Experimental Study on the Anti-Blow-off Performance of Jet Diffusion Flame with Small Amount of Fuel at the Flame Base

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1 Introduction

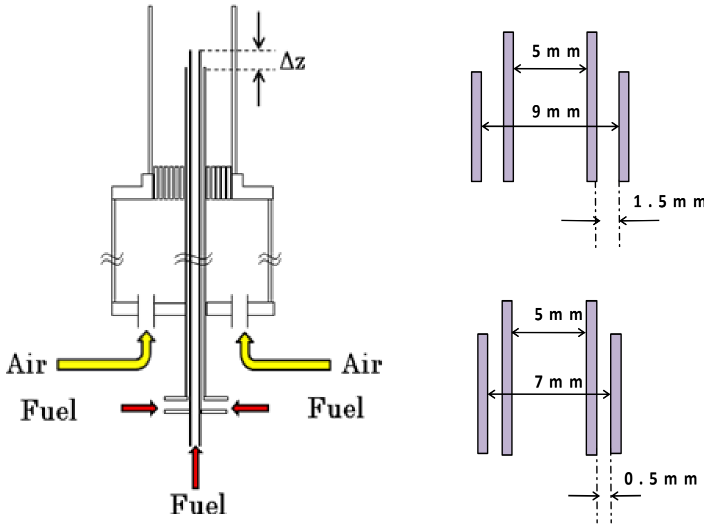
In recent years, as a solution for the fossil fuel depletion problem, biofuels such as biogas are attracting attentions because of its low impact to the global environment. Although biogas contains methane as the main ingredient, it also contains much carbon dioxide and nitrogen, which have negative effects on the flame stability since they depress the chemical reactivity due to the decreases of the flame temperature and the reactants concentrations. Actually, when this low-grade fuel is burned as a jet diffusion flame, it is very difficult to prevent blow-off. Since jet diffusion flame is a simple and widely used way of combustion, it must be an important technical issue to develop a new method to strengthen the stability of a weak jet diffusion flame in order to promote the utilization of biogas.

The mechanism of holding a jet diffusion flame at a burner rim changes a lot depending on the thickness of the rim and the flow velocity around it. As for a jet diffusion flame on an injector of small thickness, Takahashi and coworkers showed that there exists a "reaction kernel" which plays an important role in keeping the flame base at the rim [1, 2]. Based on their theory, we thought up an idea of adding a small amount of premixed gas at the rim for enhancing the reaction kernel by using a coaxial double tube burner, and performed a series of blow-off experiments for a pseudo biogas composed of methane and nitrogen [3]. In the study we investigated the influence of the gap between the exit positions of the longer inner tube and the shorter outer tube, Δz, and that of the equivalence ratio of the added premixed gas. As a result, it was found that the anti-blow-off performance almost monotonically increases with Δz for Δz < 12mm, and that as an additional gas without premixed air (i.e., ϕ=infinity) gives a sufficient effect when Δz is large. Moreover, it was suggested that the reaction zone "wing" formed at the flame base for large Δz is an exceptional configuration of tribrachial flame.

In this study, in order to examine the performance of this method more comprehensively, experiments for wider ranges of Δz and methane percentage of pseudo biogas were conducted. In addition, the effect of outer tube diameter was investigated.

