TEMPERATURE VISUALIZATION OF EXTENDED FLAME FROM OPENING USING INFRARED IMAGE PROCESSOR

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ABSTRACT

This paper illustrates the use on an infrared image processor as a new temperature measurement and display method of the heat flow formed by an extended flame from an opening using a reduced model. In order to visualize the temperature distribution of the hot air, a stainless steel net and a ceramic sheet were set in the path of the heat flow as subject for the infrared image processor during separate experiments. The visualized temperatures were compared with the corresponding temperatures obtained by using chromel-alumel thermocouples. Temperatures obtained by the infrared image processor were lower than the ones indicated by the thermocouples. The upper part of the thermal trajectory line (i.e. maximum temperature line along the flow) obtained by the visualized temperatures was located further from the vertical wall than the ones indicated by the thermocouples and Yokoi's data. This newly developed method gave a clear and wide enough temperature contour map for the experimental study of the flame extension.

1. Introduction

An extended flame from an opening during a fully developed fire is the principal source causing a fire to spread to the upper part of a building or neighboring building. In 1988, unfortunately a fire occurred in the First Interstate Bank Building in Los Angeles U.S.A. In this fire flames erupted^[1,2] from the opening (i.e., broken windows) causing the fire to progress rapidly to the upper story. The fire occurred on the 12th floor of the building and spread upward eventually reaching the 16th floor. This fire incident showed that the extended flames from openings played a fundamental role in the upward spread of the fire. Recently, the construction of buildings of which the walls are covered with glass are increasing. These buildings offer an excellent view and good looks, however, openings such as doors and windows made of glass will break when exposed to flames. Consequently, openings caused by the breaking and fall-

ing glass fracture the building's compartmentation designed. Therefore, it is necessary to study the extension behavior of the flame from an opening because it may accelerate the spread of the fire to upper stories.

Many researchers have studied the extended flame behavior from an opening. Yokoi^[3,4] and Bullen et al.^[5] showed temperature distributions along the trajectory (in other words, maximum temperature line along the heat flow) based on both dimensionless analysis and careful experimental data. Hasemi^[6] noted flame shapes (flame length and thickness) instead of temperature distribution represents the behavior of an extended flame from an opening. Sugawa et al.^[7,8] showed the similarity in respect to the characterized dimensionless extended flame length from an opening and the dimensionless heat release rate using a full scale fire test and a 1/15 reduced scale test. Sato^[9,10] simulated the heat flow from an opening along building walls. The flow in

a corridor or in a building driven by a model fire has been visualized and studied by many researchers^[11-14].

In fire modeling, buoyancy is the main driving force. Accordingly, the temperature visualization method is a very important application to advance the understanding of the heat flow behavior from a fire source. However, there are only a few reports based on the temperature visualization of the heat from a fire source. The objective of this technical paper is to describe a new temperature measurement technique developed for the understanding of the heat flow behavior which is formed by extended flame from an opening. We used an Infrared image processor to detect the subject which was placed in the heat flow field. The subject acted as an Infrared-ray emitter for the image processor. The K-type thermocouples (chromel-alumel thermocouples) on a rake were used and the which data obtained were compared with the results using the image processor.

2. Experiment

2-1. Model Compartment

Figure 1 shows the schematic view of the model

compartment. The model was constructed from an iron frame and 25mm thick ceramic panels. The size of the model was 1000mm(W)×1475mm(L) and 330mm(H). A vertical extended wall, 1000mm(W)×1630mm(H)×25mm(T), was set above the opening to represent a model of an upper story. An extended apparent ground level was attached to the model at its base to give the flow-boundary for the inflow of air from the atmosphere. The set-up model represented a ground level compartment. In the fire scenario the fire occurred at the base of the building with an opening facing the exterior or to an atrium space in a building.

Two kinds of opening, a full opening and a 1/3 opening, were used to study the effects of an opening shape on the extension behavior of the erupted flame. A pentroof and a fascia were also attached separately in some experiments. The length of the pentroof and the fascia employed were 5cm and 10cm, respectively.

2-2. Model Fire Source

A rectangular gas diffusion burner, 100mm(W)×880mm(L), was the model source. It was placed at the end wall in the compartment. The fuel used was pro-

Figure 1 Model compartment used for the experiments.

pane gas which was supplied through a regulator from tanks. Four different flow rates of fuel, 30, 40, 60 and 80 liters/min were used.

