COMBUSTION CHARACTERISTICS OF C_3H_8/C_4H_{10} FLAMES AFFECTED BY AIR FLOW BLUFF BODY ON NON-PREMIXED SLOT BURNER

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Abstract

This study is to investigate the C_3H_8/C_4H_{10} combustion flames with variation of air flow bluff body on non-premixed slot burner. The C_3H_8 and C_4H_{10} were applied in this study as the main composition of liquefied petroleum gas (LPG). In order to apply C_3H_8 and C_4H_{10} combustion with safety, the IDF slot burner with two fuel exit and one air exit were selected to investigate with non-premixed combustion. This study focused on the effects of air flow bluff body shape (cylinder, spiral and droplet shape) with variation of equivalence ratios and firing rates for combustion characteristics such as flame structure, flame temperature and emission. The results showed that the highest premixed flame ratio and the lowest CO were obtained from spiral shape of air flow bluff body. Moreover, the flame characteristics of spiral shape were wider compared to the cylinder and droplet shapes of air flow bluff body. This study could be applicable to smartly design for LPG combustion on non-premixed burner.

Keywords: Slot burner, air flow bluff body, spiral shape, cylinder shape, droplet shape, non-premixed combustion

Introduction

Nowadays, LPG is applied in many sectors, especially in households and industrial sectors. As the application of LPG in many sections, the LPG consumption trends to increase significantly (Energy Policy and Planning Office, 2018). The LPG mainly compose of propane (C_3H_8) and butane (C_4H_{10}), which the different compositions were used for many countries. The combustion of C_3H_8/C_4H_{10} is generally used on axial burner (Patel and Shah, 2018) and slot burner (Gao *et al*., 2019), which most of the propane fuel is mixed other fuel.

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The slot burner is applied to uniform flame temperature, which can improve combustion efficiency (Branco *et al.*, 2016). The combustion type for slot burner consists of premixed combustion and non-premixed combustion. Generality, the most slot burners often apply with premixed combustion due to high flame temperature and high combustion efficiency (Chen *et al*., 2015). However, the disadvantage of premixed flame is the phenomena of flashback flames because the flow velocity is greater than the burning velocity (Kalantari and McDonell, 2017). In order to concern the safety in combustion, non-premixed combustion was proper for diffusion flame (Angsuchoti *et al.*, 2017). Normally, the non-premixed slot burner was designed based on normal diffusion flame (NDF) burners which effected to long diffusion flame length owing to insufficient air. Thus, the inverse diffusion flames (IDF) burner was invented to improve combustion efficiency with reduction of diffusion flames (Kaewpradap and Jugjai, 2019). In the past, there were many ways to improve the combustion technology. One of the most popular methods was improved by 3T rule (Wielgosinski, 2012) which consists of temperature, turbulent and time due to enhance of the reaction rate. The 3T rule was applied to improve the burner and the volume flow rate of fuel and air to lead the fastest reaction rate and highest combustion efficiency. As the past researches, the burner was designed with 3T factors which was applied by mixing control methods to increase the burning rate. The bluff body was one of method that could control the mixing and recirculate the unburned gas for combustion (Jugjai, 2004). In general, the burner with a bluff body was usually designed on an axial burner which had symmetry of the cross-section area. Then the cross section of the different bluff body affected to the appearance of flame (Euler *et al*., 2014). However, the bluff body shape was not investigated to analyze the flame characteristics and improve combustion efficiency on slot burner.

Therefore, it is important to study the effects of the different bluff body shapes for C_3H_8/C_4H_{10} combustion flames on the IDF slot burner. This study aims to analyze flame, flame temperature, and CO emission with variation of the bluff body shapes.

