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Study on Non-Contact Surface Temperature Measurement Using Pyrometer in Cone Calorimeter

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Abstract: The surface temperature of the specimen was measured with thermocouple and pyrometer in the cone calorimeter to analyze the pyrolysis for solid fuels. When the pyrometer was used to measure temperature, heat flux from the cone heater was found to have reflected and entered the pyrometer. The performed correction temperature results were very consistent with those obtained using the thermocouple. Non-contact temperature measurement can be considered a technique to reduce measurement errors attributable to the deformation of specimen.

Keywords: Cone calorimeter, pyrometer, surface temperature, thermocouple.

1 Introduction

With computers providing greater capabilities than ever, fire modeling enables accurate prediction of fire growth that matches actual fire growth. Although this technology for prediction has yet to reach its mature stage, the properties based on the fire model theory can be utilized properly such that they suit the purpose of research on fire [Croce (2001); Gritzo, Senseny, Xin, and Thomas (2005)]. The pyrolysis model in fire modeling is calculated independently of the inside or used as boundary condition. The most typical fire modeling software is the Fire Dynamics Simulator (FDS) unveiled by NIST in 2000. The advanced FDS version 4.07 is a fire simulation tool capable of numeric pyrolysis modeling and ignition/propagation representation [Lautenberger, Zhou, and Fernandez-Pello (2005); Lautenberger, McAllister, Rich, and Fernandez-Pello (2006, 2007)] Although different properties are required depending on the pyrolysis model, the extremely limited availability of properties that can be obtained from literature in relation to the materials of actual products and facilities makes it very difficult to enter appropriate property data into the fire simulator. To resolve those problems, the estimation of thermal prop-

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erty has been studied extensively by analyzing the inverse problem based on the results of laboratory-scale experiments of specimens (cone calorimeter test). The inverse problem is related to the characterization of an object's intrinsic properties based on the measurable physical quantities. The pyrolysis properties of solid fuels were predicted using the technique that optimizes from the surface temperature and mass loss rate of the measured specimen [Lautenberger (2007)]. Accurate surface temperature and mass loss rate are essential for ensuring the accurate prediction of properties. Only similar results could be obtained when load cell is used to measure the mass loss rate due to technological constraint for the load cell. Nonetheless, a variety of methods were attempted using the thermocouple(TC) when measuring the surface temperature [Lee (2006)]. When measuring the surface temperature of the specimen using the thermocouple, there are problems such as separation of the thermocouple from the specimen or difficulty in temperature measurement at the same location due to twisting and swelling of the specimen on the pre- and post-ignition.

Thus, this study sought to increase the accuracy of surface temperature measurement by devising a new method wherein the surface temperature is obtained using the pyrometer that allows non-contact measurement in the cone calorimeter. Thereafter, the surface temperature is calibrated based on the measured relative temperature.

2 Set-up of the test

2.1 Pyromet

In this study the IR detector of the non-contact measurement apparatus used PbSe and its detecting spectral range is $3.9\mu m$. The temperature measurement range was $20 \sim 700°C$, and the resolution was $0.1°C$. Fig. 1 shows the installed pyrometer; the measurement range was marked by perforating the hood. At this time, it is important to ensure that the hood or heater is not included in the measurement range. Since the infrared thermometer used in this study involves targeting laser light to ensure that the correct surface area is measured, whether each location is covered by the measurement range can be ascertained.

2.2 Analysis of pyrometer measurement error when the heater is operating

The same pyrometer was placed at another location to identify the cause of the measurement error that occurs when the heater is operating. Fig. 2 shows the installed pyrometer, thermocouple, and specimen. The mass measurement device was removed, and the pyrometer was installed right in front to ensure that the hood and radiation cone heater are not covered by the measurement range. Therefore, the surface temperature of the specimen and cone heater could be measured directly. Surface temperature was measured at the same location as the thermocouple.

