Characteristics of the Diffusion Flame with a Hole in the Stagnation Region of an Axisymmetric Impinging Jet

Hiroyuki Torikai, Akiko Matsuo, Toshihisa Ueda and Masahiko Mizomoto
Department of Mechanical Engineering Keio University
Hiyoshi, Kohoku-ku, Yokohama 223-8522, Japan
e-mail:m966203@msr.st.keio.ac.jp

Key words: Laminar Flame, Diffusion Flame, Edge Flame, Stability, Impinging Jet

INTRODUCTION

A stabilizing mechanism of diffusion flames is of both fundamental and practical importance on design and operation of combustion systems. It is well known that the stability of a diffusion flame is dominated by characteristics of the edge flame. The edge flame is roughly considered as a flame sheet edge formed in a partially premixed region. However there is no consensus on the stabilizing mechanism of an edge of a diffusion flame. Many configurations and methodologies have been adopted in the study on the role of the edge flame for the flame stability and the structure of the edge flame. In a jet configuration, the flow field around the edge flame is complex because of the occurrence of an entrainment of the surrounding air and the influence of the shape of a burner rim. (Takahashi et al. (1988)). A diffusion flame, formed in a boundary layer of a flat plate with fuel injection, is easy to grasp the flow field around the edge flame, but the flame is formed as two dimensional shape having the lateral flame edges which affect the stabilizing phenomena (Ueda et al. (1982), Ramachandra et al. (1984)). On the other hand, a counterflow burner has been successful to study extinction mechanism of a pure diffusion flame because the flow field is simple and is uniquely determined by a stagnation velocity gradient. Moreover, valuable information on reaction kinetics can be derived from the extinction conditions of a counterflow diffusion flame (Tsuji et al. (1966)).

By virtue of the above considerations, we proposed herein a novel burner system for stability study in the counterflow flame by closing a part of the fuel issuing exit with a solid disk. In the present work, the blowoff limits were measured with the novel burner by varying the fuel ejection velocity and the disk diameter for prevention of fuel issuing.

EXPERMENTTAL APPARATUS AND METHOD

The burner system consists of a round nozzle and a flat plate with a porous disc (Fig. 1). Air jet from the nozzle impinges on the plate, while a fuel, methane, is issued from the porous plate, and a diffusion flame is formed. A hole is made in the middle center of the flame by installing a solid disk over a central part of the porous plate surface. The diameter of disks is shown in Table 1. The stagnation velocity gradients were obtained from the air flow velocity profiles near the impinging plate without fuel ejection. The blowoff limits were measured on each porous plate by varying the stagnation velocity gradient. The stagnation velocity gradient aq (1/sec) is defined as the stagnation velocity gradient at which the whole flame blew off.

RESULTS AND DISCUSSION

FLAME APPEARANCE

Figure 2 shows typical flames. Figure 2(a) shows a pure diffusion flame with no disk. With increasing the disk diameter, the hole in the flame becomes gradually clear.

There are several blowoff types in the present burner. The blowoff processes are roughly categorized into two types. The type A is blowoff without any separation of the flame, and the type B with separation. In the type A, the flame keeps the stable flame shape until the flame suddenly blows off. The blowoff process of the type B in porous plate P4 is shown in Figs. 3. Figure 3(a) shows the stable flame shape. With an increase in the stagnation velocity gradient, the separation occurs in a part of the flame in Fig. 3(b). The separation region is spread over the flame surface shown in Fig. 3(c). Figure 3(d) shows the flame shape near the blowoff, and then the blowoff occurs abruptly. The blowoff processes over the fuel ejection velocity vf =15cm/sec in each porous plate are classified as shown in Table 1.

BLOWOFF LIMITS OF THE DIFFUISON FLAME WITH AND WITHOUT A HOLE

Figure 4 shows blowoff limits of methane diffusion flames with and without a hole as functions of fuel ejection velocity and the stagnation velocity gradient. When the fuel ejection velocity is small, the stagnation velocity gradient at the blowoff of each flame is steeply increased with increase in the fuel ejection velocity. If the fuel ejection velocity is sufficiently large, the stagnation velocity gradients at the blowoff of each flame become nearly constant. It indicates that there exist the critical stagnation velocity gradients of each flame. For a pure diffusion flame (P0), the blowoff at the small fuel ejection velocity is due to thermal quenching by interaction between the flame and the solid surface, and the blowoff at the critical stagnation velocity gradient is due to chemical limitation on the reaction rate of the flame zone (Tsuji et al. (1966)). The critical stagnation velocity gradient vf=20cm/sec in P0, is 349 1/sec, which quantitatively agrees with that of Tsuji et al. (1966). Since other porous plate indicates similar tendency with P0, the diffusion flames with a hole also have blowoff due to the limitation of chemical reaction rate and blowoff due to thermal quenching. The value of the critical stagnation velocity gradient decreases as the disk diameter is increased, in other words, the stability of the flame having a hole is decreased with increase of the hole diameter.

