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Intrinsic Instability of C_3H_8/C_4H_{10} /air flames on Ceramic Porous Board

Amornrat Kaewpradap[1,*] and Sumrerng Jugjai[1]

[1] Department of Mechanical Engineering, King Mongkut's University of Technology,
126 Prachauthit Road, Bangkok, 10140, Thailand
[*] Corresponding Author: amornrat.kae@kmutt.ac.th, +66-2470-9267, +662-470-9111

Abstract

In this present, C_3H_8/C_4H_{10} mixtures as the main compositions of Liquefied Petroleum Gas (LPG), are used widely in Thailand for combustion in household and replacement of fossil fuel in the parts of transportation and industry. This study, the ratio of C_3H_8/C_4H_{10} mixtures were used as 70% and 30%, respectively to investigate the intrinsic instability of C_3H_8/C_4H_{10}/air flames on ceramic porous board. In order to reduce the emission of fossil fuel, it was focused to smartly control the lean combustion system of C_3H_8/C_4H_{10}/air mixtures in this study. Since the lean combustion was treated with variation of equivalence ratio (ϕ), the cellular flames formed owing to diffusive-thermal instability. When the equivalence ratios were varied, the cell size and the light emission were observed as the characteristics of intrinsic instability. As the results, the cellular flames were observed at ϕ = 0.49-0.57 and the premixed flames blew off at ϕ < 0.45. When the equivalence ratio decreased, the cell size was greater and the light emission was more complicated due to the increase of instability intensity. This result showed that the cell size and light emission of cellular flames elucidated the intrinsic instability of C_3H_8/C_4H_{10}/air mixtures.

***Keywords**:* Intrinsic instability, C_3H_8/C_4H_{10}/air mixtures, Ceramic porous board, Cellular flame.

1. Introduction

In the past, the combustion derived from fossil fuel, is applied for both industrial and private sectors, which emits carbon dioxide and nitrogen oxide as the greenhouse gases. To reduce the emission gases, fossil fuel was taken place with low carbon fuel such as liquefied petroleum gas (LPG) and natural gas (NG)[1]. However, the reduction of greenhouse gases was concerned for LPG/air combustion. In order to decrease the emission gases, the lean combustion system was studied such as hydrogen/air combustion and methane/air combustion [2-4]. The lean combustion is that the mass diffusion of deficient reactant is in excess of heat diffusion then the cellular flame forms due to the diffusive-thermal instability [5-6]. In lean combustion premixed flames, diffusive-thermal instability has a great influence on the unsteady behavior, flame shape, diffusive-thermal instability and thermal instability. The cellular flame structure induced by intrinsic instability, was experimented and performed by Markstein [7-8].

Intrinsic instability, there are three basic phenomena of premixed flames, i.e. hydrodynamic instability, diffusive-thermal instability and body-force instability [9]. The hydrodynamic instability is caused by the thermal expansion of reactive gases through the flame fronts. The diffusive-thermal instability is caused by the preferential diffusion of mass and heat and it has a destabilizing and stabilizing instabilities for Lewis number (Le<1.0) and Le>1.0, respectively [10-11]. The body-force instability is caused by the different density between above and below gases. However, the influence of the body-force instability depends on the flame propagation at sufficiently small burning velocity. Actually, the premixed flames are during the high burning velocity range, which are hardly affected by the body-force instability.

As the study the past, hydrocarbon/hydrogen/ carbon monoxide/air premixed flames was studied with addition of methane and the cellular flames occurred by intrinsic instability [12]. The study of $CH_4/O_2/CO_2$ flames to perform and qualify the cellular structure due to intrinsic instability [13]. Moreover, the shape, fluctuation and size of cellular flames were investigated to smartly control the lean combustion system [14]. The previous study, the $CH_4/C_2H_6/CO_2$ flames on ceramic porous board was experimented to study the cell size and lighting emission of cellular instability intensity [15]. The equivalence ratio for cellular premixed flames of $CH_4/C_2H_6/CO_2$ mixtures is 0.88-0.95 and premixed flames blew off at ϕ < 0.85. When the equivalence ratio becomes lower, the cell size increases and the normalized of light emission intensity becomes higher owing to intrinsic instability.

This present, the combustion in household transportation and industry parts, LPG was used widely in Thailand [16]. For LPG in Thailand, it mainly composed of propane (C_3H_8) and butane (C_4H_{10}) [17]. The composition of LPG for this study was selected as the ratio of C_3H_8/C_4H_{10} mixtures used as 70% and 30%, respectively. To reduce the greenhouse gases, it is necessary to study the lean combustion of C_3H_8/C_4H_{10}/air. The goal of this study is to obtain the characteristic of cellular flames such as cell size and light emission with different equivalence ratios to smartly control the lean combustion system.

