Recent Developments of Tubular Flame Burners

S. Ishizuka

Graduate School of Engineering, Hiroshima University
1-4-1 Kagamiyama, Higashi-Hiroshima 739-8527 Japan

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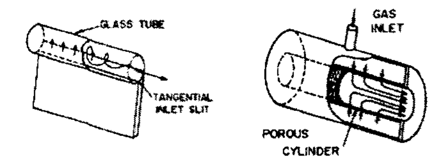
Abstract: As a new type of flame, tubular flame has attracted much attention from a fundamental viewpoint and many experimental and theoretical studies have been made on its characteristics. Recently, it is also recognized that the tubular flame has great potentials as practical combustor because its stability range is very wide in fuel concentration and also in injection velocity. Thus, tubular flame burners have been developed for various kinds of fuels. They are gaseous fuels of methane, propane, hydrogen, and by-product fuels gases in steel making processes including BFG (Blast Furnace Gas), LDG (LD Converter Gas), and COG (Cokes-Oven Gas), liquid fuels of kerosene, A-type and C-type heavy oils, and a solid fuel of biomass powder. In this paper, recent developments of the tubular flame burners have been briefly introduced.

A tubular flame can be established in a rotating, as well as non-rotating, axisymmetric, stretched flow field (see Figs.1-2[1]). This flame consists of an inner region of hot burned gas and an outer region of cold unburned gas, between which exists a thin tubular shaped reaction zone. Due to its symmetrical temperature distribution, an almost adiabatic condition is achieved. Additionally, due to the rotational motion in the swirl-type burner, the flame is aerodynamically stabilized. In fact, the lean and rich limits are very close to the flammability limits determined by the standard method (see Table 1[2]).



(a) Swirl type (b) Counterflow type

Fig.1. Two types of tubular flame burners [1].

Fig.2. Appearance of flame (Swirl type).

Table 1. Lean and rich limits of tubular flames [2].

Reference	Method		CH_4 Lean	CH_4 Rich	C_3H_8 Lean	C_3H_8 Rich	H_2 Lean
This work	Tubular	$D = 13.6$ mm	5.3	13.0	2.6	9.0	4.5
	flame	$D = 18$ mm	4.9	13.2	2.3	10.0	3.8
	(rotating)	$D = 21$ mm	4.8	13.7	2.3	10.2	3.7
		$D = 28$ mm	4.6	14.0	2.2	—	3.5
Ishizuka	Tubular flame (nonrotating)		4.7	15.1	2.0	9.8	4.2
Zabetakis	Propagating flame		5.0	15.0	2.1	9.5	4.0
Ishizuka and Law	Binary flame		4.8	15.8	2.0	9.7	4.1

Thus, the tubular flames have great potential as practical combustors. At present, various scales and types of tubular flame burners have been developed. Figure 3 shows the setup of a 0.2 MW tubular flame burner with a diameter of 4 inches and a length of about 1.2 meters. The fuel/air premixture is injected tangentially from the closed end and the burned gas exits from the open end. A large area laminar flame up to 0.3 m^2 can be easily established inside the burner (see Fig.4). The temperature and compositions of the burned gas determined by thermocouples and gas chromatography are almost the same as those calculated by assuming chemical equilibrium.

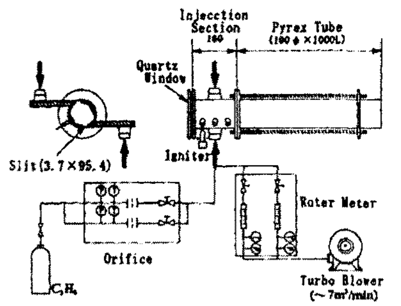


Fig.3. A tubular flame burner of 0.2 MW[3].

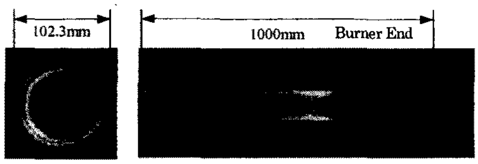


Fig.4. Appearance of flame (Fuel: Methane, Equivalence ratio: 0.6, Air flow rate: 140 m^3/h) [3].

This burner, however, needs pre-mixture of fuel and air; dangerous flame flash-back may happen to occur. This becomes a barrier for making a large-sized, and hence, large heat-output tubular flame burner. This barrier can be overcome by injecting fuel and oxidant separately from different slits (Fig.5). In spite of separate injection, a tubular flame with a uniform flame front could be successfully obtained. Figure 6 shows an optically accessible tubular flame burner for this study. It has four quartz windows at its periphery and a round quartz window at its closed end. As shown in Fig.7, tubular-shaped flames can be obtained for the rapidly mixed combustion as well as for premixed combustion.

