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Flame stabilization with a tubular flame

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Abstract

A new technique to stabilize a flame in a high-velocity stream with use of a tubular flame has been proposed. To elucidate the validity of this technique, an experiment has been conducted by mounting a tubular flame burner on the nozzle. Flame stability limits and temperature distributions around the burner port have been determined, and experiments have been extended to the ducted combustion to measure pressure fluctuations and to analyze the burned gases. Results show that the tubular flame can successfully stabilize the main flame up to 130 m/s, which is the upper limit of the present supply facility. The main flame is well anchored at the exit of the nozzle, and the tubular flame efficiently supplies heat and radicals to the main flame. In the ducted combustion, the pressure fluctuations are reduced significantly. The exhaust gas analyses, however, indicate that an almost chemical equilibrium condition can be achieved at 50 m/s, but not at 90 and 130 m/s. Since the energy input relative to the main flame is just 6.1% at 130 m/s, the present tubular burner is not enough to burn all the unburned gas completely at high velocities, although the main flame can be anchored. The slit length and/or the slit width of the tubular flame burner should be larger to overcome this shortage. From the above results, it is concluded that the tubular flame has a potential for stabilizing a flame in a high-speed stream.

Keywords: Flame stabilization; Tubular flame; High-speed flow; Pilot flame

1. Introduction

Flame stabilization is one of the important subjects in combustion research, and many efforts have been made on this problem [1]. As illustrated in Fig. 1, conventional ways to stabilize flame in a high-speed stream are to insert a bluff body and to use its rear stagnation region with recirculation of hot burned gas [2–4] or to use an opposing jet to stabilize combustion in its stagnation region of low-velocity [5]. The pressure loss in the main stream, however, is significantly large because the drag force is proportional to the square of its velocity. To avoid this difficulty, one can use a recess wall or a step [6] and a pilot flame [7,8]. The flame, however, is prone to blow-off because the flow in the wall recess or the pilot flame is disturbed directly by the main stream; the hot recirculating gas in the wall recess or the pilot flame is damaged by strong velocity fluctuations of the main stream.

Recently, it has been found that a flame of tubular shape can be established in a stretched vortex flow (Fig. 2A) [9,10]. This flame is thermally stable because conductive heat loss behind the flame is negligible due to its symmetrical temperature distribution, and, in addition, the flame is also aerodynamically stable according to the Rayleigh stability criterion because the flow field

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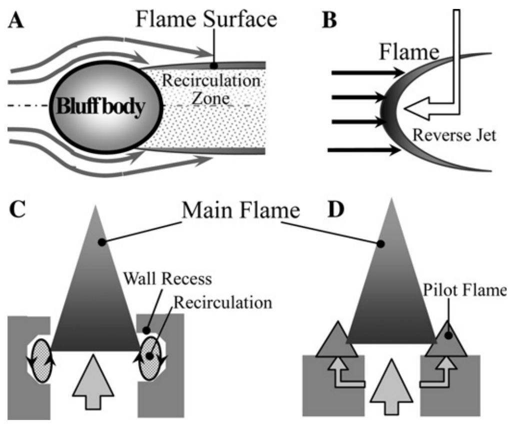

Fig. 1. Methods of flame stabilization, (A) bluff body, (B) opposing jet, (C) recess wall, and (D) pilot flame.

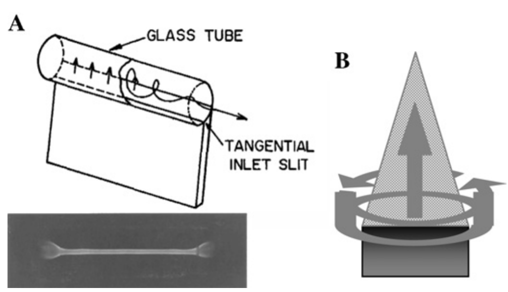

Fig. 2. Tubular flame and a proposed concept for flame stabilization with a tubular flame.

consists of an inner burned gas region of low density and an outer unburned gas region of high density. It is also interesting to note that the tube diameter within which a tubular flame is formed is increased from its original size of 13.4 mm [9] to 4 inc., and one end of the burner can be closed to use it as a tubular flame burner [11].

Thus, it is reasonable to reach an idea to put a tubular flame at the periphery of a high-velocity stream to stabilize the main combustion (see Fig. 2B). The tubular flame can be established in a rotating flow field near the wall, and the tangential flow is perpendicular to the direction of the main stream. The main stream is situated downstream the tubular flame. Thus, the tubular flame can be expected to be strong enough to supply hot gas and radicals to the main flame, without being disturbed by the main stream of high velocities.

As a first step, we conduct an experiment to show how well the tubular flame can stabilize a flame in a high-speed stream. In the following, the experimental apparatus used, and the obtained results on stability limit, temperature distribution, amplitude of pressure fluctuations, and exhaust gas analyses are presented. Just to note that from a fundamental viewpoint, this study initiates a new laminar flame problem, i.e., interaction between a laminar tubular flame and a main flame.

2. Experimental

Figure 3 shows the experimental set-up used in this study. The main burner consists of a diffuser, a settling chamber, and a contraction nozzle, which ensures a flat velocity profile at the exit of the nozzle. The exit diameter is 18 mm. To stabilize the main flame, a tubular flame burner was mounted on a plate at the plane of the nozzle exit. The inner diameter of the tubular flame burner is 50 mm. A combustible mixture is tangentially injected from four tangential slits 2-mm wide and 30-mm long, and a flame of tubular shape can be established near the inner wall of the burner. The length of the inner wall is 60 mm.

To obtain a high-velocity at the nozzle exit, a turbo blower that provides a maximum flow rate of 6 m^3/h with a maximum static pressure of 1300 mm-Aq (Mutoh, MI-12N/6) was used. This gives flow velocities up to 130 m/s at the nozzle exit. A compressed air was fed to the tubular flame burner from a compressor. Fuel used was propane. Flow rates of these gases were metered with calibrated float-rotameters and then, they were mixed and fed to the burners. Temperature profiles were determined with a silica-coated, Pt/Pt-13%Rh thermocouple, whose wire diameter was 0.2 mm. No corrections for radiative heat loss have been made.

To demonstrate how well the tubular flame can stabilize combustion in a high-speed stream, a stainless steel tube of 100-mm diameter and 500-mm long was mounted on the tubular flame burner and used as a combustion chamber. To fix this tube with a plate of 15-mm thick, the length of the inner wall of the tubular flame burner was shortened to 45 mm. A quartz tube of 100-mm

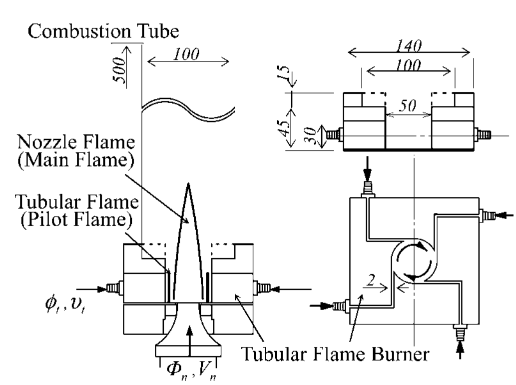

Fig. 3. Schematics of the experimental apparatus.