DETERMINISTIC PROPERTIES OF WALL FIRE

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1. ABSTRACT

Measurements were made of flame height L_f on vertical surface burner with side and back walls. Flame height is represented as a functional relation as, $L_f/D_V \propto Q_w^{*2/3}$ or $L_f \propto (Q/D_H)^{2/3}$, where Q_w^* is dimensionless heat release rate, $Q_w^* = (Q/D_H)/(\rho_0 C_p T_0 \sqrt{g} D_V^{3/2})$, D_H and D_V are width and height of the burner respectively. The similarity of mean temperature distribution in the flow is assumed in the parameter. Then it can be rewritten to give mean temperature, $\Delta T/T_0 \propto (X/(Q_w^{*2/3} D_V))^{-1}$ in the region which heat release entirely finished in. In the region of the local Reynolds number $Re(=VX/\nu)>30{,}000$ of the wall plume along an adiabatic wall, the flow developes in fully turbulent and the local Froude number $Fr\ (=V/(\beta \Delta T g X)^{1/2})$ becomes almost constant. So it provides mean velocity, $V/\sqrt{g} \propto (Q_w^{*2/3} D_V)^{1/2}$. Experimental results of mean temperature and velocity show the same power relation with the estimates. Without side walls there is an effect of a slight decrease of flame height, temperarure and velocity along the vertical center line.

Then without back wall on the vertical surface burner, flame height L_f is represented as $L_f/D_V \propto Q_w^{*1/2}$, so that temperature and velocity are estimated similarly as above, $\Delta T/T_0 \propto (X/(Q_w^{*1/2} D_V))^{-4/3}$ and $V/\sqrt{g} \propto (X/Q_w^{*2} D_V^4)^{-1/6}$. Experimental results of mean temperature and velocity in the plume region show the same power relation with the estimates, too.

Keywords:wall fire, flame height, temperature, velocity, dimensional relationship

2. INTRODUCTION

Wall fire has been investigated extensively[1-6], because it plays an important role in the spread of fire. Radiative and convective heat flux in the flame and convective heat flux in the plume to wall surface accelerate the increase of pyrolysis zone. Previous work[5,6] regards the properties of wall flame as those of flame on line source. Strictly there are many differences between, for example decomposit gases effluent at a right angle to plume axis or in experiments line source has some width.

This study is concerned with deterministic properties of turbulent diffusion flames, e.g. flame height, temperature and velocity, on vertical surface burner under natural convection condition.

3. EXPERIMENTAL DESCRIPTION

The apparatus was located in an interior room having plan dimensions of 17×11m and exaust hood height of 2.5m. The experiments were conducted using two 0.25×0.5m burners combined with, which are mounted ceramic blanket to level their surface. Therefore, the dimensions of the burner, width×height are 0.5×0.5m 0.5×0.25m, 0.25×0.5m and 0.25×1.0m. Liquified Petroleum Gas (C_3H_8 97%) was used as the fuel. Back wall was mounted on the burner and side walls with 0.5m width were mounted close to both sides of the burner. The walls was as tall as exaust hood and made by calcium silicate board. The burner was tested on even condition with the ground whether fuel effluents uniformly before set up. It was verified that exhaust hood has no influence on the plume up to the hood height.

After steady state of burning, flame was recorded in videotape. Flame height was measured along the vertical center line of the burner from the lower edge of it, by still pictures on the monitor, at a framing rate of 30 frames a second, randomly selected sequences corresponding to 180 frames of each experiment.

4. RESULTS AND ANALYSIS

Results of flame height were displayed in Fig.1(a) with heat release rate per unit burner width Q/D_H. Although there is some scatter in data, their trend follows the correlation of those on line source shown experimentally by Hasemi[5] and theoretically by Delichatsios[1] as,

$$L_f \propto (Q/D_H)^{2/3} \qquad \text{or} \qquad L_f = 0.056\times(Q/D_H)^{2/3} \tag{1}$$

Without side walls, it was observed that flame fluctuated and soot adhered to back wall and at an angle of 0~15° to vertical from a little heigher than the lower edge of the burner. It indicates the extent of the plume, so that flame height became lower than that with side walls.

