Flame Stretch Rate of Laminar Flame Base just before Flashback at Different Burner Temperatures

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Introduction

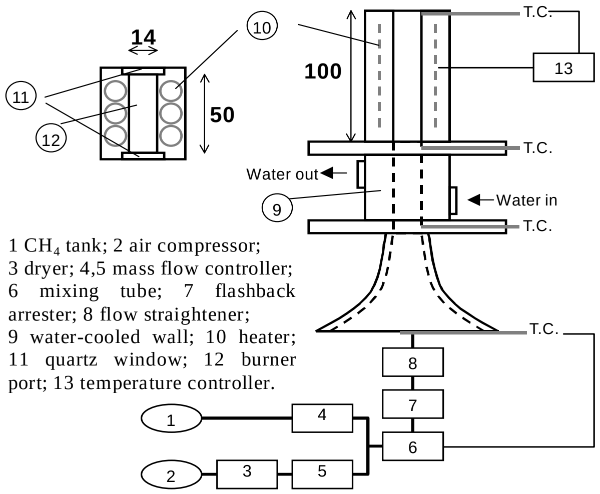
Flashback is generally attributes to the mechanism that the laminar flame propagates upstream in boundary layers when its normal velocity exceeds the local flow velocity (Lewis and von Elbe 1987). It is well known that increasing of the burner temperature makes flashback easy to occur. At a flame base, however, the phenomenon becomes complicate because the local burning velocity is modified by the heat flux to the burner, the ambient air dilution and the flame stretch effect. Especially it is very important that all effects on flashback become clear. In this study, we investigated experimentally the relation of the flame stretch rate and the other factors at a stationary flame base just before flashback. We measured the velocity distribution by PIV and the temperature profiles in the vicinity of the burner rim at a different burner temperature.

Experimental Apparatus

The flashback limits were measured using a rectangular port burner containing a heater inside. Fig. 1 shows the schematic of the experimental apparatus. The well-premixed methane/air mixture exhibited sufficiently laminar. The burner temperature was controlled according to the output from the thermocouple. The heating section was 100 mm long, and had two opposite quartz windows. The rectangular burner port was 50 mm deep and 14 mm wide. The flame maintained a two-dimensional static tented shape when the flame was stable. The velocity distribution of the stationary flame base just before flashback was measured by PIV. A laser sheet with a 0.6(t)mm (a Double-Pulsed Nd:YAG Laser: 532.4nm, 20mJ) was irradiated from the upper side of the burner system. Silica particles (about 1.1μm) were seeded into the unburned mixture. The temperature in the vicinity of the flame base was measured by thermocouple (type R, ϕ0.05mm with silica coating).

Experimental Results

The mean flow velocities V_m under the standard condition at the flashback limits are plotted in Fig, 2 as a function of the burner temperature T_w. T_w was controlled at 323, 373 and 473 K. The flashback occurred at faster V_m when T_w is high. Fig. 3 shows the profiles of the fluid temperature at the burner port each T_w at V_m = 0.5 m/s. The x-axis represents the distance from the center of the burner width, and the burner wall is x = 7 mm. The fluid temperature is highest in the vicinity of the burner rim due to preheating from the burner wall. Fig. 4 shows the velocity vector distribution just before flashback using the PIV (T_w = 373K). The heavy line indicates the flame base. The similar distributions of Fig. 4 (T_w = 373K) were obtained in the case of T_w = 323K and 473K. We confirmed that the laminar flow velocity in these areas became fast at high T_w.