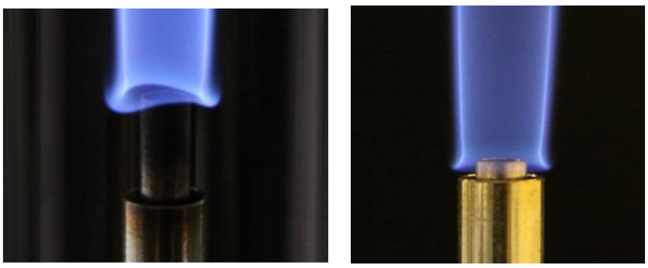
2 Experimental device

Figures 1(a) and 1(b) show a schematic view of the experimental device containing a coaxial double tube burner, and an enlarged view of the top portion of the double tube burner, respectively. In this study the gap Δz between the exit positions of two tubes is changeable. The inner tube size is 5mm (inner diameter)×6mm (outer diameter), while two kinds of tube are used for the outer tube. One's size is 7mm×8mm and the other's is 9mm×10mm. All tubes are made of stainless (SUS304). Pseudo-biogas fuel composed of methane and nitrogen is introduced from the bottom ends of the inner tube and the narrow passage between the two tubes, and injected from the top ends of them. Moreover, the ambient air is injected through a straw bundle set at the upstream around the outer tube, which is thought to rectify the air flow sufficiently. In order to isolate the air flow from the atmosphere, a glass chimney of 60 mm in inside diameter and 300 mm in length was installed.



(a) (b)

Fig. 1 (a) Schematic view of the coaxial burner, (b) Magnified view of the top of the coaxial tubes.



(a) (b)

Fig. 2 Direct photographs of the base of diffusion flames:
(a) Δz= 12 mm, (b) Δz= 2 mm.

3 Experimental result

In the previous studies we found that the added gas of pure fuel without air can sufficiently improve the anti-blow-off performance of the flame for large Δz [3]. Therefore, in this study we adopted only the fuel itself (the mixture of methane and nitrogen) as the gas to be added. We conducted two kinds of blow-off experiments, that is, by the ambient air and by the main flow of fuel. Figures 2 (a) and (b) show the typical appearance of flame base for Δz = 12mm and 2mm, respectively. It is seen that the "wing" is more clearly formed for Δz = 12mm. In the case of large Δz there is a wide region between the outer tube exit and the flame base, in which premixed gas of the added fuel and the ambient air is formed. Our numerical study [3] revealed that in the region there is a relatively steep gradient of equivalence ratio from lean to rich, which must be suitable to a tribrachial flame with only one wing [4].

In the experiments of blow-off by air, main fuel injection velocity U_{fuel} and the additional fuel velocity U_{add} were fixed 300cm/s and 50cm/s, respectively, and the methane concentration of the fuel is changed. In the experiments of blow-off by fuel, on the other hand, the ambient air velocity U_{air} and methane concentration of the fuel are fixed 10cm/s and 30%, respectively, and the additional fuel injection velocity U_{add} was changed from 0 to 60cm/s. In this study, we defined "blow off" as the fact that the flame base passes the position of 1cm downstream of the inner tube exit. Δz is changed from 4mm to 26mm for D_{out} (outer diameter of the inner tube) = 8mm, and from 4mm to 16mm for D_{out} = 10mm.

Figures 3 and 4 show the critical (blow-off) ambient air velocity U_{air} as a function of methane concentration in the fuel for D_{out} = 8mm and 10mm, respectively. It is seen that in all cases except Δz = 22mm for D_{out} = 8mm, the critical U_{air} decreases with the methane concentration, and increases with Δz in general. It is note that every Δz has a critical methane concentration under which flame cannot be held no matter how small the ambient air velocity is. Here, in order to make it easier to grasp the whole result of the critical methane concentration, Tables 1 and 2 list the critical U_{air} on the map of methane percentage vs. Δz. Not that the figures listed in the map are the values of critical U_{air}, and green figures and boxes mean that the flame can exist on the burner at least one condition of U_{air}. It is seen that the leanest condition of methane at which the flame can be held is 22% for Δz = 14mm and D_{out} =8mm, and 24% for Δz = 12mm and D_{out} =10mm. That is, there is the best value of Δz at which

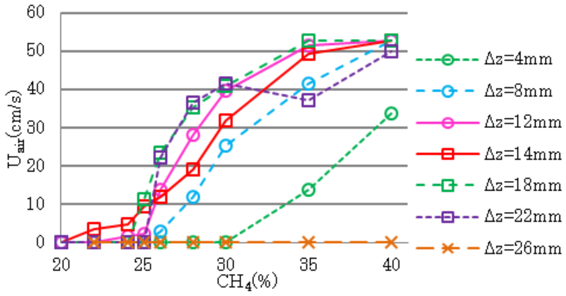


Fig. 3 Critical ambient air flow velocity as a function of CH_4 concentration. (D_{out}=8mm, U_{add}=50cm/s).

