FLAME CHARACTERISTICS OF GROUP FIRES

YOSHIHIRO FUKUDA[1], DAISUKE KAMIKAWA[1], YUJI HASEMI[1] AND KOJI KAGIYA[2]
[1]School of Science and Engineering, Waseda University, Tokyo, Japan
[2]National Institute for Land and Infrastructure Management, MLIT, Japan

ABSTRACT

In this paper, assuming the group fire in a densely inhabited area with weak small wooden buildings, we performed the reduced scale model experiments to investigate the property of fire merging. To study the phenomenon, a lot of experiments were performed using crib and liquid fuel. Now, two or more propane porous burners are used, and the flame height, heat flux, and temperature distribution on the center axis of fires are measured.

Consequently, the influence of heat release rate, number of fires and distance between fires upon the fire merging property is demonstrated. It is found that each element affected flame merging property, especially the number of fires seemed to be the most important element.

1. INTRODUCTION

There are many areas densely and disorderedly inhabited by weak small buildings in numbers of big cities of Japan. This has been recognized as a serious problem that needs urgent solution from the view of regional safety. The present densely inhabited areas in Tokyo were formed through the industrial revolution and the population concentration during the postwar economic growing period. These areas have been disorderedly developed in order to meet the demands for houses.

In the Great Kanto Earthquake (1923), almost 200,000 wooden buildings were burnt down and 43% of the old Tokyo urban areas were lost. In addition, around 80,000 victims in Tokyo were due to the earthquake fires. Kobe also suffered great blow in the Great Hanshin Earthquake (1995). The fires caused by this earthquake imprinted anew the terror of the city fires on our minds. Even in recent days, large fire in the shopping area in Wakkanai (June, 2002) burned out about 7000m^2 area. We can understand from those experiences that the city area fire still will occur in Japan, again.

When a fire breaks out in those areas, the flame-merging phenomenon often happens. This phenomenon is believed to make the fire more destructive, cause difficulties in fire fighting and often cause fire whirls. In order to assess the risk of city fires, we need to research on flame merging property. This study intends to quantify the condition for flame merging by reduced scale model experiments using propane porous burners as the fuel. Quiescent environment is assumed as the first trial of such experiment.

2. EXPERIMENTAL DESCRIPTIONS

2.1 General

Experimental set up is shown in Fig.2. We used 15cm-square propane porous burners (afterward, one width of square burner (15cm) is written as D). Gesso boards were placed at the height of the burners surface to simulate the ground surface.

We measured flame height, heat flux, and temperature distribution on the center axis of the fires. Flame was recorded with digital video, and the reported value of flame height was the average of the visible flame tips height. Incident heat flux was measured with 15mm diameter Schmidt - Boelther heat flux gages (150kW/m^2 range). Temperature was measured with K-type (chromel-alumel) thermocouples (ϕ0.2mm).

We changed separation distance between burners (S), heat release rate (Q) and number of burners (N). The separation distance, S, was chosen as 0, 1cm(D/15), 2cm(D/7.5), 3cm(D/5). The S/D values were chosen to represent typical urban block arrangement in densely inhabited area. For each S and N, heat release rate was changed as shown in Table.1. Heat release rate was controlled by flow rate of propane, and was calculated assuming the complete combustion.

Q^* shown in Table.1 is the dimensionless heat release rate defined as

$$Q^* \equiv Q / \rho C_p T_o g^{1/2} D^{5/2} \qquad (1)$$

It is widely recognized that, for a single source, unconfined flame length L_f is controlled by dimensionless heat release rate Q* and calculated using the semi-empirical formula

$$L_f = \gamma Q^{*n} \cdot D \quad (Q^* \geqq 1.0 : n=2/5,\ Q^*<1.0 : n=2/3) \qquad (2)$$

Q^* : Dimensionless heat release rate Q : Heat release rate(kW)
ρ : Density of ambient air(kg/m^3) C_P : Specific heat of air(kJ/kg・K)
T_0 : Ambient temperature(K) g : Gravitational acceleration(m/s^2)

In this paper, the flame height is picked up as the most significant index that indicates the flame merging effect. When L_f is calculated from Q* and D of single source, this L_f represents the flame height without the merging. Once the flame begins to merge, its height can be expected to become higher than the value calculated by this formula.