SUMMARY

A novel burner system is proposed for the stability study of an edge flame. In the burner, the diffusion flame with a hole is formed stably in the stagnation region of an axisymmetric impinging jet. Each diffusion flame with a hole has blowoff limit of the critical stagnation velocity gradient that indicates blowoff due to the limitation of chemical reaction rate. The critical stagnation velocity gradient decreases as the hole diameter of the flame is increased.

REFERENCES

Ramachandra, A., and Raghunandan, B., Combust. Sci. Technol., 36, 1984, pp.109-121.

Takahashi, F., Mizomoto, M., and Ikai, S., J. Heat Transfer 110, 1988, pp.182-189.

Takahashi, F., and Schmoll, W. G., Twenty-Third Symposium (International) on Combustion, The Combustion Institute, 1990, pp.677-683.

Tsuji, H., and Yamaoka, I., Eleventh Symposium (International) on Combustion, The Combustion Institute, 1966, pp.979-984.

Tsuji, H., and Yamaoka, I., Twelfth Symposium (International) on Combustion, The Combustion Institute, 1968, pp.997-1005.

Tsuji, H., and Yamaoka, I., Thirteenth Symposium (International) on Combustion, The Combustion Institute, 1970, pp.723-731.

Ueda, T., Mizomoto, M., Ikai, S., and Kobayashi, T., Combust. Sci. Technol., 27, 1982, pp.133-144.

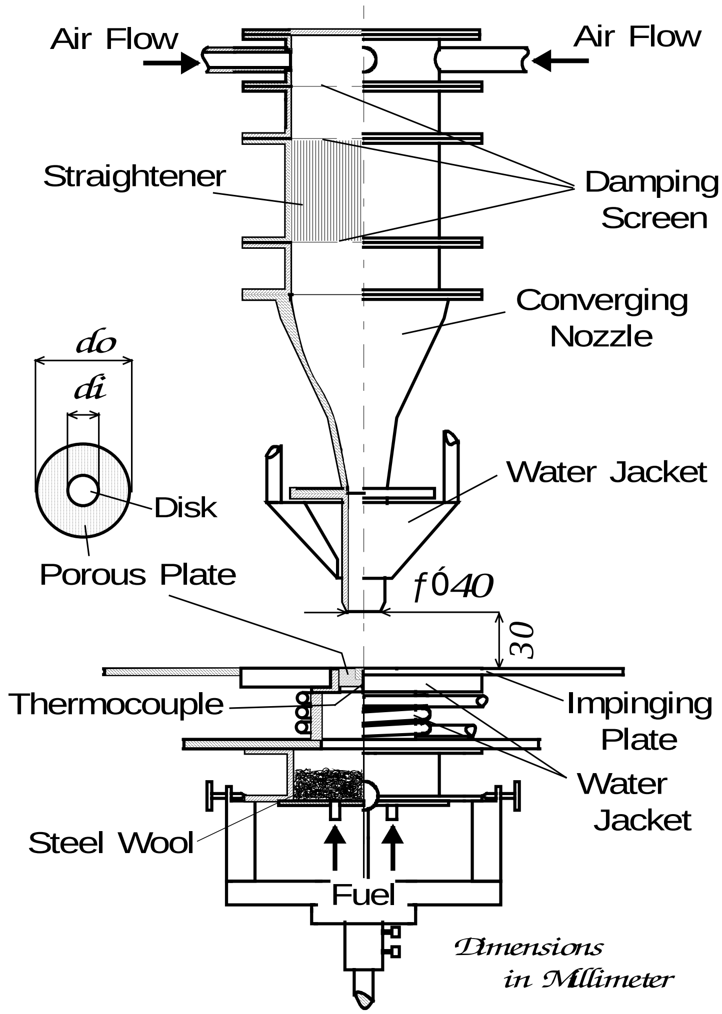
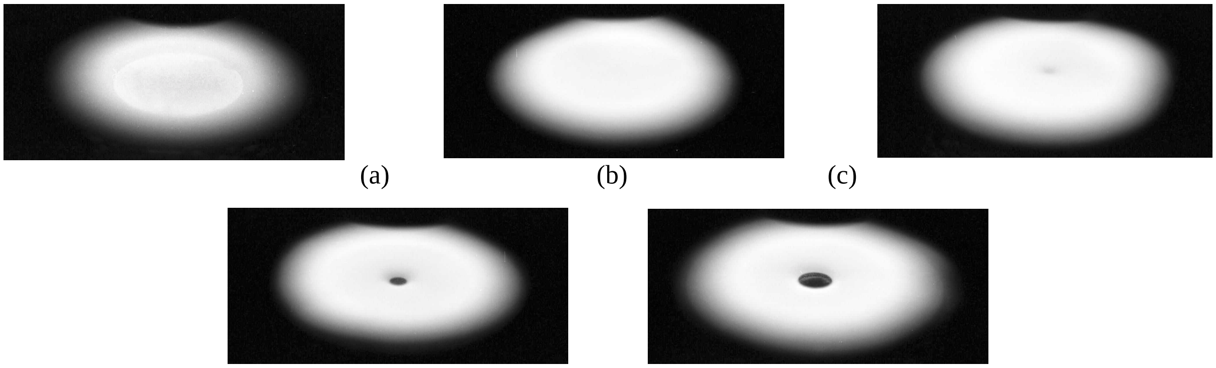