In another way flame height is displayed by dimensionless parameter[5] $Q_w^* = (Q/D_H)/(\rho_0 C_p T_0\sqrt{g}D_U^{3/2})$, where C_p is the specific heat of air, ρ_0 and T_0 is the ambient density and temperature, respectively. Fig.1(b) shows the correlation between L_f/D_U and Q_w^*. The relationship is represented as,

$$L_f/D_U \propto Q_w^{*2/3} \qquad \text{or} \qquad L_f/D_U = 6.0\times Q_w^{*2/3} \tag{2}$$

In this parameter the similarity of the distribution of mean temperature in the flow is assumed. So Equation (2) indicates the same excess temperature ΔT at mean flame heights. Equation (2) is recasted with exess temperature term at height X as Thomas[7], where β is the expansion coefficient, g is the gravitaional acceleration,

$$\frac{X}{D_U} \propto \left[\frac{V}{(\beta\Delta T g D_U)^{1/2}}\right]^{2/3} \propto \left[\frac{Q/D_H}{\rho_0 C_p T_0\sqrt{g}D_U^{3/2}}\cdot\frac{T_0^{3/2}}{\Delta T^{3/2}}\right]^{2/3} \propto Q_w^{*2/3}\frac{T_0}{\Delta T}$$

$$\therefore\ \Delta T/T_0 \propto (X/(Q_w^{*2/3}D_U))^{-1} \tag{3}$$

Note that Equation (3) is applied to the temperature in the plume where heat release is entirely finished.

Cheesewrite[2] has found that for Grashof number $Gr(=(\beta g(T_w-T_0)X^3/\nu^2)$ between 2×10^9 and 10^{10}, the flow

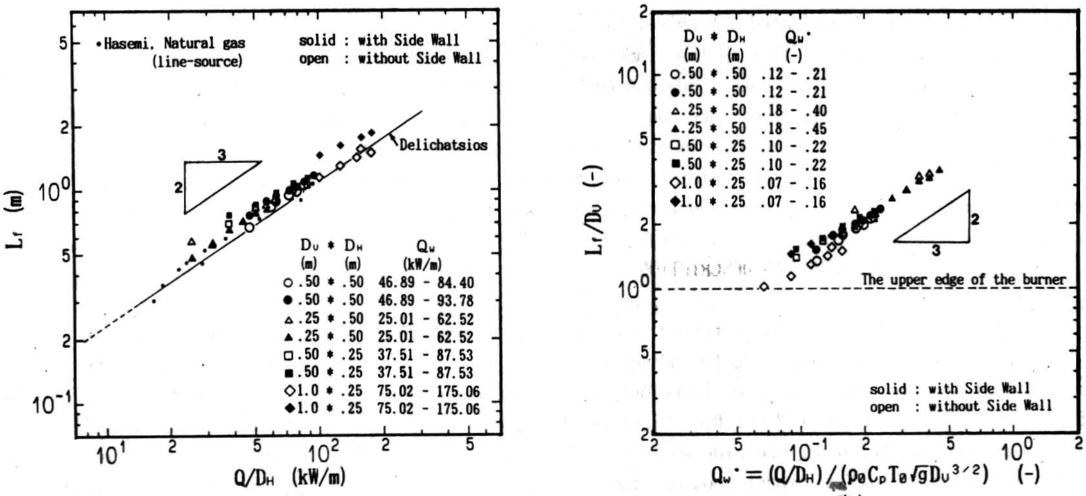

Fig.1 Flame height versus heat release rate with back wall

origined by natural convection on a vertical wall becomes transitional region from laminar to turbulent, and fully developed turbulent flow for Grashof number greater than 10^{10}. Here T_w is wall temperature, ν is a kinematic viscosity. Grella and Faeth[6] have shown this transitional region with the local Reynolds numbers Re and turbulent flow for the local Reynolds number greater than 30,000. The local Froude number is constant for a fully developed turbulent buoyant flow along an adiabatic wall. In this study all flow is considered to be fully developed turbulent flow and the local Froude number is to be constant. Then following relationship is derived from the constant local Froude number and Equation (3),

$$V/\sqrt{g} \propto (Q_w^{*2/3} D_U)^{1/2} \tag{4}$$

As for the properties of the plume above the square and line source, studies of McCaffrey[8] and Yokoi's[10] above the square source and Yokoi's[10] above line source indicate the validity of the derivation of Equation (3) and (4).

