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Investigation of hydrogen and electrolytic oxy-hydrogen addition to propane flames using planar laser-induced fluorescence

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ABSTRACT

The effect of H_2 and electrolytic oxy-hydrogen (EOH) on lean burn (LB) hydrocarbon (propane) flame was investigated using planar OH laser-induced fluorescence (LIF). Analysis of OH species in EOH- and H_2-blended flames was conducted under ultralean ($\Phi = 0.15$) burn conditions. A stability map of the flame was obtained for various equivalence ratios (0.1–1) with H_2 and EOH addition. The stable region of the flame expanded up to a very low equivalence ratio (0.1) with 40% EOH. The EOH-blended flame had a smaller flame height than the H_2-blended flame because of the higher laminar burning speed of the former. The OH concentration in the EOH-blended flame was much higher than that in H_2-blended flame under LB conditions. The OH concentration remained high for the EOH-blended flame with decreasing equivalence ratio or increasing Reynolds number. EOH addition thus enhances OH species generation and the laminar burning velocity of lean burn flame.

1. Introduction

Hydrocarbon fuel is widely used in various applications, for example, as an industrial energy supply and in commercial burners. Because of the growing global energy consumption and increasing concern about the environment, research on high-efficiency clean combustion has been attracting much attention. Lean mixture combustion has great potential to increase the thermal efficiency and decrease emissions. However, hydrocarbon fuels have limitations such as low flame stability and low ignitability under lean burn conditions. Hydrogen is a potential fuel that can be used to generate pollution-free clean energy, and researchers continue to analyze its flame. However, its severe flashback and unstable flame propagation under lean burning conditions limit its use in most practical combustors. Hydrogen also explodes easily because of its wide range of flammability limits (4.65–93.9%) and thus requires special handling equipment for safety. One means of overcoming these drawbacks is to use a mixture of hydrogen and hydrocarbon fuels. The addition of hydrogen has been found to effectively increase the lean burn limit of hydrocarbon fuels [1]. It has been demonstrated that the addition of hydrogen can enhance the flame stability of hydrocarbon fuels under lean conditions [2]. Choudhuri and Gollahalli [3] studied the characteristics (flame length, pollutant emission, radiative heat loss fraction, and volumetric soot concentration) of hydrogen-hydrocarbon blended fuel for various mass fractions of hydrogen. Zhen et al. [4] measured the emission and heat transfer of a premixed propane-hydrogen flame for various mass fractions of hydrogen, reporting an increase in the flame temperature and NOx emission and a decrease in CO emission. The more efficient oxidation of CO into CO_2 reveals that the addition of hydrogen induces a more complete combustion (30% reduction of CO concentration). The laminar burning velocities and combustion characteristics of propane-hydrogen-air premixed flames were measured by using a spherically expanding flame; the analyses were carried out at elevated pressures and temperatures and with different hydrogen fractions [5,6]. Trang et al. investigated the origins of the enhanced burning rate, intensified reactivity, and increased flame temperature by measuring the laminar flame speeds of butane-air mixtures with hydrogen addition [7]. Further, the effects of the hydrogen fraction and equivalence ratio on the laminar flame speed of syngas were studied by using OH-PLIF images [8,9].

However, from a practical perspective, hydrogen addition has some limitations, such as storage difficulties and safety risks. On-board electrolytic hydrogen production can overcome the

Abbreviations: EOH, electrolytic oxy-hydrogen; LHV, lower heating value; LIF, laser-induced fluorescence; MFC, mass flow controller.

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limitations of pure hydrogen addition. Electrolytic oxy-hydrogen (EOH) gas is a stoichiometric mixture of hydrogen and oxygen produced from water through electrolysis [10]. The addition of hydrogen and oxygen was predicted to be more beneficial than the addition of pure hydrogen in terms of flame speed, temperature, lean flammability limit, and CO concentrations [11]. Since the