Figure 1: Merging flames

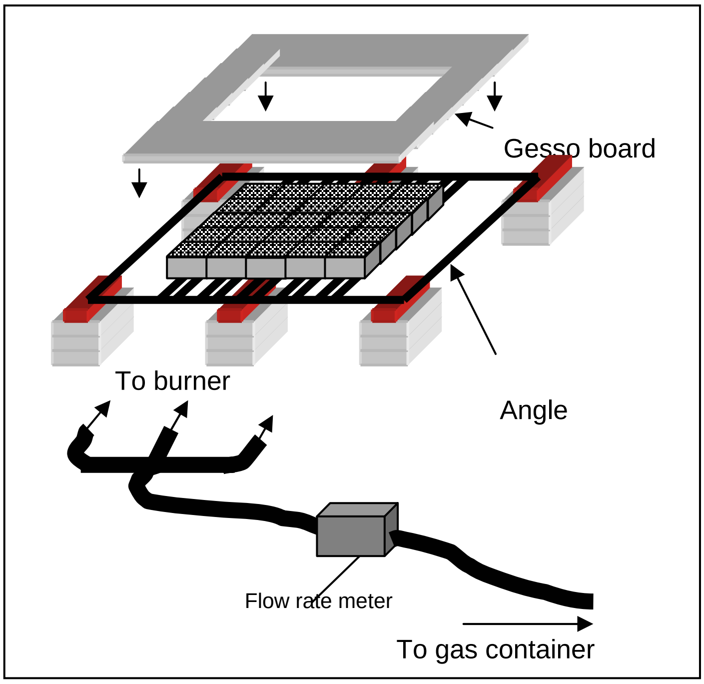


Figure 2: Experiment set up

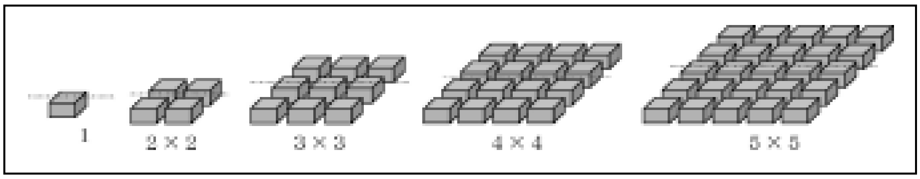


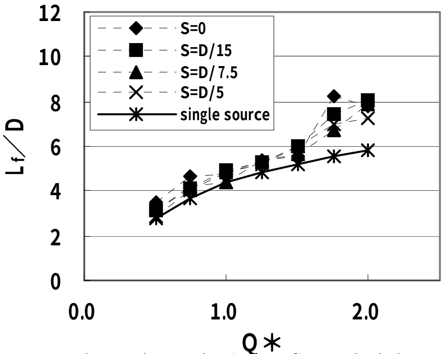
Figure 3: Arrangement of the fuels

Table 1: Propane gas flow rate per one burner

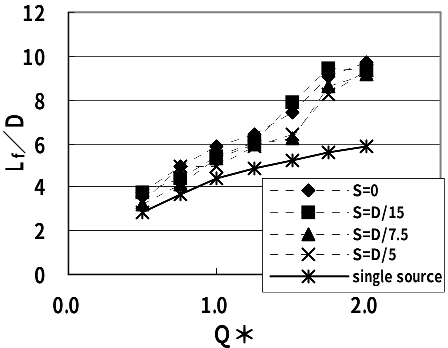
Q*	0.50	0.75	1.00	1.25	1.50	1.75	2.00
Q （kW per single burner）	5.0	7.5	10.0	12.5	15.0	17.5	20.0
Propane gas flow rate（L/min）	3.3	4.9	6.6	8.2	9.9	11.5	13.2

2.2 Experimental Results

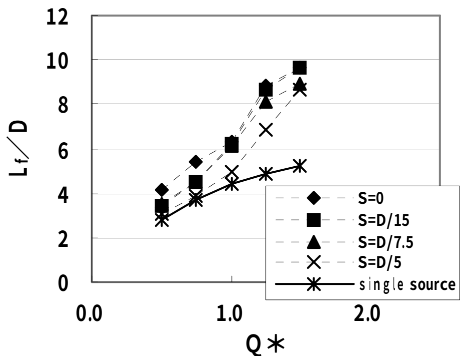
Fig4～Fig7 show the relationship between Q* and flame height divided by D (=15cm). The curves for ‘‘single source’’ represent equation (1) for γ =4.4, which give the best fit for the single source during the present test.



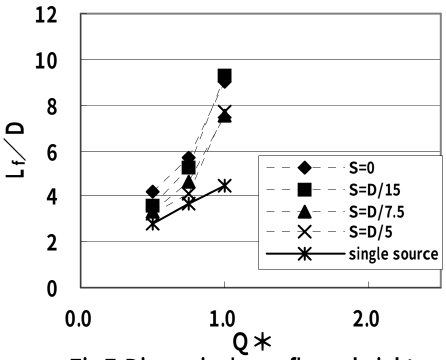
Fig,4 Dimensionless flame height
(2×2burners)



Fig,5 Dimensionless flame height
(3×3burners)