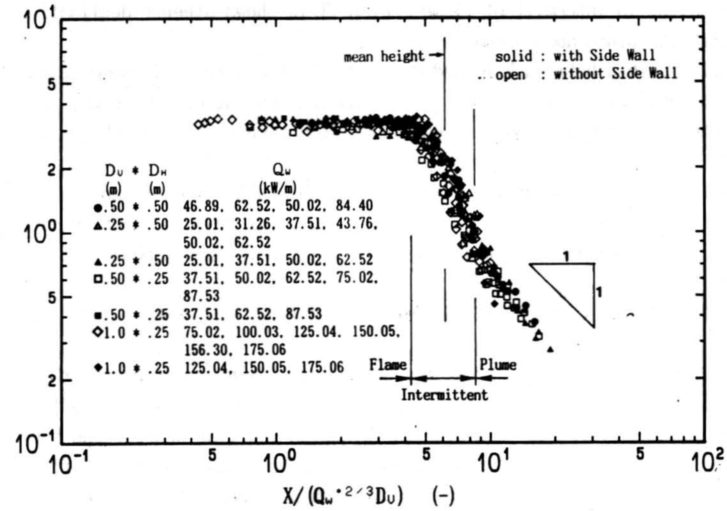

Fig.2 $\Delta T/T_\theta$ versus $X/(Q_w^{*2/3}D_U)$ with back wall

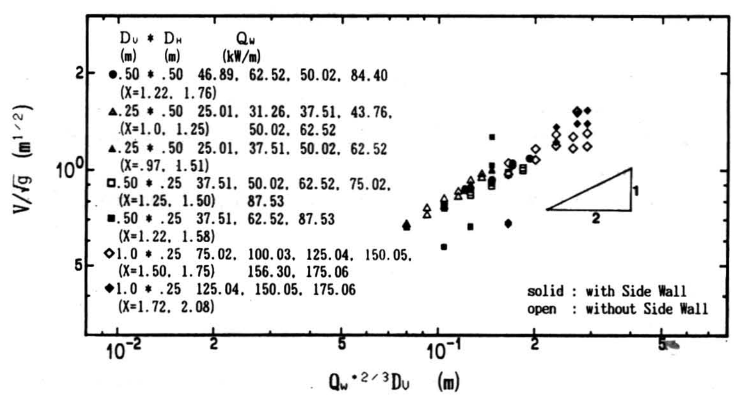

Fig.3 $V/\sqrt{g}$ versus $Q_w^{*2/3}D_U$ with back wall

5. EXPERIMENTAL DESCRIPTION

In order to examine the expected relationship of Equation (3) and (4), the following experiments were conducted. The apparatus mentioned above was used to operated for at least 30 minites before taking measurements. Measurements of temperature and velocity along vertical center line of the burner at the distance of 5mm from the wall surface were performed with 0.1mm diameter chromel-alumel thermocouples and bidirectional pressure probes[9] at the interval of 5 seconds for 5 minutes after steady condition. The distance from the wall surface was decided by pretests which temperature measurements at 10 points in height were performed at four distant 1, 5, 10 and 20mm from the wall surface. The data at 5mm were the maxima in them. No correction for measured temperature has been employed for radiation error by soot adhesion and conduction error.

