J Vis (2010) 13:183–185
DOI 10.1007/s12650-010-0030-5

SHORT PAPER

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Measurement of temperature distribution for the flickering phenomenon around the premixed flame by using laser speckle method

Received: 18 October 2009 / Accepted: 17 February 2010 / Published online: 15 April 2010

1 Introduction

Buoyancy plays an important role in flames with low-fuel velocity. It was reported that the flame repeated rising and descending when the fluid around the flame was static (Durox et al. 1990; Kato et al. 1998; Sato et al. 2001). The phenomenon is called flickering and was investigated indirectly using a video camera, a photo diode, etc. However, there is no paper on the relationship between the flickering and the temperature field.

In this paper, the time course of the temperature field around the premixed flame has been measured by using the laser speckle method (Fujisawa et al. 2009) with high-speed camera, paying attention to the flickering.

2 Experimental apparatus and procedure

To obtain the premixed flame, methane gas at the rate of 1.2 L/min and air at 12 L/min are premixed and fed into a stainless pipe with 12 mm internal diameter, d_i, and 1.5 mm thickness. The equivalence ratio is 0.95. The temperature distribution in the premixed flame is measured by using the laser speckle method (Fujisawa et al. 2009). The light of the argon ion laser, whose noise is cut by a special filter, is dispersed by ground glass. Then, the laser speckle patterns are formed and collimated by the plano-convex lens. The speckle patterns around the flame are taken by the high-speed camera with 1,024 × 1,024 pixels. In this study, the maximum displacement of the speckles is about 2 pixels. The frame rate of the camera is 500 frames/s. The displacement between the speckle patterns with the flame and without the flame is calculated by the PIV method. The temperature distribution is calculated by using the movement distance and the following Gladstone–Dale's equation (Fujisawa et al. 2009).

$$\begin{aligned} n &= 1 + K\rho \\ &= 1 + K\frac{PM}{RT} \end{aligned} \quad (1)$$

where n, K, ρ, P, M, R and T show refractive index (–), Gladstone–Dale's constant (m^3/kg), density (kg/m^3), pressure (Pa), molecular weight (g/mol), gas constant (=8.314 J mol^{-1} K^{-1}) and temperature (K), respectively.

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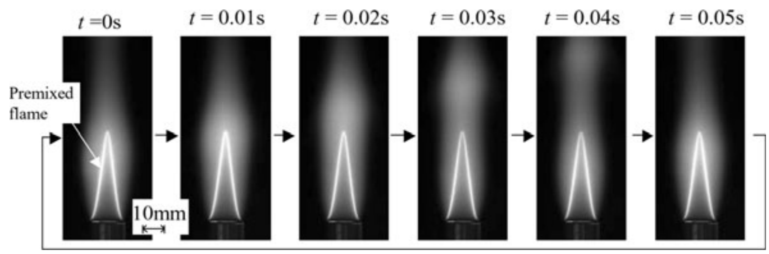

Fig. 1 Snapshots of the premixed flame with the flickering

Furthermore, the visualization of the premixed flame is also conducted by using the high-speed camera. The temperature measurement and the visualization are conducted individually.

3 Results and discussion

Figure 1 shows the time course of the visualization for the premixed flame. At $t = 0$ s, the flame consists of the internal premixed flame and the external diffusion flame. The distance between edges of the diffusion frame has the maximum value at the top of the premixed flame. The configuration of the internal premixed flame, which can be decided by the combustion rate due to the equivalence ratio and the total gas flow rate, does not change even if the time passes. On the other hand, the position of the maximum distance between the edges of the external diffusion flame moves downward with time. At $t = 0.03$ s, the external diffusion flame becomes constricted near the top of the internal premixed flame. After the elapse of more time, the constricted structure moves downward and vanishes. The external diffusion flames at $t = 0.05$ s and at $t = 0$ s have almost the same configuration. According to Kato et al. (1998), the frequency of the flickering changes from 10 to 20 Hz at 0.6 mm $< d_i <$ 2.8 mm. As the frequency in the present work, which can be decided by the density gradient between the gas around the premixed flame and the ambient air, is about 20 Hz, the mechanism of the flickering does not depend both on the type of the flame and the nozzle diameter.

Figure 2 shows the time course of the temperature distribution for the premixed flame. At 0 s $\leq t \leq$ 0.01 s the vortex generates around the external diffusion flame near the nozzle exit because of Kelvin–Helmholtz instability (Kato et al. 1998). As new air is supplied by the vortex, the combustion is accelerated near the nozzle exit. As a result, a high-temperature zone is formed. As combustion rate

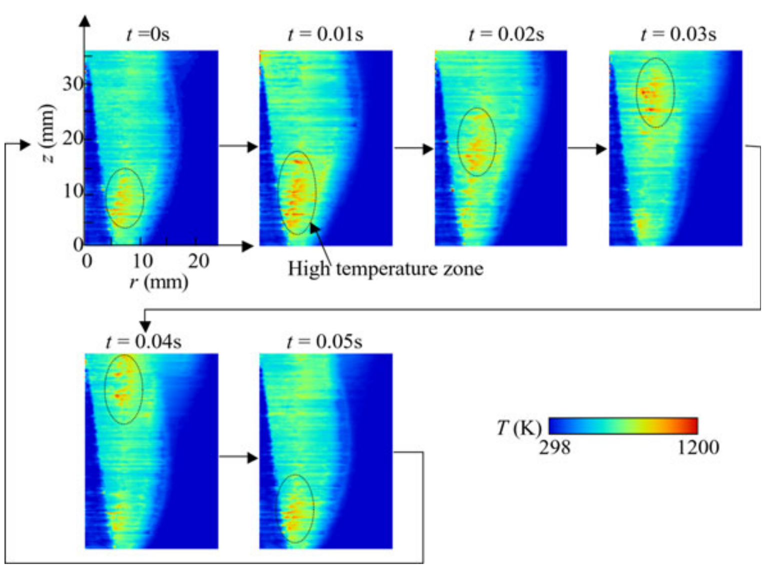

Fig. 2 Time course of the temperature distribution for the premixed flame by the laser speckle method

decreases at the nozzle exit due to the presence of excessive oxygen with low temperature at $t = 0.02$ s, the gas at this region falls in temperature. At 0.02 s $\leq t \leq$ 0.04 s, the accelerated zone of the combustion is shifted downwards as time elapses. Furthermore, at $t = 0.05$ s, the accelerated zone of the combustion appears also near the nozzle exit and then the temperature distribution is almost same as that at $t = 0$ s. In Fig. 2, the maximum temperature of the premixed flame is over 2,000 K so could not be shown. The thickness of the premixed flame suggested to about a few tens of micron to 200 μm (Mizutani 2006). The resolution of the PIV method is about 50 μm/pixel; therefore, the high temperature of the premixed flame could not be detected. Furthermore, there is the displacement of the speckles not only along the radial axis but also along the vertical axis. In the future work, the matter and the validity of the temperature measurement by the laser speckle method with high resolution will be studied.

Acknowledgments This work was partly supported by a Grant-in-Aid for Young Scientists (B) (No. 18760127) from the Ministry of Education, Science, Sports and Culture of Japan Society for the Promotion of Science, JSPS Core-to-Core program (No. 18004) and Tokuyama Corp. Our special thanks are extends to Prof. S.E. Pratsinis and Prof. W.J. Stark in ETH Zurich for the discussion of the particle formation in the premixed flame.

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