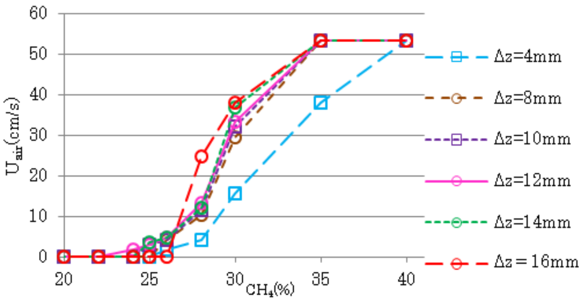


Fig. 4 Critical outer air flow velocity as a function of CH_4 concentration. (D_{out}=10mm, U_{add}=50cm/s).

Table 1 Mapping of critical outer air flow (cm/s). (D_{out}=8mm, U_{add}=50cm/s).

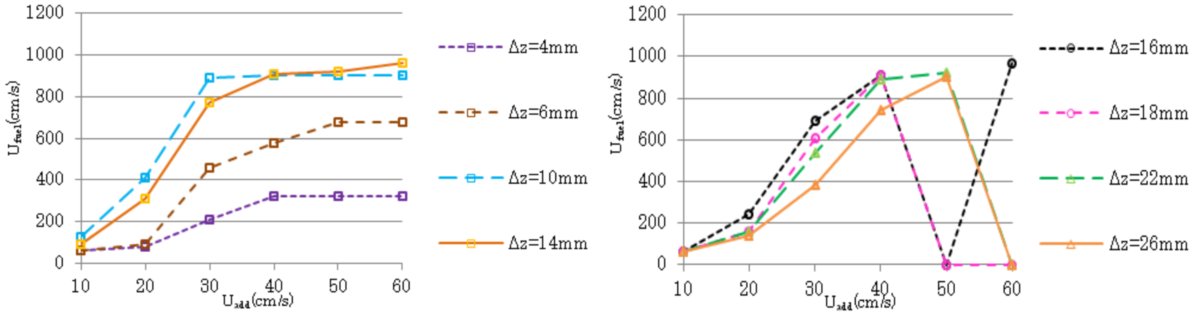
Δz(mm)	CH_4(%)	20	22	24	25	26	28	30	35	40
4		0	0	0	0	0	0	14	34	46
6		0	0	0	0	4	4	17	39	53
8		0	0	0	0	3	12	25	41	53
10		0	0	0	0	11	20	33	47	53
12		0	0	2	2	14	28	40	52	53
14		0	4	5	10	12	19	32	49	53
16		0	0	0	5	13	31	37	53	53
18		0	0	0	11	23	35	41	53	53
20		0	0	0	12	25	32	45	46	53
22		0	0	0	0	22	37	41	37	50
24		0	0	0	0	0	0	0	47	53
25		0	0	0	0	0	0	0	0	48
26		0	0	0	0	0	0	0	0	0

Table 2 Mapping of critical outer air flow (cm/s). (D_{out}=10mm, U_{add}=50cm/s)

Δz(mm)	CH_4(%)	20	22	24	25	26	28	30	35	40
4		0	0	0	0	2	4	16	38	53
6		0	0	0	0	1	7	30	53	53
8		0	0	0	0	4	10	30	53	53
10		0	0	0	3	4	12	32	53	53
12		0	0	2	3	5	13	33	53	53
14		0	0	0	4	5	12	37	53	53
16		0	0	0	0	0	25	38	53	53

the lowest grade fuel can form a jet diffusion flame, and for Δz larger than this best value the anti-blow-off performance decreases. Considering that any flame cannot be held for the methane percentage less than 40% in the case of Δz=26mm and D_{out} =8mm, which is thought to be close to the case without additional fuel, this lowest value of 22% is astonishing.

