Temperature Effect on the Radiation-Corrective Gas Temperature Measurement

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1. Introduction

When a thermocouple is placed in a gas flow stream, there are two sources of the bias error in gas temperature measurement, including the radiation on the thermocouple and the conduction through the sheath tube as shown in Figure 1.

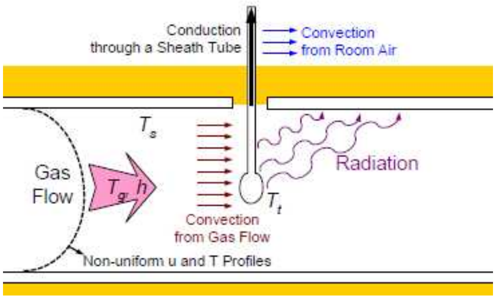

Figure 1 Sources of Error in Gas Temperature Measurement

Especially, the radiation error is inherent due to a relatively large radiation heat transfer from a thermocouple surface to its surroundings. Two thermocouples with unequal diameters are relatively simpler than the other radiation correction methods. Kim et al. [1, 2] has investigated the gas temperature measurement methodology and device to correct the radiation bias effect at a very high temperature condition. In previous experiments [3], the method had the good applicability on the heating chamber, which had enough immersion length to neglect the conduction effect through the sheath tube. In the case of the pipe, the conduction effect through the sheath tube resulted in the overestimation of the measured temperatures between two thermocouples.

In this study, the method was experimentally estimated at a higher gas temperature and larger mass flow rate than those of the previous experiments [3].

2. Reduced Radiation Error & Experimental Setup

The radiation from the thermocouple sheath tube to the surroundings is an inherent bias error for the gas temperature measurement. When it is assumed that the energy dissipation is negligible, the measure temperature is determined by the energy balance between convection and radiation on the sheath tube surface as the following equation.

$$h_t\left(T_g - T_t\right) = \varepsilon\sigma\left(T_t^4 - T_S^4\right) \qquad (1)$$

The estimation on the effective radiation surroundings temperature of a thermocouple sheath tube is necessary to predict the true gas temperature through radiation-correction. But, the surroundings temperature is not precisely defined due to the difficulty of the measurement of the inner surface temperature distribution and the calculation of the view factor. The reduced radiation error (RRE)[4] was defined by the ratio of the radiation error of the larger diameter thermocouple over the measured temperature difference between two unequal diameter thermocouples as the following equation.

$$\begin{aligned} RRE &= \frac{T_g - T_2}{T_1 - T_2} \\ &= \frac{\varepsilon\sigma\left(T_1 + T_2\right)\left(T_1^2 + T_2^2\right) + h_1}{h_1 - h_2} \end{aligned} \qquad (2)$$

where the subscripts 1 and 2 denote the small diameter and the large diameter, respectively. The convective heat transfer correlation was referenced from Whitaker [5]. It was the correlation for the sphere in the external convective flow.

In the pipe, a couple of the ground junction K-type thermocouples with unequal diameters were installed at the inlet and the outlet of the test sections as shown in Figure 2. The combination of 1/8 inch and 1/16 inch was selected for stable usage at the high temperature range above 800°C without thermocouple failure. The outer surface of the pipe and the sheath tube were never thermally insulated for the safety at high-pressure and high-temperature conditions.

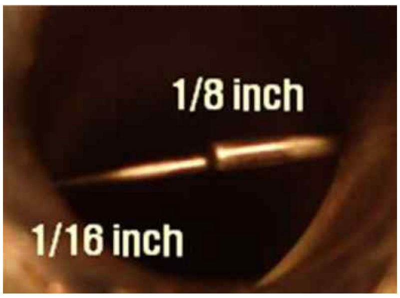

Figure 2 Two Thermocouples in the Pipe [3]

3. Results & Discussion

Figure 3 shows the temperature histories in the circular channel of the pipe. Since the inner wall of the pipe always had a lower temperature than the internal gas flow temperature, the measured temperatures from a 1/16 inch thermocouple is always higher than those from a 1/8 inch thermocouple.

