Experimental Study on the RRE Method at High Pressure and High Temperature Environments

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1. Introduction

Gas temperature measurement has a larger bias than liquid temperature measurement due to the following factors; the low convective heat transfer coefficient from gas flow, a non uniform flow velocity and temperature profiles, large radiation effect, and thermal conduction through the thermocouple sheath tube.

The bias effect of the above factors on gas temperature measurement were ascertained in Kim et al [1-2]'s low pressure and low flow experiments. The difference between the temperature measurements from 1/16" and 1/8" thermocouples were about 15~30℃. Though the Reduced Radiation Error method [3] is suitable for the correction against radiation bias, the energy dissipation through the sheath tube resulted in the large uncertainty of the gas temperature measurement. In this study, the effect of the RRE method is estimated in a high pressure and high temperature gas environment.

2. Methods and Results

2.1 Reduced Radiation Error (RRE)

If it is assumed that the energy dissipation effect is negligible, the measured temperature through the thermocouple is determined from the energy balance between convection and radiation on the sheath tube surface.

Since, unequal diameters of two thermocouples result in the difference between their convective heat transfer coefficients, there is the measured temperature difference between two thermocouples. RRE method enables to correct the radiation error without the temperature measurement on the surroundings near the thermocouple as the following equation [3].

$$RRE = \frac{T_g - T_1}{T_1 - T_2} = \frac{h_{rad} + h_2}{h_1 - h_2} \qquad (1)$$

where the subscripts 1 & 2 mean the large diameter and the small diameter, respectively. The correlation for the convective heat transfer coefficient was referenced from Whitaker [4].

In the present, 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 [5].

2.2 Experimental Loop

Hong et al. [6] designed a small scale gas loop which is focused on the test of a ~10 kW capacity of process heat exchanger. In this study, the primary loop was operated to obtain the experimental condition at high pressure and high temperature. The primary loop composed of a gas bearing circulator, a pre-heater, a main heater, test section, a heat exchanger, a water cooling system, a nitrogen supply system, nitrogen purification system, and a flow control valve as shown in Figure 1.

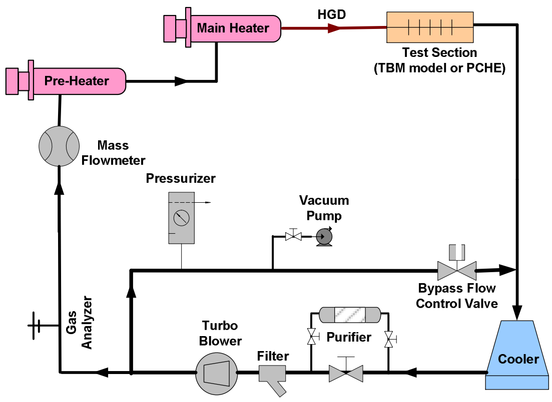
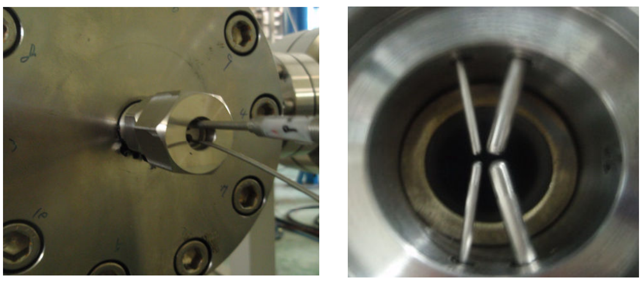


Fig. 1. Schematic Diagram of Experimental Loop

A couple of the K-type thermocouples with unequal diameters were installed at the outlet of heaters and the inlet and outlet of the test sections as shown in Figure 2. Especially, both ground and unground junction thermocouples were installed at the inlet and outlet of the test section. Though the combination of 1 mm and 1/16 inch was more reasonable for RRE, the combination of 1/16 inch and 1/8 inch was selected for stable usage at the high temperature above 800℃ without thermocouple failure.



(a) Outlet of heaters (b) Inlet & Outlet

Figure 2 Thermocouples Installed for RRE Tests

2.3 Gas Temperature Measurement near Heated Surfaces

In the previous tests [2], the measured outlet temperature of the main heater was much higher than the measured temperature at the inlet of test section. The difference between two temperatures was about 300 ℃. The flow condition is 50 lpm at the atmosphere. So, the mass flux is enough low for the flow regime to be laminar.

These results showed the overestimation of gas temperature by the radiation heat transfer from the heated surfaces. So, two thermocouples were installed at the outlet of the heaters to estimate RRE effect on the gas temperature measurement near the heated surface.

Table I summaries the experimental results near the heated surfaces in this study. The measured temperature from 1/16 inch thermocouple was always higher than that from 1/8 inch thermocouple, because the effective surrounding temperature is smaller than the gas temperature. In this study, the mass flow rate is twenty times large as the previous experiment. So, the convective heat transfer is more dominant than the radiation heat transfer between the surface of the heaters and the surface of the liner.

Table I Measured and Calculated Temperatures at the Outlet of the Heaters [℃]

	Pre-Heater	Main Heater
1/16 inch TC	442.1	516.8
1/8 inch TC	438.7	505.9
Gas T through RRE	453.1	555.8
Effective Surrounding T	430.0	480.0

2.4 Gas Temperature Measurement at Inlet and Outlet of the Test Section

When the thermocouple is installed in the narrow flow channel, the temperature indicated by thermocouple is different from the true gas temperature due to not only the radiation effect but also the conduction heat loss to the room air at the high temperature gas. Table II summarizes the experimental results on the measured temperatures in the narrow flow channel. In the previous tests [2], the thermal insulation around the sheath tube decreases the temperature difference between 1/16 inch and 1/8 inch thermocouples from 40℃ to 16℃. Since the mass flow rates in these tests are larger than those in the previous tests [2], the conduction effect through the sheath tube is weakened by the large heat transfer coefficient and the relatively flattened radial temperature profile. At the similar temperature condition, the temperature differences between two thermocouples are smaller than those in the previous experiments [2]. Though high mass flow rate weaken the conduction effect, the reasonable wall temperature couldn't be calculated due to the sheath tube without insulation.

Table II Measured and Calculated Temperatures at the test sections[℃]

Case	1	2	3	4
Flow Rate [kg/min]	0.020	0.639	0.639	0.920
1/8 inch TC	170.3	204.8	206.0	224.6
1/16 inch TC	210.7	212.7	208.9	229.4
Gas T through RRE	305.7	234.5	216.6	242.8

1: insulation, ground-junction thermocouple [2]
2: insulation, unground-junction thermocouple
3: insulation, ground-junction thermocouple
4: no insulation, ground-junction thermocouple

3. Conclusions

These experimental results showed the applicability to the gas temperature measurement in the high temperature and high pressure gas condition. When the thermocouple was installed in the heater, the thermocouple had enough immersed length to neglect the conduction effect. Also, large mass flow rate weakened the sheath conduction effect. In the future, we will experimentally estimate the RRE effect at the very high temperature gas and the high mass flow rate. The experimental data will give us more reliable data for RRE application.

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