Figure 1 Experimental apparatus

Porous Plate	P0	P1	P2	P3	P4
Inner Diameter di[mm]	0.0	1.0	3.0	5.0	10.0
Inner Diameter di[mm]	40.0	40.0	40.1	40.3	41.2
Type of Blowoff	A	A	A	B	B

Table 1 Porous plate and type of blowoff process

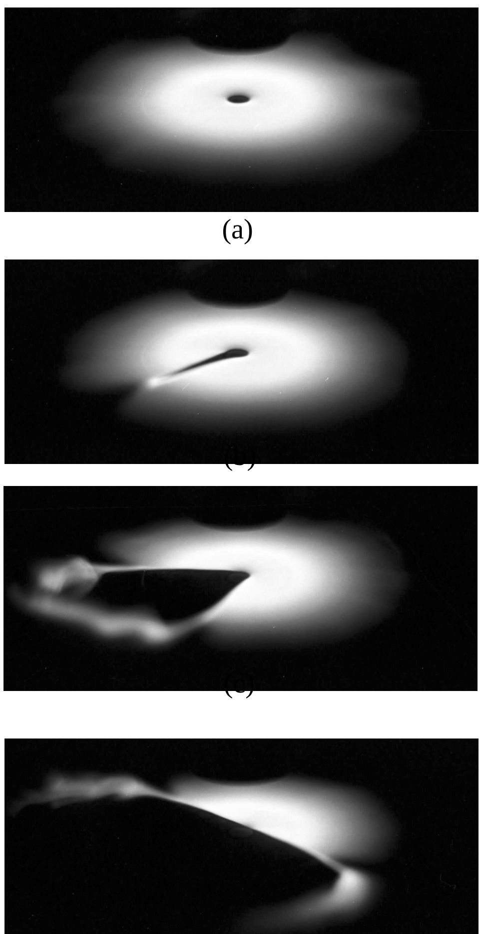


(a) (b) (c)

(d) (e)

Figure 2 Direct photographs of the flame
Fuel: Methane, Stagnation velocity gradient: a=46 1/sec,
Fuel ejection velocity: vf=4 cm/sec, (a) Porous plate: P0 (b) P1 (c) P2 (d) P3 (e) P4.

Figure 3 Blowoff process of the flame
Porous plate: P4, Fuel ejection velocity: vf=7 cm/sec



(a) (b) (c) (d)

(a) Stagnation velocity gradient: a=107 1/sec
(b) a=116 1/sec (c) a=128 1/sec (d) a=136 1/sec

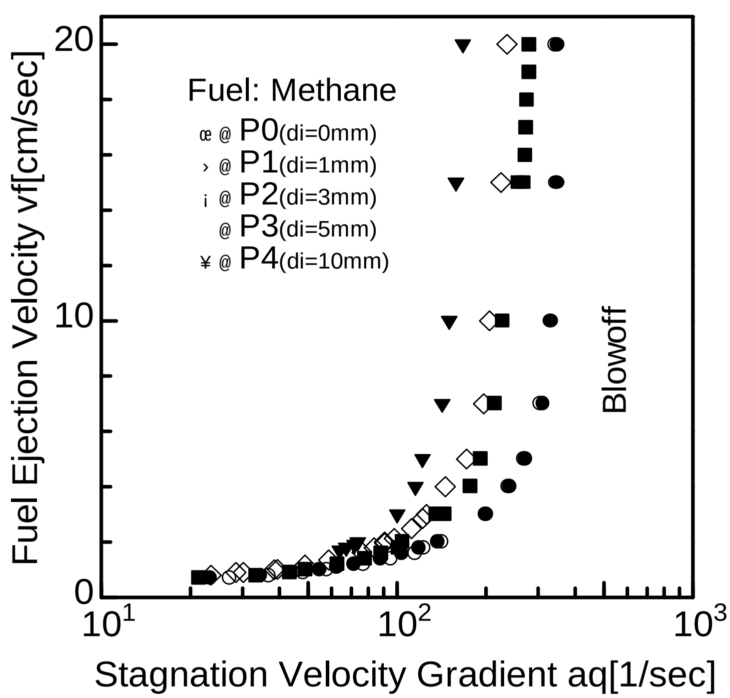


Figure 4 Blowoff limits