Materials and Methods

Experimental Setup

Figure 1(a) shows the experimental setup for study of C_3H_8/C_4H_{10} combustion flames on non-premixed slot burner which was designed as shown in Figure 1(b) as the geometry of the slot burner, there are two outlets of fuel in both side slots and an air outlet in the middle slot. The C_3H_8/C_4H_{10} combustion flame on slot burner were investigated with variation of bluff body shapes as cylinder, spiral and droplet as shown in Figure 1(c). The fuel gas composition with 70% of C_3H_8 and 30% of C_4H_{10} called synthetic LPG was applied with atmosphere air as an oxidizer the flow rate was applied at 20 L/min with variation of the equivalence ratio Φ = 1.0-2.0 and firing rate *F.R.* = 2.0-4.0 kW. When the fuel and air were ignited, the photos of flame characteristic were taken by digital camera, flame temperature was measured by thermocouple and CO emission was detected by exhaust gas analyzer.

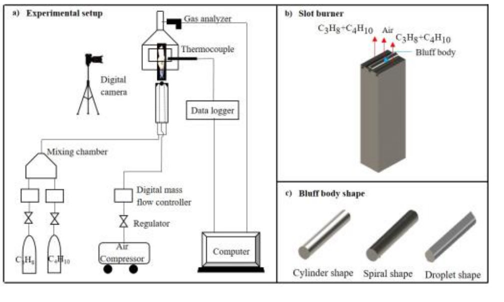

Figure 1. Schematic of a) experimental setup b) geometry of slot burner and c) bluff body shape

Combustion Equation

Combustion equation was calculated by 70% of C_3H_8 and 30% of C_4H_{10} as fuel with the air which is an oxidizer used for the analysis of a percentage by the mole as shown in Equation (1).

$$C_xH_y+a(O_2+3.76N_2) \rightarrow xCO_2+(y/2)H_2O+3.76aN_2 \quad (1)$$

Equivalence Ratio

The equivalence ratio (Φ) is a difference between actual fuel-air ratio or $(F/A)_{actual}$ and stoichiometry fuel-air ratio or $(F/A)_{stoi}$ are defined as shown in Equation (2).

$$\Phi = \frac{(F/A)_{actual}}{(F/A)_{stoi}} \quad (2)$$

Firing rate, F.R.

The firing rate (*F.R.*) is the input rate of fuel which is derived from the low heating value (*LHV*) and the mass flow rate of the fuel ($\dot{m}_f$) as shown in Equation (3).

$$F.R. = \dot{m}_f \times LHV \quad (3)$$

Flow Velocity

There are air flow velocity (U_a) and fuel flow velocity (U_f) for this study. The air and fuel flow velocity are the ratio between volume flow rate of air and fuel (Q_a and Q_f) and slot area of air and fuel (A_a and A_f) as shown in Equations (4) and (5) respectively.

$$U_a = Q_a / A_a \quad (4)$$

$$U_f = Q_f / A_f \quad (5)$$

Flame Structure Analysis

The structure of the diffusion flame is caused by uncontrolled combustion when fuel and air sprayed out fuel gradually spread to the air in show Figure 2. The areas where the two touch each other will generate momentum and burn. There is an area out sprayed caused to the fuel and air there are thorough mixing and high burning rate. This area will cause a blue flame or premixed flame. If the fuel diffusion slows down increase the height of the flame the area which is the luminous zone or diffusion flame, the gas flow characteristics (Patel and Shah, 2018). The conditions of the experiment are following Table 1.

Premixed Flame Ratio

Premixed flame ratio represents the ratio between the premixed flame length (L_{pf}) and the flame length (L_f) as represented in Equation (6).

$$premixed\ flame\ ratio = \frac{premixed\ flame\ length, L_{pf}}{flame\ length, L_f} \quad (6)$$

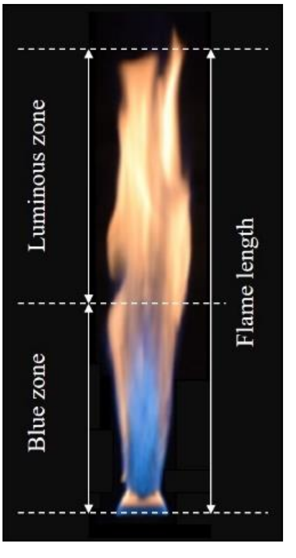

Figure 2. The structure of diffusion flame (Vipul and Rupesh, 2018)