Figures 5 (a) and (b) show the critical fuel injection velocity U_{fuel} as a function of additional fuel velocity U_{add} for D_{out}= 8mm. It is seen that the critical U_{fuel} increases with U_{add} except the conditions of U_{add} > 40cm/s for Δz= 16mm and 18mm, and U_{add} > 50cm/s for Δz= 22mm and 26mm. Under these conditions the flame abruptly becomes very difficult to be held, and the reason for this has not been clarified yet. It is seen that the anti-blow-off performance increases with Δz up to Δz= 10mm, and further increase of Δz larger than 14mm does not bring about marked improvement of the performance.



(a) (b)

Fig. 5 Critical fuel injection velocity as a function of the additional fuel velocity (D_{out}=8mm, U_{air}=10cm, CH_4=30%)

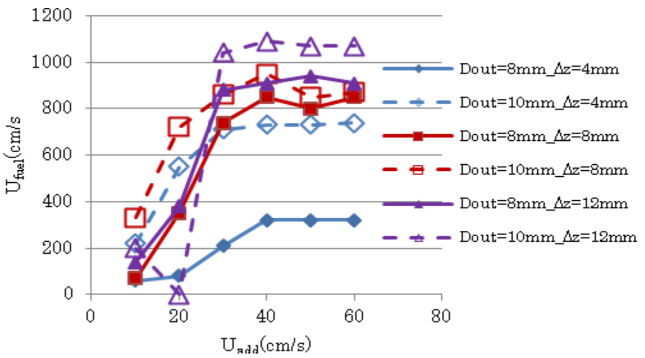


Fig. 6 Comparison of critical fuel injection velocity as a function of the additional fuel velocity (U_{air}=10cm/s)

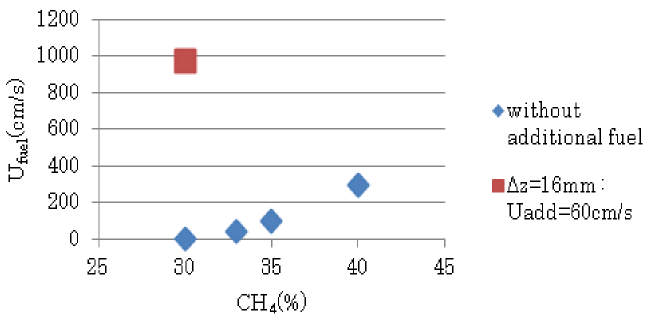


Fig. 7 Comparison of critical fuel injection velocity between with and without additional fuel (D_{out}=8mm, U_{air}=10cm)

Figure 6 compares the results of critical fuel injection velocity between D_{out}= 8mm and D_{out}= 10mm for Δz= 4, 8, 12mm. It is seen that, except the condition of U_{add}= 20cm/s and Δz= 12mm, the anti-blow-off performance is better for D_{out}= 10mm. Here, in examining the cause of this phenomenon, we have to be aware of the fact that the difference of D_{out} causes a large difference of the amount of additional fuel, in addition to the effect on the flow configuration. Figure 7 compares the anti-blow-off performance for the blow-off by fuel injection, between the cases with and without additional fuel. There plotted the value of 970cm/s for 30% methane, which is the peak value of critical U_{fuel} in this study (Δz= 16mm, U_{add}= 60cm/s). It is noted that for this methane concentration the flame cannot be held at all without additional fuel. Even for the 40% methane case, the critical U_{fuel} is less than 1/3 of the peak value of the 30% case with additional fuel.

5 Conclusions

In this study we conducted blow-off experiments of jet diffusion flame on a coaxial double tube burner in which small amount of additional fuel is added at the flame base, for a wide range of the gap between the two tube exits, Δz, and the methane concentration in the pseudo-biogas fuel. As a result, the following knowledge was obtained.

・In the case of blow-off by ambient air flow, Δz= 12~14mm is the best value, with which fuel of the lowest grade in this experiment (methane percentage is 22~24%) can be burned as a jet diffusion flame.

・In the case of blow-off by main fuel flow, Δz= 10~14mm show the best anti-blow-off performance. Δz larger than 14mm brings about an abrupt occurrence of difficulty of flame stabilization. D_{out} (outer diameter of the outer tube) =10mm show better performance than the D_{out} =8mm case.

References

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