(a) Top view (b) Front view

Figure 1. Schematic of the experimental

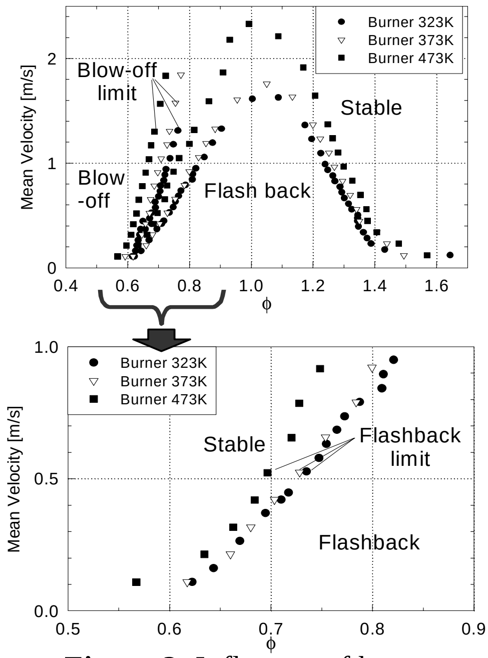


Figure 2. Influence of burner temperature on flashback and blow-off

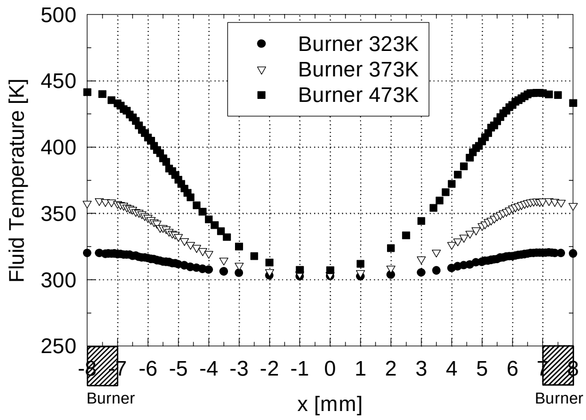


Figure 3. Temperature profiles of unburned gas at the burner port

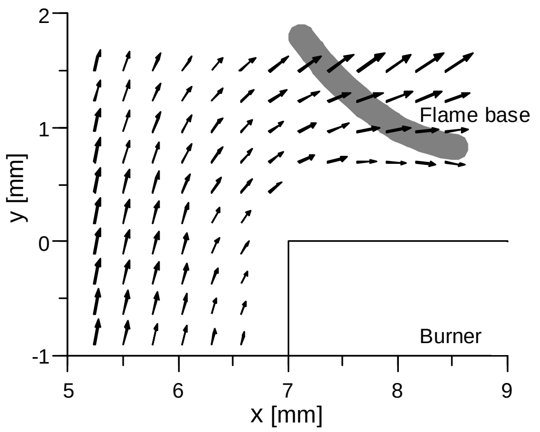


Figure 4. Velocity vector distribution at T_w= 373 K (V_m=0.5 m/s and ϕ_{fb}=0.67)

Table 1 Factors to Flashback

T_w K	ϕ_{fb}	T_u K	T_{ad} K	dV/dx 1/s	S_{u0} m/s	κ_{peak} 1/s	S_u/S_{u0}	S_u m/s	q W/m^2	D_{N2CH4} mm^2/s
323	0.68	320	1878	230	0.25	380	1.048	0.26	8900	249
373	0.67	360	1906	282	0.32	346	1.037	0.33	10700	256
473	0.65	440	1963	359	0.45	333	1.036	0.47	15700	276

Factors to Flashback

Following the Lewis and von Elbe, the flashback is discussed by comparing flow velocity gradient dV/dx and burning velocity S_u at the quenching distance. In general, the increasing of S_u by preheating is particularly effective in flashback at high T_w. In this section, however, the other factors listed in Table 1 will be discussed in detail. T_u is the preheating temperature in the vicinity of the burner rim, T_{ad} is the adiabatic flame temperature on the conditions of ϕ_{fb} and T_u. Table 1 also lists dV/dx at the burner port obtained by PIV.

First of all, a flame stretch rate κ is estimated by the experimental results of the velocity distribution and the flame curvature. κ is expressed as follows (Chung 1984):

$$\kappa = \frac{1}{A}\frac{dA}{dt} = -\left\{\nabla \times \left(\vec{V}_{fluid} \times \vec{n}\right)\right\} \cdot \vec{n} + \left(\vec{v} \cdot \vec{n}\right)\left(\nabla \cdot \vec{n}\right) \tag{1}$$

where $\vec{V}_{fluid}$ is the flow velocity at the flame, $\vec{v}$ is the velocity of the flame surface (here, $\vec{v} = 0$ in a stable flame), and $\vec{n}$ is the unit normal vector of the flame surface.