6. RESULTS AND DISCUSSION

Fig.2 shows the relationship between $\Delta T/T_0$ and $X/(Q_w^{*2/3}D_v)$. Alhough there is some scatter in data, $\Delta T/T_0$ in plume region is proprotional to -1 power of $X/(Q_w^{*2/3}D_v)$ as Equation (3) indicates. Without side walls, just like flame height, Fig.2 indicates that the extent of the plume made mean temperature lower than those with side walls. In intermittent flame region $\Delta T/T_0$ shows steeper declination than that in plume region in contrast with the plume above square source.

Fig.3 shows the relationship between $V/\sqrt{g}$ and $Q_w^{*2/3}D_v$. Although there is some scatter in data, $V/\sqrt{g}$ in plume region is proprotional to 1/2 power of $Q_w^{*2/3}D_v$ and independent of the height as Equation (4) indicates. There are larger discrepancy in data using 1.0×0.25m burner, because the data involve those in intermittent region.

In this study the local Froude number is indicated as a constant value of about 1.22, fairly equal to the experimental result of Ahmad and Faeth[3] 1.28 and all the local Reynolds numbers exceeded 30,000 at all points where velocities were measured, so that they were fully developed turbulent flow.

7. DETERMINISTIC PROPERTIES OF WALL FIRE WITHOUT BACK WALL

As for the plume without back wall, Sparrow[4] has derived following relationship theoretically, $\Delta T \propto (X/D_v)^{-3/5}$ and $V/(\beta \Delta T g D_v)^{1/2} \propto (X/D_v)^{1/5}$. But it is possible to consider that at sufficient height above the burner, the plume becomes symmetric just like the plume on the line source. The buoyancy flux within the plume is conserved, so that the local Froude number is to be a constant as McCaffrey[8] reffered. As the experiments with back walls, from the dimensional relationship between dimensionless flame height and dimensionless heat release rate, the power relation of temperature and velocity can be derived.

Fig.4 shows the experimental results between L_f/D_v and Q_w^* without back wall. It is represented as,

$$L_f/D_v \propto Q_w^{*1/2} \qquad \text{or} \qquad L_f/D_v = 4.0\times Q_w^{*1/2} \tag{5}$$

Comparing with flame heights with back wall at the same Q_w^*, flame heights become lower and the power relation changes. This is because the air is entrained directly into the flame at the height of the upper edge of the burner, so that flame emits stronger light above the upper edge of the burner than below. Without side walls, there is no effect on flame heights.

Assuming the constant local Froude number, the following relationship of temperature and velocity is derived from Equation (5),

$$\Delta T/T_0 \propto (X/(Q_w^{*1/2}D_v))^{-4/3} \tag{6}$$

$$V/\sqrt{g} \propto (X/Q_w^{*2}D_v^{4})^{-1/6} \tag{7}$$

In order to examine the estimated relationship of Equation (6) and (7), the experiments were conducted. The apparatus and the method were the same mentioned above.

Fig.5 shows the relationship between $\Delta T/T_0$ and $X/(Q_w^{*1/2}D_v)$. Although there is some scatter in data,

$\Delta T/T_{\theta}$ in plume region is proprotional to -4/3 power of $X/(Q_w^{*1/2}D_v)$ as Equation (6) indicates. Without side walls, similar to flame height, there is no effect on mean temperature. In intermittent flame region as the temperature distribution with back wall, $\Delta T/T_{\theta}$ shows steeper declination than that in plume region.

Fig.6 shows the relationship between $V/\sqrt{g}$ and $X/(Q_w^{*2}D_v^4)$. Although there is some scatter in data, $V/\sqrt{g}$ in plume region is proprotional to -1/6 power of $X/(Q_w^{*2}D_v^4)$ as Equation (7) indicates.

In this study the local Froude number is indicated as a constant value of about 1.03.

8. CONCLUSIONS

Flame heights on vertical source with or without back wall were formulated by dimensionless heat release rate. In case that the buoyancy flux within the plume is considered to be a constant, mean temperature and velocity at each height in the plume region are able to be predicted from the relationship between dimensionless flame heights and dimensionless heat release rate.