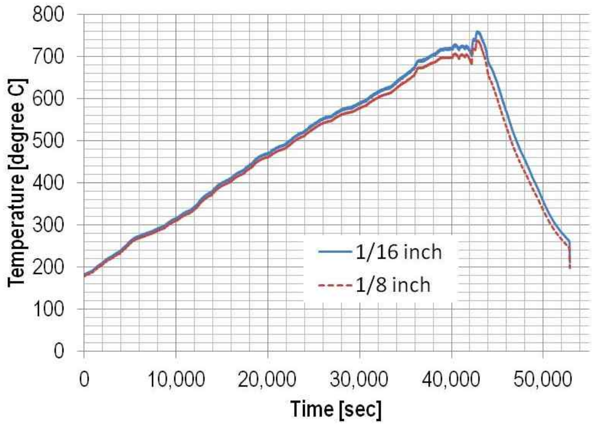

Figure 3 Measured Temperature Histories

Figure 4 presents the RRE parameter histories from the previous temperature histories. The radiation heat transfer coefficient between the thermocouples was increased with increasing the measured gas temperature through the thermocouples. Therefore, the RRE values at the high temperature region were higher than those at the low temperature region.

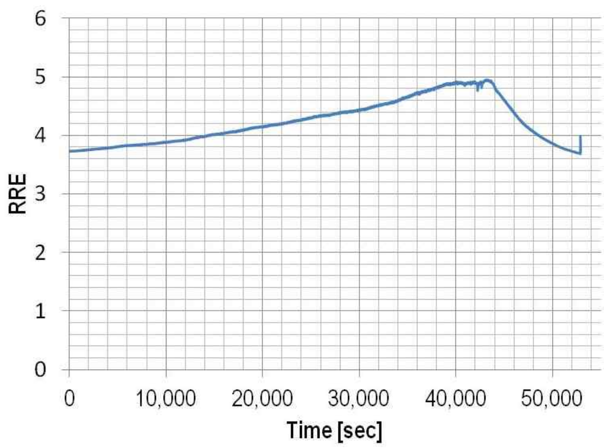

Figure 4 Measured Temperature Histories

Table 1 shows the experimental results of the measured temperatures, the calculated gas temperatures, and the calculated effective surrounding temperatures. When the radiation-corrected temperature from equation (2) was a true gas temperature, the effective radiation surroundings temperature could not calculated from equation (1). But the conduction loss effect at the large mass flow rate is smaller than that at the small mass flow rate. It means that the RRE method has better applicability at the high temperature region. Because the convective heat transfer coefficient and the radiation heat transfer coefficient are large enough to neglect the conduction effect through the sheath tubes.

Table 1 Summary of RRE Experimental Results

Mass V [kg/min]	$T_{1/16}$ [°C]	$T_{1/8}$ [°C]	RRE	T_g [°C]	$\varepsilon\sigma T_s^4$ [kW/m²]
0.76	160.8	146.5	3.61	198.0	-18.47
0.81	247.2	227.9	3.64	297.8	-28.92
0.76	360.2	328.1	3.63	444.7	-51.08
0.81	474.4	430.2	3.67	592.3	-79.33
0.71	552.1	493.6	3.69	709.6	-101.95
1.42	191.4	189.1	3.73	198.0	-2.92
1.51	288.1	284.7	3.85	297.8	-4.10
1.54	430.3	425.5	4.08	444.6	-3.18
1.50	567.3	559.1	4.38	592.3	-4.80
1.34	689.0	675.3	4.75	732.0	-7.59
1.40	750.3	731.7	4.90	810.2	-16.91

4. Conclusion and Future Works

Experimental results that the RRE method would have reasonable predictability for the gas temperature and the effective surrounding temperature. Large mass velocity resulted in the decrease of the sheath tube conduction effect on the gas temperature measurement. In the future, a detail analysis will be performed for the sensitivity studies on the effect of the flow and temperature distributions in the circular channel.

ACKNOWLEDGMENTS

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