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MARCH 1-7, 2000

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Norman Y. Mineta, Secretary
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Dr. Cheryl L. Shavers, Under Secretary of Commerce for Technology
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Raymond G. Kammer, Director

Behavior of Flame/Plume Flow in and near Corner Fire
-Entrainment Coefficient For Corner Fire -

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Experimental study on the flow behavior in and near corner fire was carried out using a model fire source changing the distance from the corner and heat release rate. Temperature, upward velocity, and CO_2 gas concentration were measured systematically in flame region and in lower part of the plume. Flame length and the height where the peripheral part of the flame touched to the wall were also observed. Based on the horizontal distributions of temperature, CO_2 gas concentration, and upward velocity, mass fluxes were estimated at several measuring heights. Then increased mass fluxes between the measuring heights were calculated and air entrainment coefficients were estimated as a function of separation distance. The air entrainment coefficient is smaller than that in the free boundary condition in case of a fire locates within the dimensionless separation, S/D, of 3.

Key Words: corner fire, air entrainment, mass flux

1. Introduction

Flame height in a free boundary condition is well correlated with dimensionless heat release rate Q*. Many researchers have proposed the models on this correlations [1], and in these correlations the efficiency of burning reaction is included as the coefficient between dimensionless flame height and Q*. As air entrainment into a flame and plume is restricted by walls, so that flame and plume properties must be perturved resulting in flame extension. Many items, such as furniture, trash can, bed, etc., are set near and in corner for real life. In this situation, considering real fire scenario for better fire safety, it is necessary to consider the flame and plume behavior from a fire which locates in a corner. The near and in a corner fire gives the flame extension and leaning to corner and/or walls resulting rapid fire propagation to ceiling and then which gives rapid flashover in a compartment. The flow behavior in and near corner showed different manner [2] from that from a fire in a free boundary. However, there is not enough knowledge on this flow behavior. In this paper, we deal with the flow behavior from a fire set in and near corner. We would like to make clear the air entrainment coefficient quantitatively.

2. Experimental Procedures

Three types of square propane gas burner of 10cm x 10cm, 25cm x 25cm, or 50cm x 50cm were used respectively as model fire source giving 4.5kW to 200kW. Main series of the experiments, presented in this paper, were carried out using 4.5kW, 7.5kW and 15kW fire from a 10cm x 10cm square burner. The square burner, which gives a turbulent diffusion gas flame, locates on the 45 degree line from a right angle (90 deg.) corner taking the dimensionless separation, S/D, of 0, 0.5, 1.0 and 2.0. Where S is separation from wall to a burner and D is length of a burner. Figure 1 shows the schematic plan view of an arrangement of a burner and wall.

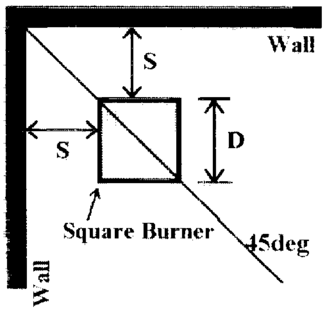

Figure 1 Layout of the fire source in and near corner.

Two walls were composed by several ceramic boards of 25mm thick with 1.7m wide and 3m high and no ceiling was attached them. Flame height and its leaning behavior was observed and recorded by a video system. Temperatures and upward velocities in several horizontal planes were measured systematically and which were recorded every 5 sec. Their time-averaged data were estimated and which were used to calculate the upward mass fluxes at several horizontal planes.

3. Results and Discussion

3-1. Cross section of the Flame and Plume Area

Figure 2 shows the representative cross sections of the excess temperature maps including the regions