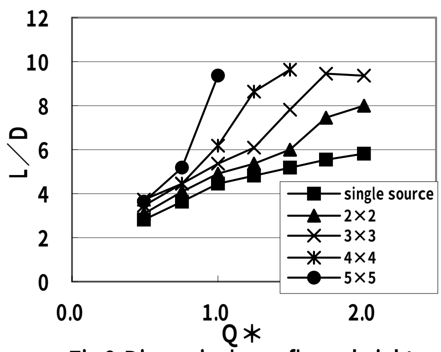
Fig,6 Dimensionless flame height
(4×4burners)



Fig,7 Dimensionless flame height
(5×5burners)

Flame height is close to the ‘‘single source’’ one up to a certain value of Q*, but it jumps once Q* exceeds that value. This jump is believed to be a result of the flame merging effect. The value of Q* where flames starts to merge varies according to the number of burners, and its value is around Q*=1.75 for 2×2 burners, Q*=1.5 for 3×3 burners, Q*=1.0 for 2×2 burners, and Q*=0.75 for 5×5 burners. Thus, the minimum Q* to generate the flame merging becomes lower as the number of burners increases.

The growth of merged flame height against ‘‘single source’’ one is also varies according to the number of burners. For 2×2 burners, the height of merged flame is 1.2～1.3 times larger than that of ‘‘single source’’, 1.5 times for 3×3 burners, 1.8 times for 4×4 burners, and twice for 5×5 burners. Thus, the more the number of burners becomes, the larger the growth of merged flame height becomes.



Fig,8 Dimensionless flame height
(S=D/15)

Fig.8 is the relationship between L/D and Q* for S=D/15. From this figure, we can confirm the difference of the flame merging properties according to the increase of the number of burners. As the number of burners increases, the value of Q* where jump begins becomes lower, and the extent of growth become larger.

In this experimental condition, it is confirmed that fires hardly merge as long as its Q* remains small. According to this fact, fire merging phenomenon in the real densely inhabited area should be prevented by keeping Q* of each building low. To decrease Q*, it is important to improve the fire safety performance of the outside wall, and so on.

And it is confined that the increase of the number of burners has great influence on fire merging property. This is because shortage of oxygen caused by increase of the number of burners. For example, seeing the Fig.8, the flame height of 5×5 burners for Q*=1.0, S=D/15, is around 1.5 times larger than that of 4×4 burners for same conditions. In the city area, once the fire merging phenomenon occurs, its large fire causes difficulties in fire fighting and serious destruction by accelerating fire spread. To prevent the fire merging attributed to multitude of fire source, it is significant to zone these areas finely by roads, green lungs, fire-retardant structure, or something works as fire belt.

Here, we focus on the influence of separation distance. Before the experiments, separation distance was thought to be the most effective element to flame merging property. From the results, however, the scale of separation distance was found to be not very influential to flame height nor to the critical condition for the flame merging.

In the experiment, assuming separation distance between buildings or road width in densely inhabited area, we changed the separation distance as S=0、D/15、D/7.5、D/5. From Fig.4～Fig.7, the scale of separation distance seemed to be not very influential to flame height although it has slight difference at the time flame starts to merge. Especially separation distance doesn’t affect the height of merged flame so much. Under the distance D/5, merged flame almost stays constant.

Using propane burners as the fuel, flame merging property could be demonstrated at steady state. But in the real fire, its burning rate changes according to time flow and flame merging phenomenon itself. Therefore, we should apply these results to real combustible material. Now, the experiments with wood cribs are scheduled to investigate the correlation between flame merging property and burning rate.

3. CONCLUSIONS

From model scale experiments with propane burners, we demonstrated the correlations among fire merging property, heat release rate, number of fire sources and separation distance.

We newly accomplished following conclusions.

1. Growth of the number of burners has great influence on fire merging property. When the number of burners increased, fires merged at small heat release rate. From this study, in the case of Q*=1.0 for each burners, the flame merging is expected to be restrained by controlling the number of burners within 3×3 ones.

2. When the heat release rate of each burner remains small, fires are hardly merging, and affection from the number of burners and separation distance is little. From this study, in the case within 5×5 burners, fires are close to ''single source'' under the value of Q*=0.75.

3. In the range of the experiment conditions, the influence of the separation distance on the flame merging property is smaller than that of the number of the burners and the heat release rate. Especially when the separation distance is under D/5, the flame height hardly affected by the separation distance excluding the moment when the flame began to merge.

REFERENCES

B. Cetegen, E. E. Zukoski, T. Kubota, 1982. *Entrainment and Flame Geometry of Fire Plumes,* NBS-GCR-82-402.

Y. Hasemi, T. Tokunaga, 1984. *Flame Geometry Effects on the Plumes from Turbulent Diffusion Flames*, Fire Science and Technology, Vol.4.

S. Sugawa, 1992. *Merging Flame Height from Multi Fire Sources*, Summaries of research presentation, Association For Fire Science and Engineering, 197-198.