2-3. Method of Temperature Visualization

Figure 2 is a view of the subject used in the heat flow experiments and the image processor. The heated subject's thermal irradiance was recorded by the image processor. The intensity of the thermal irradiance of the subjects was in the range of $8-13\mu\text{m}$. This was translated to temperature and displayed in 16 color stages on a CRT.

Two kinds of subjects were used as the emitter of infrared-ray. One was a stainless steel net and the other was a ceramic sheet which were hung in the flow during separate experiments. The mesh size of the stainless steel net is $2\text{mm} \times 2\text{mm}$ and the covering the area of $1\text{m} \times 2\text{m}$. The ceramic sheet was $0.6\text{m} \times 1.2\text{m}$ and 2mm thick. It was composed of ceramic fiber of 60-70 wt.% consisting of silica, aluminum oxide, and zirconia, and an inorganic binder of 30-40 wt.%, with the specific gravity of approximately 0.25.

The infrared image processor had a Mercury-Cad-

mium-Tellurium (Hg-Cd-Te) detector system which was cooled and to keep at a constant reference temperature by using liquid nitrogen. The wave length band for the detector was $8-13\mu\text{m}$ in order to avoid the absorption of the infrared-ray by water vapor in the atmosphere. One image frame of the temperature was processed every 2 sec and recorded on a floppy disk.

The incomplete combustion of hydrocarbon gas (propane gas in this experiments) produced soot which built up on the surface of the stainless steel net and on the ceramic sheet. It was very important to define the emissivity of the subject to convert the intensity of the irradiance into temperature. It was impossible to measure the emissivities for all imaging units on the subject. Therefore, we employed the apparent emissivity of 0.996 (almost black body) for both the stainless steel net and the ceramic sheet because they were coated almost homogeneously with fresh soot.

Temperature imaged sections, in other words the setting location of the subject, were chosen at the center of the opening for both full opening and the 1/3 opening models. Temperatures were also measured along the vertical direction using 0.32mm K-type ther-

Figure 2 Schematic view of flow visualization

(a) without a pentroof or a fascia

(b) with a pentroof of 10cm

(c) with a fascia of 10cm

(d) without a pentroof or a fascia, 1/3 opening

Photo 1 Photograph given by the infrared image processor.

The propane gas was burnt at the rate of 60 liters/min.

mocouples for every 4cm spacing. The rake of thermocouples was moved horizontally to produce a wide temperature distribution and a temperature distribution contour map.

3. Results and Discussion

3-1. Visualized Temperature by Infrared Image Processor

(a) Full opening without a pentroof or a fascia

Photo 1-a shows the visualized temperatures obtained by the infrared image processor. The propane gas flow rate of 60 liters/min was fixed. In this case, the aspect ratio of the opening was 1/3 (33cm high $\times$ 90cm wide). It was clearly observed that the smoky heat flow from the opening adhered to the vertical wall. This behavior was also pointed out by Yokoi^[4] based on his

experimental data when the opening becomes wider.

(b) Full opening with a pentroof of 10cm

Photo 1-b shows the visualized temperature map when a 10cm pentroof was set at the opening. In this case, stand-off between the vertical wall and the upward flow was clearly observed. Therefore, more fire safety may be given to the upper story with a pentroof than without one at the same heat release rate. However, from this experiment the optimum length of the pentroof against the extended flame is not exactly clear.

(c) Full opening with a fascia of 10cm

Photo 1-c shows the visualized temperature contour map when the 10cm fascia was placed at the opening.

Figure 3 Contour map of temperature.

(a) based on the infrared image processor

(b) based on thermocouple

The flow rate of fuel is 30 liters/min and 1/3 opening.

Comparing this photo to the prior two photos, the region of high temperature ($T > 360^\circ\text{C}$) in this case is wider in photo 1-c. This is because the ambient fresh air which flowed into the compartment by convection was restricted by the fascia, therefore flammable gases could not burn in the heat zone of the compartment. Consequently, inflammable gases flowed over the fascia and mixed with the entrained ambient fresh air, quickly burning showing an extended flame.