In any event, the heat output of the radiation electric heater was $1.67[kW/m^2]$. Table 1 summarizes the results of measurements with the thermocouple and infrared thermometer for the respective measurement locations. Temperature distribution at the measurement points of the pyrometer was obtained by setting emissivity to 1.0. When the heater was operating, the surface temperature of the cone heater was measured with a smaller error compared to the specimen. Figs. 2 and 3 present the comparison of the measurement position and temperature distribution. The temperature measured with pyrometer was higher than that measured with the thermocouple when the surface temperature of the specimen was measured. In contrast, the temperature measured with the pyrometer was lower than that measured with the thermocouple when the surface temperature of the heater was measured. Since those results were obtained by setting emissivity to 1.0, it is logical from the standpoint of physics that the surface temperature measured with the pyrometer is lower than that measured with the thermocouple. The higher temperature in the specimen implies that the pyrometer is exposed to the additional radiation energy besides the energy radiated from the surface. This experiment showed that the radiation energy from the radiation cone heater reflected and entered the pyrometer when the radiation cone heater was operating.

Figure 1: Pyrometer install and measurement range of pyrometer at each position

Table 1: Temperature results of thermocouple and pyrometer each positions

Position		Specimen	Heater surface
Average temp. $[^{\circ}C]$	TC	45.396	108.72
	Pyrometer	72.859	95.296
Relative error[%]		60.50	-12.34

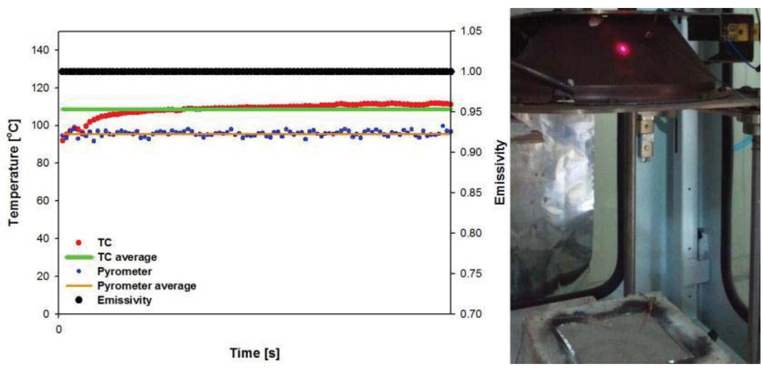


Figure 2: Temperature distributions at the heater surface on heater operating

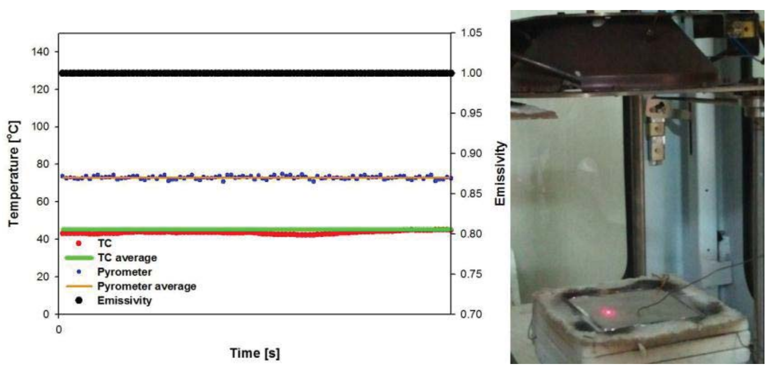


Figure 3: Temperature distributions of specimen surface on heater operating

2.3 *Correction of the Pyrometer*

The received radiance at the sensor positioned a certain distance from the object can be divided into 2 types as illustrated in Fig. 4. One is the self-emitted radiation of the specimen and the other is reflected radiance from emitted of cone heater.