2. Experimental Apparatus

The experimental apparatus for this study is shown in Fig.1. This experimental apparatus shows C_3H_8/C_4H_{10}/air mixtures (C_3H_8=70% and C_4H_{10}=30%), and the premixed flames were performed on ceramic porous board with 67 mm of diameter. Air from the air compressor was fed into the system with 0.2 mbar The equivalence ratios of mixtures were measured by VA/SA/FA20S series glass rotameter. The light emission intensity of flames were detected by photodiode (HAMAMATSU S1223-01) for wavelength between 320 and 1100 nanometer, and recorded by NI Lab view with data logger and computer. The digital camera (Nikon d800e) was used to take photographs of flames.

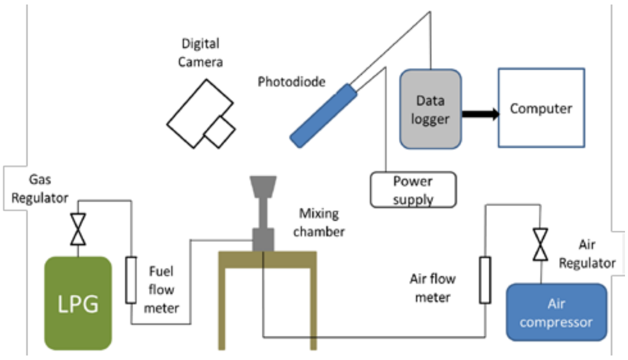

Fig. 1 Experimental apparatus

3. Methodology

This experiment was treated with variation of C_3H_8/C_4H_{10}/air mixtures (C_3H_8=70% and C_4H_{10}=30%) and air flow rate. The equation (1) and (2) are show the chemical equation of LPG in proportion of C_3H_8=70% and C_4H_{10}=30%. The flow rate was fixed to 70 L/min with the average velocity 0.331 m/s. The mixture/air flow through the ceramic porous board then the cellular flames formed.

3.1 Equivalence ratio

When the ratios of mixtures and air flow rates as the equivalence ratio (ϕ) were varied to the lean combustion, the cellular flames were found. The equivalence ratio calculated from eq.(3) is defined as the actual fuel-air ratio and the stoichiometric fuel-air ratio shown in eq.(4). To compare the characteristic of flames with variation of equivalence ratio, a digital camera (Nikon d800e) was used to take the photographs of flames. The emission light from premixed flames was detected by a photo diode (HAMAMATSU, S1223-01) connected with digital voltage supply (Commue HY-3020). The output from photodiode was converted to voltage by NI lab view program. The intensity of light emission varied with time, was normalized by its average value.

$$0.7C_3H_8 + 3.5(O_2+3.76N_2) \rightarrow 2.1CO_2 + 2.8H_2O + 13.16N_2 \quad (1)$$

$$0.3C_4H_{10} + 1.95(O_2+3.76N_2) \rightarrow 1.2CO_2 + 1.5H_2O + 7.33N_2 \quad (2)$$

$$\phi = \frac{(F/A)}{(F/A)_{stoi}} \quad (3)$$

$$(F/A)_{stoi} = \frac{\dot{m}_{fuel}}{\dot{m}_{air}} \quad (4)$$

3.2 Cell size of cellular flames

The definition of cell size is the distance between cusps of cellular flame fronts (Fig.2). In this study, the cell size was investigated to illustrate the instability intensity.

Fig.2 Definition of cell size

4. Results and Discussion

As the lean combustion system, the variation of C_3H_8/C_4H_{10}/air mixtures (C_3H_8=70% and C_4H_{10}=30%) and air flow rate were treated with 70 L/min of mixture flow rate then the C_3H_8/C_4H_{10}/air flames were observed as shown in Table 1. The equivalence ratios were varied from 0.45-0.59.When the lean combustion of C_3H_8/C_4H_{10}/air mixtures was treated with variation of equivalence ratio, the cellular flames formed owing to diffusive-thermal instability. Fig.3 and 4 show the top-view and side view photographs of cellular flames at ϕ =0.49, ϕ =0.53 and ϕ =0.57. The equivalence ratios increase from 0.49 to 0.57, the cell sizes decrease from 17.9 mm to 5.9 mm owing to the weaken instability. The previous study showed that the cell size of $CH_4/C_2H_6/CO_2$ /Air mixtures at ϕ =0.95 was 7.6 mm as shown in Fig.5 [15]. As the same equivalence ratio, the cell size of C_3H_8/C_4H_{10}/air mixtures is smaller compared with $CH_4/C_2H_6/CO_2$/Air mixtures due to decrease of instability intensity. In addition, the cellular flames were observed between ϕ = 0.49-0.57 and the premixed flames blew off at ϕ =0.45 as shown in Fig.6 and 7. The results showed $CH_4/C_2H_6/CO_2$ /Air mixtures have more sensitivity of intrinsic instability than C_3H_8/C_4H_{10}/air mixtures. This result showed that the cell size and light emission of cellular flames elucidated the intrinsic instability of C_3H_8/C_4H_{10}/air mixtures.