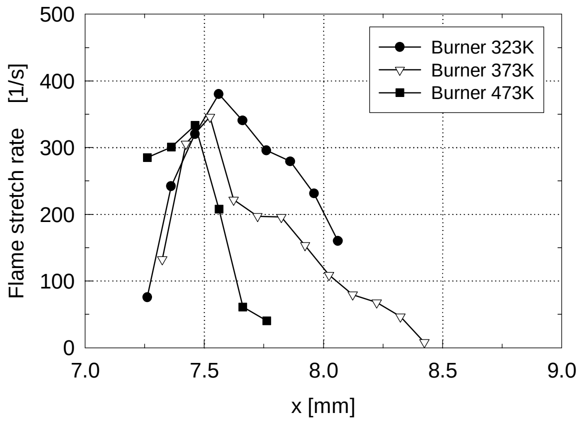


Figure 5. Flame stretch rate along the flame base just before the flashback limit. (V_m=0.5 m/s. ϕ_{fb}=0.68, 0.67 and 0.65 at T_w=323, 373 and 473K respectively)

Fig. 5 shows that κ has the peak positive value (x = about 7.5mm). Fig. 5 also shows that the peak κ becomes small at high T_w. And now, Lewis number Le is smaller than unity for the lean methane/air flame, therefore S_u is increased by κ. Increase of S_u accelerates flashback. A variation of S_u caused by the stretch effect is expressed as follows (SUN 1999):

$$\frac{S_u}{S_u^0} = 1 + \frac{Ze}{2}\left(\frac{1}{Le} - 1\right)\frac{\alpha^0 \kappa \delta_T^0}{S_u^0} + (\nabla \cdot \vec{n})\delta_T^0 \qquad (2)$$

where Ze is the Zeldovich number, α^0 is the factor according for the thermal expansion effect, δ_T^0 is the laminar flame thickness, S_u^0 is the laminar burning velocity by preheating. S_u/ S_u^0 is estimated from Eq. (2) at the peak κ in Table1. S_u increases within a few percentage points, and its rate of increase becomes small at high T_w.

Next, the heat loss to the burner q is estimated from the following Eq. (3). q inhibits flashback due to falling in flame temperature.

$$q = h(T_a - T_w) \qquad (3)$$

where h is the heat transfer coefficient, and T_a is the flow temperature. Here, V = 0.25 m/s is obtained from PIV and T_a = about 536, 631 and 854K (T_w=323, 373 and 473 K) is measured by using T. C.; these values are in the area above the burner (x = 7 - 9mm and y = 0.5 - 1mm). q from Eq. (3) are shown in Table 1. q at T_w = 473K is about 1.76 times as large as that at T_w = 323K, the effect that makes S_u small becomes large at high T_w (= 473K).

Furthermore, we also consider the dilution that inhibits flashback due to slowing dawn the burning velocity of a lean flame. We investigate to compare the diffusion coefficients D. It is assumed that the concentration gradient are not much different among T_w because of the same experimental conditions of ϕ. D are shown in the Table 1 at the temperature of 1169, 118 and 1244K (T_w = 323, 373 and 473 K) by using T. C. measurement just behind the flame (x = 8mm and y = 1.5mm). These results indicate that the methane easily diffuses into ambient air at high T_w. D at T_w = 473K is about 1.1 times as large as that at T_w = 323K, the effect that makes S_u small becomes large at high T_w (= 473K) too.

It is necessary to discuss a flashback mechanism of quenching distance and recirculation effect in the vicinity of the burner rim in addition to the theory adopted from Lewis and von Elbe.

Conclusion

In this study, the effects of flame stretch rate, heat flux to the burner and diffusivity of the deficient reactant become clear at the lean methane/air flame base just before flashback. Results show that these factors have inhibitory effects on flashback for a higher burner temperature than a lower burner temperature.

Reference

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SUN, C. J., Sung, C. J., He. L. and Law, C. K. 1999 *Combustion and Flame* 118: 108-128.