Table 1. Variation of fuel volume flow rate with equivalence ratio between 1.0 -2.0 at Q_a = 20 L/min

Bluff body shape	Φ (-)	$Q_{C_3H_8}$ (L/min)	$Q_{C_4H_{10}}$ (L/min)	*F.R.* (kW)
Cylinder, spiral and droplet shape	2.0	1.80	0.77	4.09
	1.8	1.62	0.70	3.68
	1.6	1.44	0.62	3.27
	1.4	1.26	0.54	2.87
	1.2	1.08	0.46	2.46
	1.0	0.90	0.39	2.05

Flue Gas Analysis

Flame temperatures were measured with thermocouple (B-type, 0-1,800°C) the flame temperature obtained from the flame adiabatic temperature of C_3H_8/C_4H_{10}. For exhaust gases from combustion, CO emission does not exceed the standard value as the industry (industrial emission standard) defined.

Results and Discussion

Air Flow Velocity

The air flow velocity of bluff body on the side view for slot burner as shown in Figure 3. In case of spiral bluff body shape, it affected to greater average air flow velocity than that of cylinder and droplet shape bluff body shapes, respectively.

Flame Structure

Figure 4 shows photos of flame structure induced by the cylinder, spiral and droplet shapes of air flow bluff body on front view of slot burner with variation of equivalence ratio at Φ = 1.0-2.0. When the equivalence ratio increased, the diffusion flame length was higher according to the fuel ratio. The cylinder, spiral and droplet shapes influenced to the flame structure which was divided into the premixed flame and the diffusion flame. The flame of spiral bluff body shape was a shorter flame length and wider flame shape compared to cylinder and droplet bluff body shapes. This is because of higher air velocity by spiral bluff body shape induced to well-mixed between fuel and air and affected to lower flame length.

Premixed Flame Ratio

Figure 5 shows the relation between equivalent ratio and the premixed flame ratio affected by cylinder, spiral and droplet bluff body shapes. When the equivalence ratio

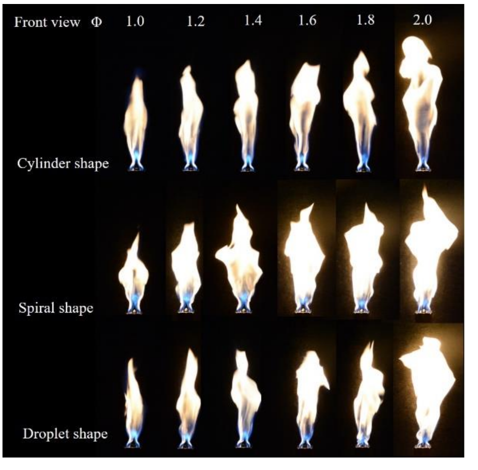

Figure 4. Photos of flame structure affected by the cylinder, spiral and droplet shapes of air flow bluff body on front views of slot burner with variation of equivalence ratio at Φ = 1.00-2.00

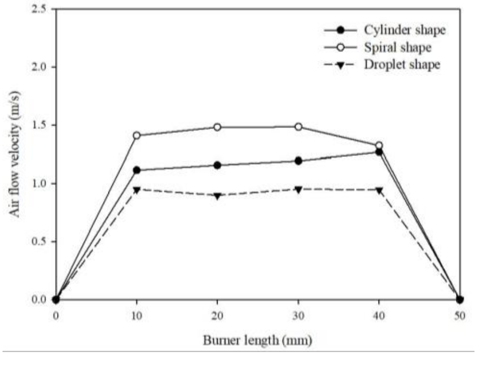

Figure 3. Air flow velocity of bluff body with variation of position of side view of slot burner