Table 1 The relation between the equivalence ratio with the appearance of the flames

Fuel Flow rate (L/min)	Air Flow Rate (L/min)	Stoichiometric Fuel-Air ratio	Actual Fuel-Air ratio	Equivalence ratio ϕ	Cell size (mm)
1.3	63.7	0.0644	0.0316	0.49	17.9
1.4	63.6	0.0644	0.0342	0.53	16.8
1.5	63.5	0.0644	0.0367	0.57	5.9

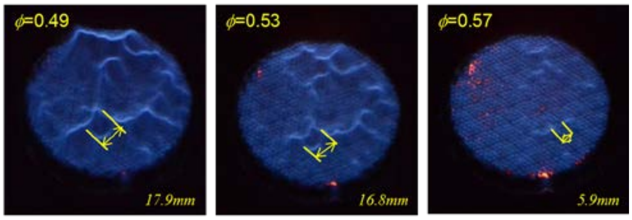

Fig. 3 The top-view photographs of cellular flames at ϕ=0.49, ϕ=0.53 and ϕ=0.57.

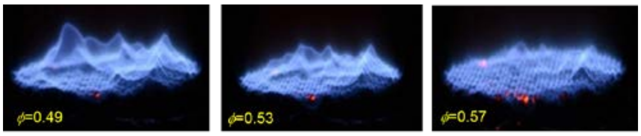

Fig. 4 The side-view photographs of cellular flames at ϕ=0.49, ϕ=0.53 and ϕ=0.57.

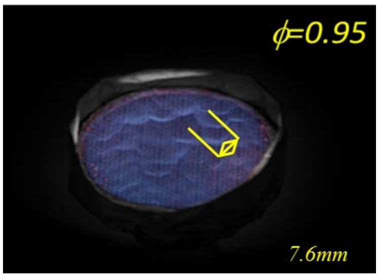

Fig. 5 The top-view photographs of $CH_4/C_2H_6/CO_2$ /Air flames at ϕ=0.95[15].

Fig. 6 The top-view photographs of blew off flame at ϕ=0.45.

Fig. 7 The side-view photographs of blew off flame at ϕ=0.45.

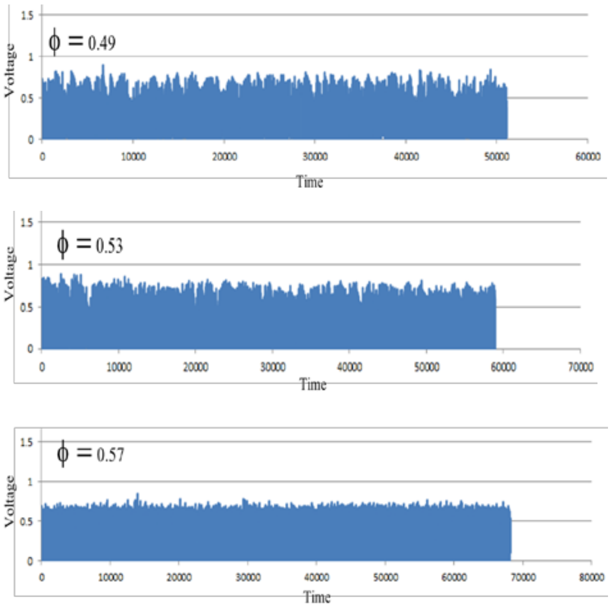

Fig. 8 The light emission intensity at ϕ=0.49, ϕ=0.53 and ϕ=0.57.

The light emission detected by photodiode and the voltage output was shown to analyze the characteristics of intrinsic instability (Fig.8). When the equivalence ratios were lower for lean combustion, the light emission had more fluctuation because of diffusive-thermal instability.

5. Conclusion

C_3H_8/C_4H_{10} mixtures as the main compositions of Liquefied Petroleum Gas (LPG), are used widely in Thailand for combustion in household and replacement of fossil fuel in the parts of transportation and industry. This study, the ratio of C_3H_8/C_4H_{10} mixtures were used as 70% and 30%, respectively to investigate the intrinsic instability of C_3H_8/C_4H_{10}/air flames on ceramic porous board. In order to reduce the emission of fossil fuel, it was focused to smartly control the lean combustion system of C_3H_8/C_4H_{10}/air mixtures in this study. The results showed the equivalence ratios were varied and the cell size and the light emission were observed as the characteristics of intrinsic instability. As the obtained results, the cellular flames were observed at ϕ = 0.49-0.57 and the premixed flames blew off at ϕ < 0.45. The results showed the equivalence ratio decrease for lean combustion system, the cell size is greater and the light emission had more fluctuation due to the strengthen instability intensity. Moreover, $CH_4/C_2H_6/CO_2$ /Air mixtures have more sensitivity of intrinsic instability than C_3H_8/C_4H_{10}/air mixtures. Thus, the obtained characteristics of cellular flames such as cell size and light emission with different equivalence ratios can be used to control smartly the lean combustion system.

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