Both can be expressed as described below.

$$L_{sensor} = L_{self,emitted} + L_{reflected} \tag{1}$$

Based on the radiation equilibrium and Kirchhoff's law, Equation (1) can be expressed as follows:

$$\varepsilon_{pyro}(\lambda)I_{\lambda b}(T_{pyro}) = \varepsilon_{surf}(\lambda)I_{\lambda b}(T_{surf}) + (1-\varepsilon_{surf})\varepsilon_{heater}(\lambda)I_{\lambda b}(T_{heater}) \tag{2}$$

Here, ε, $I_{\lambda b}$, and T denote the emissivity, blackbody radiant intensity, and absolute temperature, respectively. The subscripts $pyro$, $surf$, and $heat$ mean pyrometer, surface, and heater, respectively.

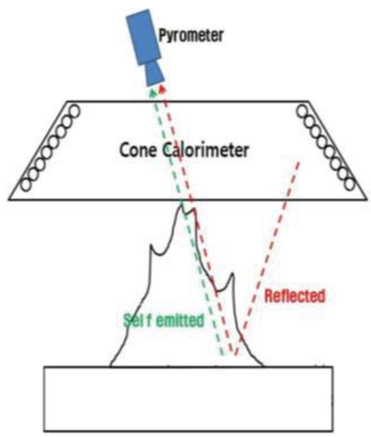
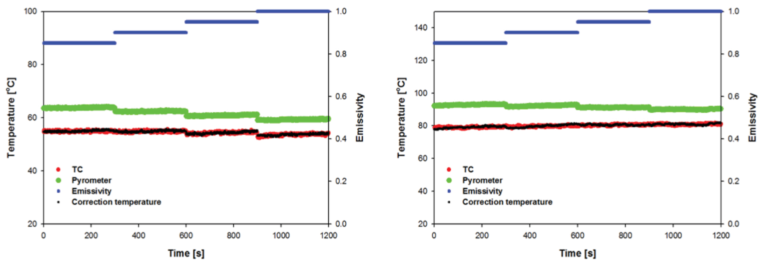


Figure 4: Radiance received by sensor

3 Result

When the heat flux of the radiation cone heater was $0.5576[kW/m^2]$ and $0.9551[kW/m^2]$, the surface temperature was measured with the pyrometer and TC for steady state. The pyrometer was corrected according to Equation (2), and the temperature distribution for various emissivities that can be set in the pyrometer was compared with the temperature measured with the thermocouple. Table 2 and 3 show the results when the heat flux of the radiation cone heater was $0.5576[kW/m^2]$ and $0.9551[kW/m^2]$. They also present relative measurement errors for the pre-correction temperature in relation to each emissivity, post-correction temperature measured with the thermocouple. Fig. 5 shows the temperature distribution at the measurement points of the thermocouple and pyrometer based on each emissivity.



(a) Heat flux=0.5576kW/m^2 (b) Heat flux=0.9551kW/m^2 .

Figure 5: Corrected results of the pyrometer

Table 2: Temperature results of thermocouple and pyrometer ($0.5576kW/m^2$)

Heat flux			$0.5576kW/m^2$			
Emissivity			0.85	0.9	0.95	1.0
Average temp. [°C]	TC		54.892	54.798	54.247	53.557
	Pyrometer	Pre-correction	63.694	62.311	60.789	59.220
		Post-correction	54.891	54.797	54.246	53.556

Table 3: Temperature results of thermocouple and pyrometer ($0.9551kW/m^2$)

Heat flux			$0.9551kW/m^2$			
Emissivity			0.85	0.9	0.95	1.0
Average temp. [°C]	TC		79.040	79.701	80.452	80.839
	Pyrometer	Pre-correction	92.770	92.189	91.1187	89.987
		Post-correction	79.038	79.696	80.451	80.838

4 Conclusion

The surface temperature of the specimen was measured with the pyrometer and TC in the cone calorimeter. Heat flux from the cone heater was found to have reflected and entered the pyrometer when the surface temperature of the specimen was measured with the pyrometer. When emissivity was set higher in relation to the two different heat fluxes, the temperature measured with the pyrometer was higher, which made sense from a theoretical standpoint. The post-correction results were very consistent with the temperature measured with the thermocouple. Therefore, non-contact surface temperature measurement is considered useful in correcting the temperature measurement errors attributable to the deformation of specimen in the cone calorimeter.

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