shows the velocity and temperature profiles in the similar condition of the experiments. The velocity profile shows that there is no difference between the velocities at two sheath ends. Also, the temperature profile shows that there is no difference between the temperatures at two sheath ends. We reconfirmed the overestimation of RRE by the energy dissipation at the sheath tube from the velocity and temperature profiles in Fig. 3.

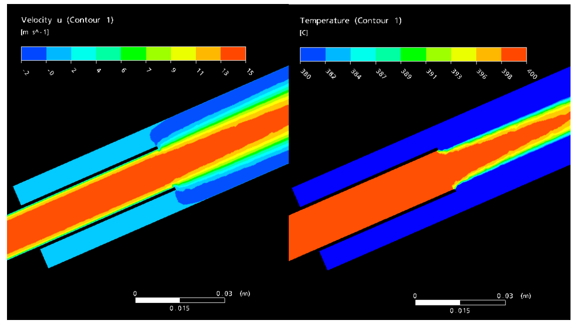

Fig. 3 Velocity and Temperature Profiles

3. Conclusion

The comparison with two cases shows that the energy dissipation effect is important to measure gas temperature, and the main effect is the source which overestimates the radiation-corrected temperature by RRE. Grounded junction must be used to decrease the energy dissipation effect.

But, it is expected that the energy dissipation effect will be confidently decreased in the case of a high pressure and high temperature gas experiment. The convective heat transfer coefficient on thermocouple is higher than that of this atmospheric experiment. To minimize the energy dissipation effect, 1/8 inch thermocouples will be replaced with 1 mm thermocouples.

ACKNOWLEDGMENTS

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