(d) 1/3 Opening without a pentroof or a fascia

Photo 1-d shows the similar temperature pattern as that photo 1-a even though the opening was reduced to 1/3 (33cm high $\times$ 32cm wide). The area of the high temperature region ($T > 360^\circ\text{C}$) caused by the extended flame is wider than the one using a full opening in the cross section of C-C', i.e., the center of the opening. It is also clearly shown that the stand-off distance between the trajectory and the vertical wall is greater than the one resulting from using a full opening. In addition, the extended flow using a 1/3 opening is thicker than the one resulting from using a full opening,

therefore, it appears the flow can extend further due to the greater flow speed.

3-2. Comparison between Temperatures Obtained by IR Image Processor and by Thermocouples

Figure 3 shows the temperature contour maps detected by the infrared image processor and the thermocouples. The flow rate of the fuel used was 30 liters/min with 1/3 opening. Both results shown were obtained at the C-C' cross section. The region of high temperature ($T > 200^\circ\text{C}$) is not clear in the IR image processor contour map since the range of measurement of an infrared image processor was set at 0 to 200°C . Temperature, detected by the infrared image processor on whole, lower than those detected by thermocouples. This difference was caused by the thermocouples being heated by both convective hot air and the radiative heat generated from the flame. Whereas the temperature detected by the infrared image processor was depended only on the radiative heat from the stainless steel net. However, the similarity of the temperature distributions in both maps were considerably confined.

Figure 4 Relationship between temperature based on IR image processor and that based on thermocouples. The flow rate of 30 liters/min was used at a 1/3 opening.

Figure 4 shows a detailed comparison of temperatures measured at the same positions illustrated in the Figure 3. This figure shows that a linear relationship between the temperatures measured by both respective methods exists within the flow region till 33cm height from the floor. This means that if the correction factor for the temperature based on infrared image processor could be calculated then the measurement for the temperature distribution could be obtained.

3-3. The Distribution of Thermal Trajectory

Figure 5-(a) and 5-(b) show the trajectory of the hot gas flow from an opening using a flow rate of the fuel at 60 and 80 liters/min, respectively at full opening. The trajectory obtained by the infrared image processor tends to be a broader shape than that based on the thermocouples' or Yokoi's data. However, it should be noted that there is a similarity between the results obtained at 60 and 80 liters/min at full opening.

Figure 5 Trajectory of hot gas issued from an opening at (a) 60 liters/min and (b) 80 liters/min.

Figure 6-(a) Correlation of temperatures between the infrared image processor and the thermocouples. A stainless steel net and ceramic sheet was used subjects. The propane gas fuel of 30 and 40 litters/min were used at full opening.

30 litters/min

- stainless steel net range 40-200 °C
- ▲ stainless steel net range 120-360 °C
- ceramic sheet range 120-360 °C

Figure 6-(b) Correlation of temperature based on IR image processor against the ratio of IR and thermocouple temperature.

40 litters/min

- stainless steel net range 40-200 °C
- △ stainless steel net range 120-360 °C
- ceramic sheet range 120-360 °C

3-4. Difference of Temperature due to Different Subject

Figure 6-(a) shows the relationship between temperatures measured by thermocouples and that based on Infrared image processor using different subject. The gas flow rates of 30 and 40 litters/min were used at full opening. Both temperatures were used at 33, 50, 75, 100, 125, and 150cm from the floor and there results were compared to each other. In Figure 6-(a), the open and closed symbols represent the average temperature and the solid line represent the temperature fluctuations during 3 to 6 minutes after ignition. In this period, the flow behavior and combustion condition were assumed to be in a quasi-steady state condition. Figure 6-(b) shows the correction factor calculated using the data obtained by the thermocouples. This figure, indicates that for the ceramic sheet the correction factor is in the range of approximately 0.8 to 1.2 and for the stainless steel net the range is approximately 1.2 to 1.5 for this experiment.

4. Conclusion

The temperature distribution in the heat flow given by

an extended flame from a fully developed model fire was clearly visualized by the infrared image processing using a stainless steel net as a subject. This result helps in understanding the qualitative heat flow behavior caused by the extended flame from an opening.

If the correction factor, which translates the temperatures obtained by processed image data to the thermocouples' data, could be calculated, then the wide temperature distribution could be obtained, not only qualitatively but also quantitatively, using an infrared image processor.

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