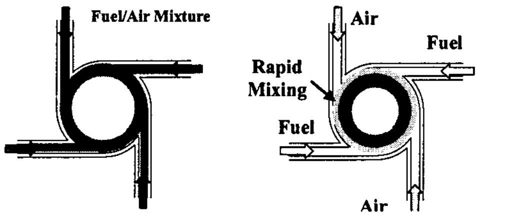


Fig.5. Premixed and rapid mixing type combustion [4].

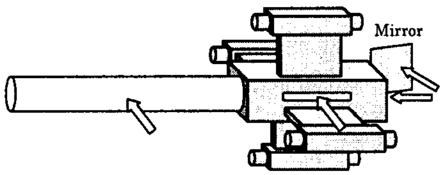
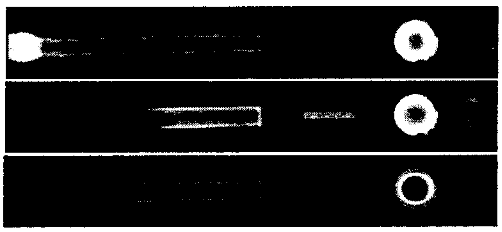
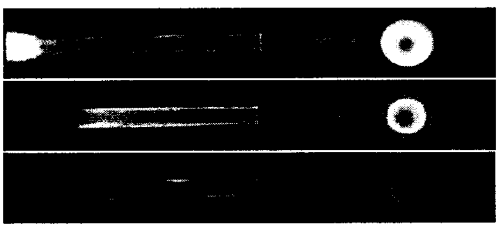


Fig.6. An optically accessible tubular flame burner [4].



(a) Premixed combustion



(b) Rapidly mixed combustion

Fig.7. Appearance of flames (burner diameter: 52 mm, equivalence ratio, 1.2 (upper), 1.0 (middle), 0.7 (lower), air flow rate : 60m^3/h, fuel : methane) [4].

A recent finding of interest is that although the flame structure of the rapidly mixed combustion is different from that of the premixed combustion; the peak concentration of OH and CH in the flame zone are much reduced and the NO concentration in the flame zone is also reduced; i.e., the prompt NO in the flame zone can be reduced by controlling the flame structure through the mixing (Fig.8). Thus, the rapidly mixed combustion has a potential for reducing NOx emission through the mixing.

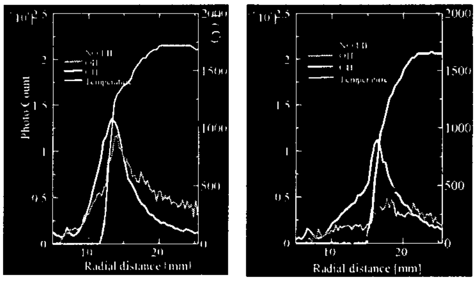


Fig.8. Radial profiles of temperature, CH, OH, and NO in the premixed (left) and rapidly mixed (right) combustion.[4]

This rapid-mixing type tubular flame combustion can be also achieved by injecting a liquid fuel directly with a spray nozzle. Figure 9 shows the schematic of the burner and the flame appearance. A blue flame can be successfully obtained for lean combustion. A recent determination with a LII system shows that with increasing the swirl intensity, the concentration of primary soot is much reduced. Thus, the tubular flame burner has a potential also for reducing SPM. A larger tubular flame burner of 2 MW, which diameter is 12 inches, has been developed, and a 40-MW burner for power station is under consideration.

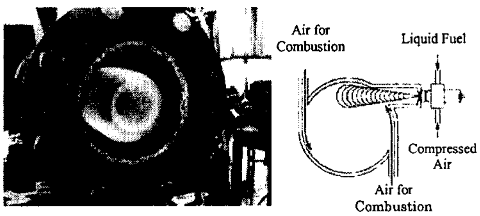


Fig.9. A tubular flame burner with direct injection of a liquid fuel (burner diameter: 5 inches, fuel: kerosene).

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[References]

[1] Ishizuka, S., Proc. Combust. Inst. 20(1985)287-294. [2] Ishizuka, S., Prog. Energy. Combust. Sci.19 (1993)187-226. [3] Ishizuka, S., et al.: Transactions of JSME 65(1999)3845-3852. [4] Ishizuka, S., et al: to appear in Proc. Combust. Inst. 31.