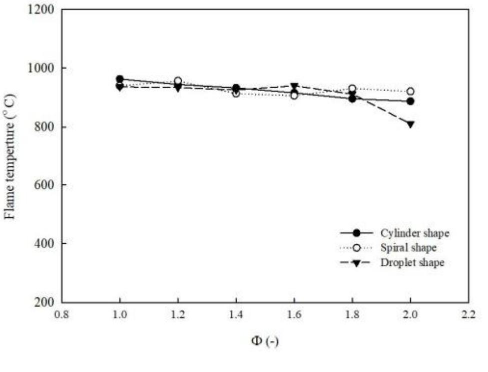

Figure 5. Premixed flame ratio affected by three bluff body shapes on slot burner with variation of equivalence ratio at Φ = 1.00-2.00

increased, the premixed flame ratio decreased due to much of fuel ratio. Meanwhile the cylinder, spiral and droplet bluff body shapes there was higher the premixed flame ratio with stoichiometry Φ = 1.0 but the spiral bluff body shape was the higher premixed flame ratio than another case. It is because of high air flow velocity and flow pattern of spiral bluff body shape affected to lower flame diffusion flame.

Flame Temperature

The temperature of flame affected by cylinder, spiral and droplet bluff body shapes to measure temperature from burner exit at distance 6 cm with the variation of equivalence ratio at Φ = 1.0-2.00 as shown in Figure 6. The influence of the highest equivalence ratio affected the decrease of flame temperature because of more incomplete combustion. The equivalence ratio, Φ = 1.0 for the influence of cylinder, spiral and droplet bluff body shapes there were the maximum flame temperature of 1,025.18, 888.02, and 992.6°C, respectively. The results show that the flame temperature induced by spiral bluff body shape was reduced due to diluted by high air flow velocity hence to the decrease of flame temperature.

CO Emission

Figure 7 shows the comparison of the CO emission when the equivalence ratios increasing, The CO emission was increased by rich fuels. The spiral bluff body shape was lower emissions compared to cylinder and spiral bluff body shapes. The air flow velocity of spiral bluff body shape was higher because of the better mixing between the fuel and air. Thus, the complete combustion was improved to decrease in the CO emission.

Conclusions

In this study, the slot burner was designed with the air flow bluff body to study flame characteristics affected by the cylinder, spiral and droplet air bluff body shapes by 70% of C_3H_8 and 30% of C_4H_{10} as called the synthetic LPG. The results are concluded as this following.

1) When the equivalence ratio increased, flame length and CO emission were greatest. The premixed flame ratio and flame temperature decreased when the equivalence ratio increased. This is because of excess fuel with untoward combustion which affected the higher diffusion flame and lowers flame temperature.

2) The spiral bluff body shape, although it was not high flame temperature, the flame length and CO emission were lower than that of cylinder and droplet bluff body shapes. Therefore, the bluff body shapes influenced to combustion characteristic because of the higher air flow velocity and better mixing between the fuel and air hence to complete combustion.

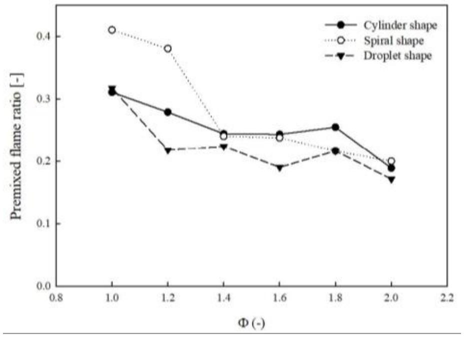

Figure 6. Flame temperature affected by three bluff body shapes on slot burner with variation of equivalence ratio at Φ = 1.00-2.00

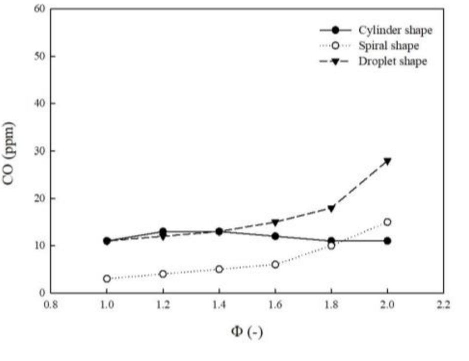

Figure 7. The CO emission affected by three bluff body shapes on slot burner with variation of equivalence ratio at Φ = 1.00-2.00

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