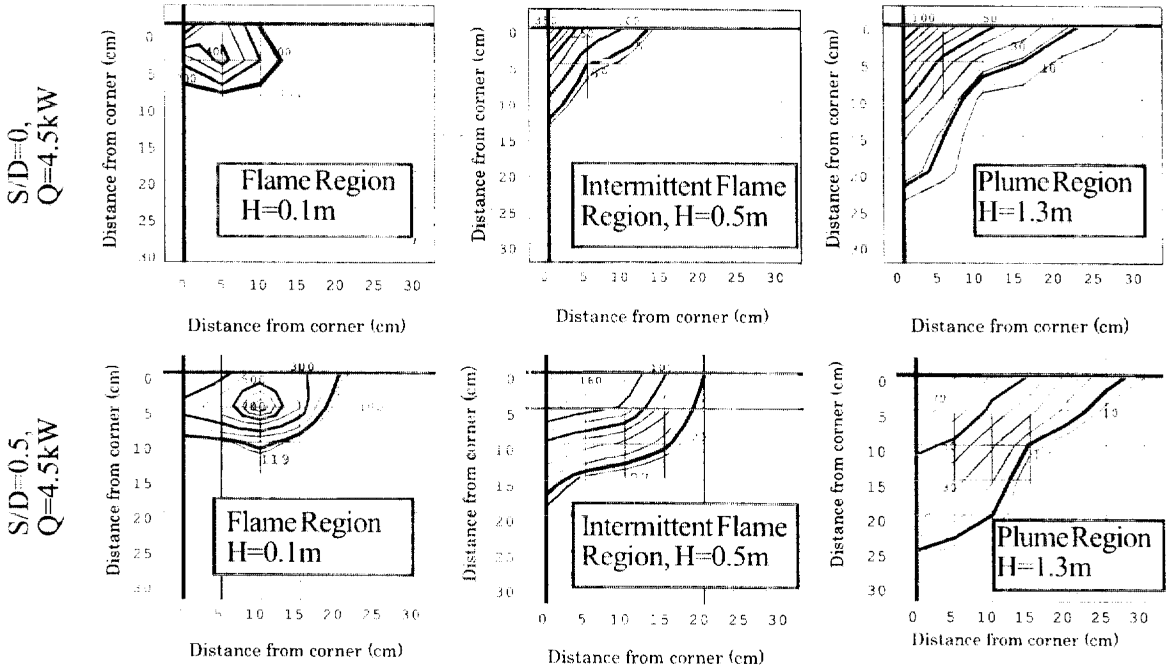

Figure 2 Representative cross section of the flow in and near corner using a 4.5kW square model fire source.

of flame, intermittent flame, and plume where the mass fluxes were estimated taking the peripherals boundary of 15% (N=15%) of the maximum value in the each cross section. The square shadow is location of the fire source. It is clearly observed that the cross sections changed from circular to triangular shape with the increase of the measuring height. These shapes indicate the ambient air entrainment was induced mostly along the 45deg line to the corner and poor entrainment was induced along the walls' surface. The mass flux in these cross sections along the height were evaluated by the summations of mass fluxes of small cells by

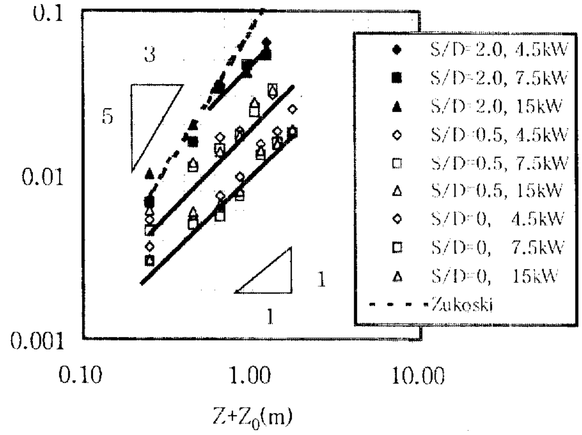

Figure 3 Upward mass flux at the several measuring planes are plotted against the height from the virtual point source. Mass fluxes are normalized $Q^{1/3}$.

$$\dot{m}_{ps} = \sum \rho v dA$$

Where $\dot{m}_{ps}$ is mass flux, ρ is gas density, **v** is upward velocity, and **dA** is cell area of the measuring cross section taking dA of 5cm x 5cm in our experiments.

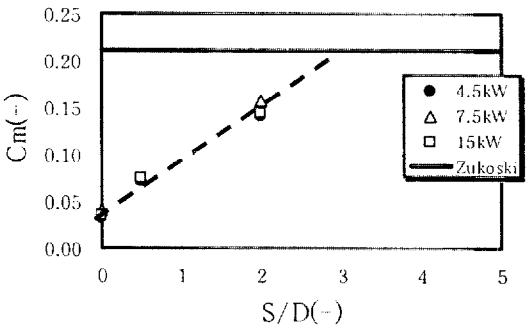

Figure 4 Entrainment coefficient as a function of dimensionless separation distance.

3.2 Mass Flux along the Trajectory

Figure 3 shows the correlation of mass fluxes normalized by heat release rate of 1/3 powered, $m_{ps}/Q^{1/3}$, with height from the virtual source point of Z+Zo. Where Zo is evaluated as $1.5\sqrt{A_f}$ after Thomas [3] taking A_f as area of the fire source. When the fire source locates far from the corner, in the case of S/D=2.0 in our experiments, the correlation between mass flux and height in the lower part of the flame showed the similar correlation that obtained in the free boundary condition. Based on the Figure 3, the mass flux along the height can be modeled and described by $\dot{m}_{ps} = k\dot{Q}^{1/3}(Z+Zo)^{5/3}$ taking the coefficient **k** of 0.21 [1]. However, the correlation in the intermittent and plume regions of the flow, and the flow from a fire source locates in and near corner, the gradient between normalized mass flux and height, $Z+Z_0$, along the trajectory changed from 5/3 to 1/1 as shown in Figure 3. These show that the ambient air entrainment into the flow is strongly restricted by walls. The height where the gradient changed from 5/3 to 1/1 corresponded to the height where the peripheral zone of the flame touched to the walls. The upward flow from a fire source which locates near corner leans to the corner of walls. Lower part of the flow, which is surrounded by ambient air, which showed the same manner of air entrainment. In cases of the fire source located in or near to a corner, S/D = 0 and S/D = 0.5 in our experiments, increasing rate of the upward mass flux showed smaller value than that obtained in a free boundary. The correlation for the flow in and near corner fire, we obtained the simple model of