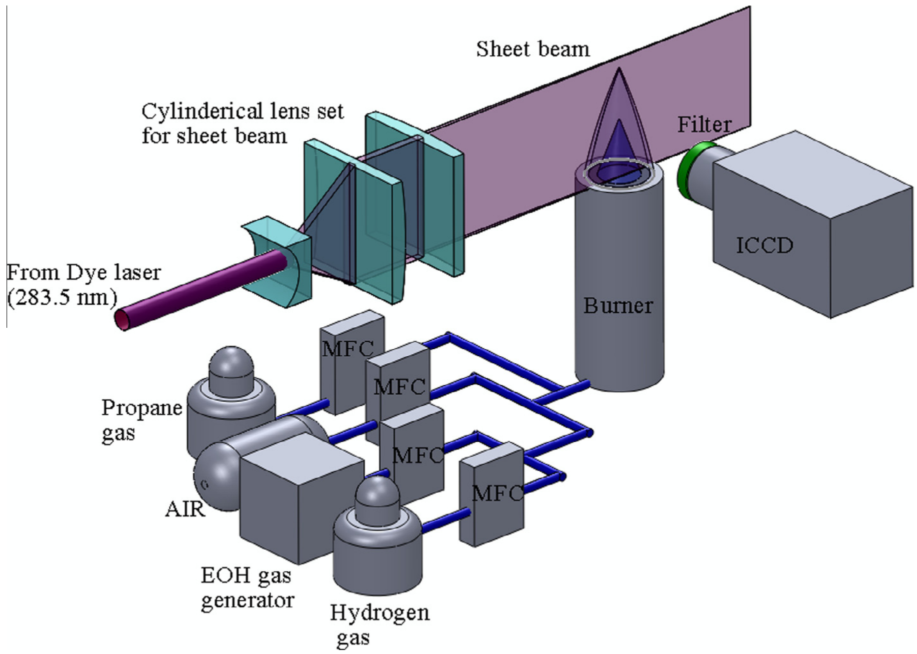

Fig. 1. Experimental setup.

Table 1
Investigated operating conditions for H_2 addition at *Re* = 1200 and Φ = 0.68.

$\propto$ (H_2) (%)	Air volume flow rate (cc/min)	Propane volume flow rate (cc/min)	H_2 volume flow rate (cc/min)	Fuel/air mixture volume flow rate (cc/min)	Mean exit flow velocity (m/s)	Viscosity of fuel/air mixture (10^{-5} N s/m^2)
0	6127.11	195.03	0	6322.15	1.34	1.74
10	6126.17	192.85	21.42	6340.462	1.34	1.74
20	6125.02	190.20	47.55	6362.788	1.35	1.73
30	6123.59	186.90	80.10	6390.612	1.35	1.73
40	6121.77	182.68	121.78	6426.248	1.36	1.73
	Propane mass flow rate (10^{-4} kg/min)	H_2 mass flow rate (10^{-6} kg/min)	Energy input rate of propane (J/s)	Energy input rate of H_2 (J/s)	Energy input rate of propane/H_2 mixture (J/s)	Flame heights (mm)
0	1.35	0.00	104.43	0.00	104.43	19.82
10	1.34	1.74	103.27	3.49	106.76	18.71
20	1.32	3.87	101.85	7.74	109.59	18.50
30	1.30	6.51	100.08	13.05	113.13	18.19
40	1.27	9.90	97.82	19.84	117.66	17.86

Table 2
Investigated operating conditions for EOH addition at *Re* = 1200 and Φ = 0.68.

β (EOH) (%)	Air volume flow rate (cc/min)	Propane volume flow rate (cc/min)	EOH volume flow rate (cc/min)	Fuel/air mixture volume flow rate (cc/min)	Mean exit flow velocity (m/s)	Viscosity of fuel/air mixture (10^{-5} N s/m^2)
0	6127.11	195.031	0.00	6322.15	1.34	1.74
10	6121.55	194.85	21.65	6338.05	1.34	1.73
20	6114.60	194.63	48.65	6357.90	1.34	1.73
30	6105.70	194.35	83.29	6383.34	1.35	1.73
40	6093.87	193.97	129.31	6417.16	1.36	1.73
	Propane mass flow rate (10^{-4} kg/min)	EOH mass flow rate (10^{-6} kg/min)	Energy input rate of propane (J/s)	Energy input rate of EOH (J/s)	Energy input rate of propane/EOH mixture (J/s)	Flame heights (mm)
0	1.35	0.00	104.43	0.00	104.43	19.72
10	1.35	1.73	104.34	2.31	106.65	18.54
20	1.35	3.89	104.22	5.20	109.42	19.07
30	1.34	6.66	104.07	8.90	112.97	16.87
40	1.34	10.34	103.86	13.82	117.68	15.35