In case with a wall on the vertical burner, side walls have an effects on flame height, temperature and velocity. But in case without a wall on the vertical burner, side walls have no effects on them.

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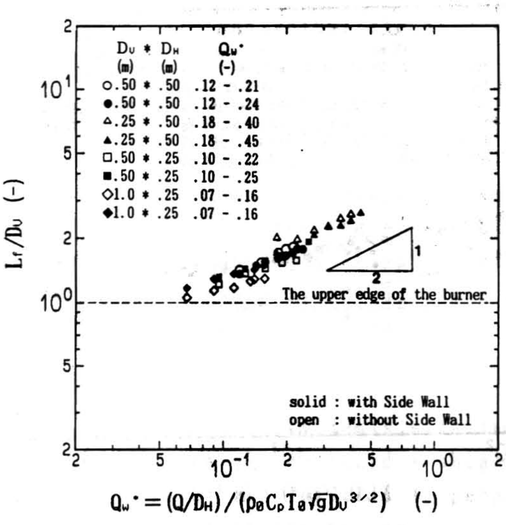

Fig.4 Flame height versus heat release rate without back wall

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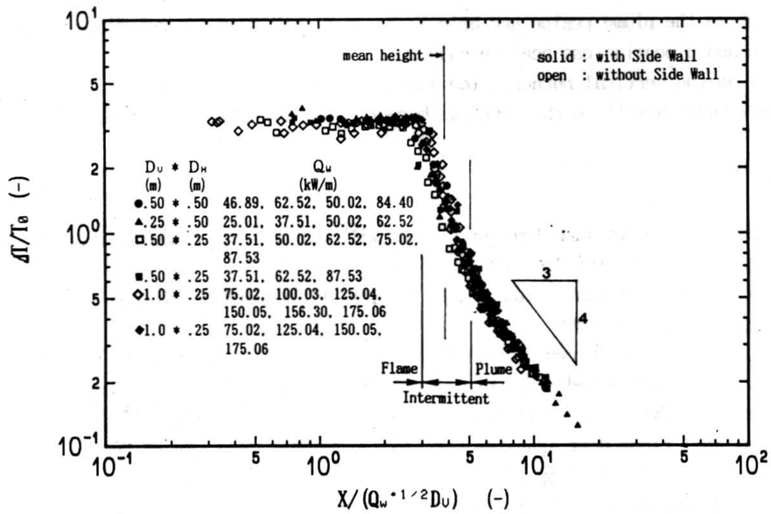

Fig. 5 $\Delta T/T_\theta$ versus $X/(Q_w^{*1/2}D_U)$ without back wall

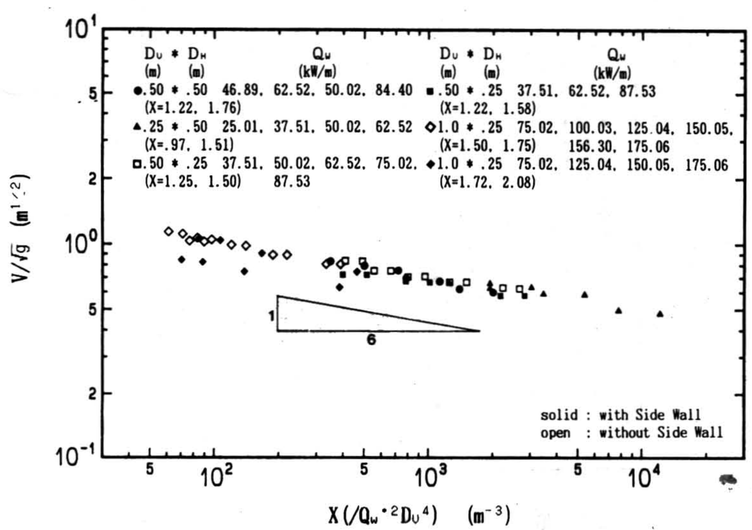

Fig. 6 $V/\sqrt{g}$ versus $X(/Q_w^{*2}D_U^4)$ without back wall