$$\dot{m}_{ps} = k'\cdot\dot{Q}^{1/3}\cdot(Z+Zo)^{1/1}.$$

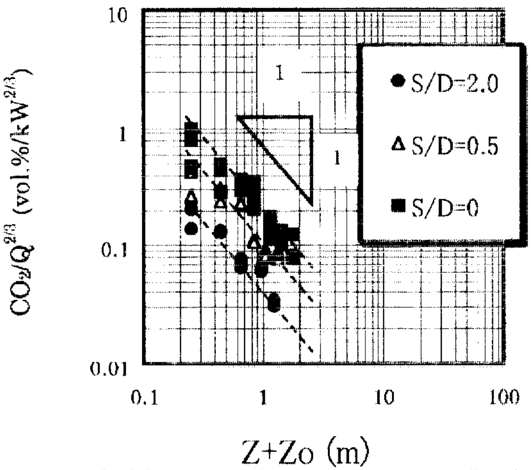

Figure 5 CO_2 gas concenetration normalized by 2/3 power of heat release rate as a function of height from the virtual point source.

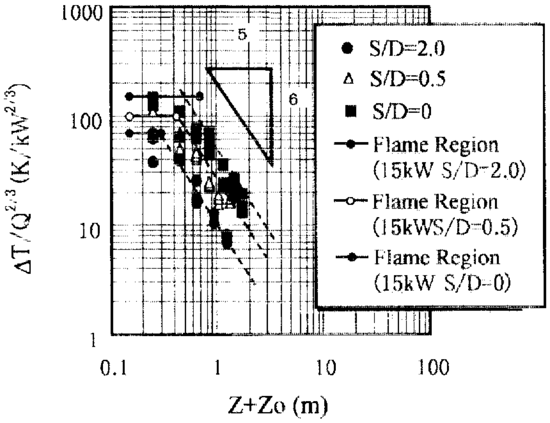

Figure 6 Excess temperature normalized by 2/3 power of heat release rate as a function of height from the virtual point source.

It is clearly identified that two kinds of increasing modes exit in the correlation between upward mass flux for far "corner fire" and "in and near corner fire" and which suggested that the amount of air entrainment was governed by the space between the flame and walls. In order to evaluate the air entrainment behavior into flame in and near corner, entrainment coefficients, Cm, were evaluated based on the mass flux and are as plotted a function of separation distance as is shown in Figure 4. This figure shows that entrainment coefficient, Cm, approaches to the value of 0.21 as dimensionless separation, S/D, increases up to about 3 which corresponds to the value obtained in the free boundary condition as was reported by Zukoski [1].

3-3. Averaged CO_2 Gas Concentration and Averaged Excess Temperature along the Trajectory

In the previous section, we evaluated the quantitative air entrainment into the flame and plume. Entrained air dilute the combustion products and which resulted in the decrease of flame temperature and CO2 gas concentration along the trajectory. Figure 5 and 6 show the CO_2 gas concentration and excess temperature decreasing modes respectively for height along the trajectory. Both physical values were normalized by the $Q^{2/3}$ changing the dimensionless separation distance S/D. Gradient of CO_2 gas concentration for height was evaluated as -1/1 and which is similar to the gradient obtained for the decreasing mode of excess temperature from a line fire source. As similar to this gradient, excess temperature along the corner space, showed the almost the same gradient as shown in Figure 6. In our case of experimental results, however, the gradient for excess temperature showed slightly greater gradient of -6/5 than that of CO_2. This discrepancies may be caused by the heat loss to walls.

The upward velocity was also measured and which showed gradient of 0 for height along the trajectory in flame and lower part of the plume suggesting the same behavior as observed from the line fire source.

The decreasing modes obtained along the trajectory for CO_2 gas concentration, excess temperature, and upward velocity implied that the hot flow from in and near a corner fire is quite similar to those from a line fire source.

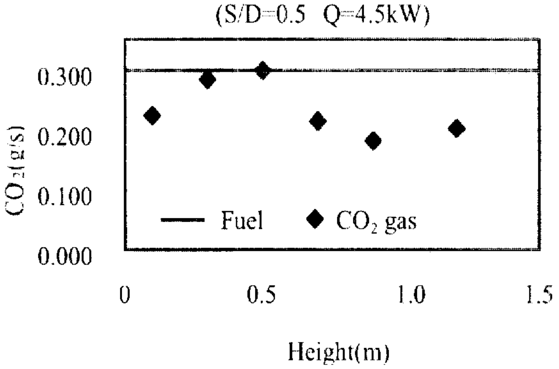

Figure 7 CO_2 mass flux along the flow.

As representatively shown in Figure 2, we estimated the periphery based on the N% method to evaluate the mass flux by integrating the upward velocity and gas density. This method liable to bring about under estimation by cutting off the peripheral part of the flow. In order to check asbout the N% (N= 15%) method, we also evaluate CO_2 mass flux taking the same N% method and compare the carbon mass balanace between fuel and CO_2 gas mass flux at measuring heights. Figure 7 shows the CO_2 mass balance between fuel and gas in flame. We assumed that carbon in the fuel reacts with O_2 stoichiometrically. In the upper part of the flame and plume, it is very difficult to measure diluted CO_2 gas concentration. This difficulty brought about the shortage in CO_2 mass balance, as shown in Figure 7, however, this figure revealed N% method taking (N=15%) is acceptable to estimate the mass flux.

3.4 Flame Height in and near Corner

Sugawa et al. [4] reported the flame extention behavior in and near corner and presented the model.

$$\frac{L}{Lo}=\left\{\frac{S^2+D^2}{4D^2+D^2}\right\}^{1/2}$$

where **Lo** is the flame height in case of the fire locates in a corner, **L** is flame height with separation **S**, **D** is side length of a square fire source. This model is appli-

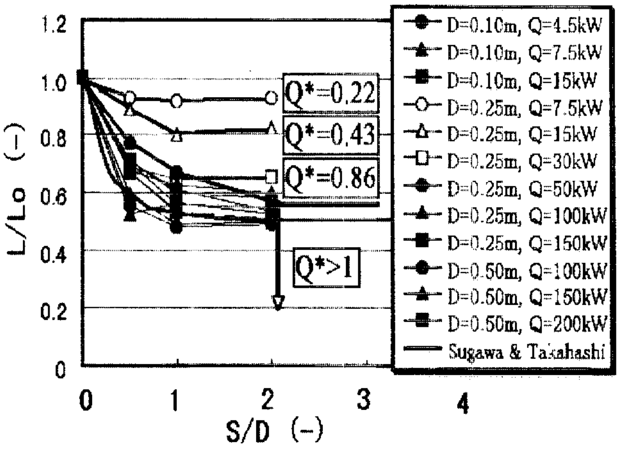

Figure 8 Dimensionless flame height against the dimensionless separation distance from wall with changing the dimensionless heat release rate Q*.

dimesnionless flame height, **L/Lo**, as a function of dimensionless separation distance, **S/D**, changing the dimensionless heat release rate of Q*. It is noted that the flames from fires of having Q*<1 indicated scarce extension behavior as if they were set in a free boundary condition. No apparent obstacle or shortage of air entrainment into flame was observed for fires having of Q*<1. Flames from greater Q* fires (Q*>1) showed pronounced flame extension when they approached to walls (or into corner) due to wall effects. It is necessary to establsih the model on flame extension behavior considering the chemical reaction for Q*<1 fires.

4. Conclusion

Air entrainment coefficient for in and near a corner fire was obatained as a function of dimensionless separation distance from a corner based on the measurements of excess temperature, CO_2 gas concentration, and upwawrad velocity. This coefficient changes from 0.03 for a corner fire and 0.21 for a fire which locates more than three times far from a corner. This result indicated that wall-effect, as a obstacle effect on air entrainment into flame, reach to about three times separation distance of a fire source's side length. Flame extension is apparently observed for a corner fire as its dimensionless heat release rate, Q*, is greater than 1. For Q*<1 fires locate in and near corner, there is little effect on the flame extension.

5. Reference

1) Zukoski, Z . Kubota, T., Cetegen, "Entrainment in

(1980/1981)

2)Takahashi, W., Sugawa, O., Tanaka, K., and Ohtake, M., "Flame and Plume Behavior in and near a Corner of Walls", Proceeding of 5th IAFSS Symposium, pp 261-271, (1997)

3) Thomas, P. H., Hinkley, P.H., Theobald, C.R., and Simms, D.L., "Investigations into the Flow of Hot Gases in Roof Venting", Fire Research Technical Paper, No.7, HMSO, (1963)

4) Sugawa, O., and Takahashi, W., "Flame Height Behavior from Multi-fire Sources", Fire and Material, vol.17, pp.111-117, (1993)