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Research Article

NUMERICAL STUDY OF SYNTHETIC LPG FLAMES AFFECTED BY VORTEX GENERATOR ON AN AIR PORT OF SLOT BURNER

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ABSTRACT:
The parameters of the vortex generator (VG) were designed to apply for non-premixed synthetic LPG combustion on a Slot Burner (SB). The objectives are improvement of mixing and increase of flame temperature. The mathematics model was used to study the effects of the parameters, there are position, angle, direction, aspect ratio (AR), and distance (S) between the vortex generator on an air port of SB, it is called VGSB. The VG was installed on an air port with 60-degree angle, CW direction, AR=0.4, and S=1 mm, it could improve the combustion characteristics due to the VG was increased the airflow velocity, induced a well-mixed between fuel and air, made the uniform temperature distribution. It was affecting to the higher flame temperature of LPG combustion.

Keywords: *Slot Burner, LPG, Flame temperature, Flame distribution, Vortex generator*

1. INTRODUCTION

Liquefied Petroleum Gas, LPG tends to be used increasingly in the household and industrial sector [1]. Especially, LPG using a lot in the food industry. The compositions of LPG are mainly composed of propane gas and butane gas with a ratio of 70:30. This is the most ratio widely used in Thailand. In addition, LPG-based industry uses several types of burners, and the slot burner (SB) is one of the most used in the food industry.

The SB was studied about the heat flux. The shapes of the SB were studied, there are round burner and slot burner [2]. The study has shown that, the SB could provide the better uniform heat flux, representing the excellent temperature distribution. The food industry requires a burner with a good temperature distribution and operational safety. The explosion is extremely dangerous to the operator. Therefore, the SB is suitable for safety in use. Because it is a non-premixed burner, it does not produce a flashback flame and does not make an explosion [3]. The previous researcher was improving the non-premixed combustion burner. Such as, the coaxial burner, it was studied in flames appeared and LPG emissions. The flame is the inverse diffusion flame (IDF). The results found that the flame length on a burner with a swirler was decreased and wider, because of increasing the air velocity [4-6] and more stable flame, it was compared with out a swirler. SFLF was increased with increasing the air velocity. The swirler with a 30° could improving a well-mixed between fuel and air. It could enhance the complete combustion. Resulting in the blue zone flame longer, low CO, and NOx emissions [4, 5]. Another burner is the SB. It was developed by studying various conditions of the bluff body (BB) [4]. The results found that the BB in a spiral shape could make the well-mixed between air and fuel. It could produce less diffusion flame and a flame temperature of 1025.18 °C. But there is a disadvantage of a diffusion flame [7]. Because it is lowering the flame temperature and increasing the CO emissions.

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Then the authors were studying the research of VG. There is the studied of heat transfer by installation the VG in the smooth tubes of air-cooled condensers. The results found that the thermal performance was increased, the VG was used as delta winglet pair [8], the shape and direction of VG affected Reynolds number and thermal performance [9, 10]. Next is the study of the VG shapes in punched triangular vortex generators (PTVGs) and punched rectangular vortex generators (PRVGs). The results shown that the triangular vortex generator is the best to control the boundary layer separation. The optimal installation angle is 12°. The distance between the vortex generator is 3 mm. The small VG can reduce the drag forces [11]. In addition, the angle between VG results in higher heat transfer [12].

The previous research, not the other authors had been applied the VG into the SB yet. Then, the authors are bring the VG applied into the SB. This research aims to improve the fuel-air mixture to lead to the complete combustion and higher flame temperatures. The study installed the VG on the air port of SB. Because the VG would influence the airflow velocity, which affects the combustion better than the fuel channels, and variables of direction, aspect ratio, angle, and distance between the VG. Studying the effect of the VG on airflow velocity and flame temperature distribution using a mathematical model.

2. METHODOLOGY

2.1 COMBUSTION CALCULATION

A combustion reaction is a reaction between fuel and oxidation. The completed combustion is a reaction at stoichiometric. The carbon dioxide (CO_2) and water (H_2O) are obtained as the combustion products. The combustion equation at stoichiometry is shown in eq. (1) [13].

$$C_aH_b + (a+(b/4))\ (O_2 + 3.76N_2) \rightarrow aCO_2 + (b/2)\ H_2O + 3.76(a + (b/4))N_2 \tag{1}$$

Equivalence ratio is defined as the ratio of the fuel mass flow rate to the air mass flow rate divided by the same ratio at the stoichiometry of the reaction considered [13, 14].

$$\Phi = \frac{(A/F)_{act}}{(A/F)_{stoi}} = \frac{(\dot{m}_a/\dot{m}_f)_{act}}{(\dot{m}_a/\dot{m}_f)_{stoi}} \tag{2}$$

Firing rate, F.R. is the heated feed rate expressed as the proportion of energy from the fuel input that can be found from the Low heating value and mass flow rate [13, 14].

$$F.R. = \dot{m}_f \text{ x } LHV$$

2.2 VGSB MODEL

The Slot Burner is a type of burner for the industry. SB is a rectangular burner with an air port in the middle and the two-fuel channels at the outlet. This study was considered at the top of the burner with 30 mm height. The VG is an accessory, installed into the air port in 4 pairs to create a small vortex that makes well-mixed, as shown in Fig. 1. And AR can be obtained from h/L of VG.

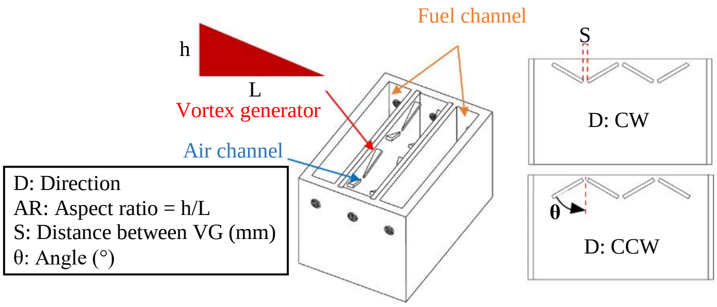


Fig. 1. Geometry and VG installation characteristics.

2.3 VGSB CONDITIONS

This study used mathematical modelling with the Ansys Student 2021 R1 to simulated the non-premixed combustion of LPG on a SB with various VG conditions, as shown in Table 1. Case A is a SB without the VG, and case B is the initial conditions of VGSB [10].

Table 1: VG conditions for simulation.

Case	Position		Angle			Direction		Aspect ratio (AR)			Distance (S) (mm)		
	F	A	30°	45°	60°	CW	CCW	0.2	0.3	0.4	0	1	2
A													
B		●		●		●		●				●	
C		●	●			●		●				●	
D		●			●	●		●				●	
E		●			●		●	●				●	
F		●			●	●			●			●	
G		●			●	●				●		●	
H		●			●	●				●			●
I		●			●	●				●	●		

3. SIMULATION METHOD

The non-premixed combustion model was applied for SB and VGSB at stoichiometry. The compositions of LPG are propane and butane at 70:30 % by volume. The LPG was inserted into the bottom of the burner, and feeding the air at the lowest flow rate that the burner can ignite and stabilize flame, with 2 kW, the airflow rate is 20 L/min. The fuel flow rate at the stoichiometry is 1.29 L/min [4]. The room temperature is 300 K at atmospheric pressure of 1.01 bar. The program was setup as follows, the flow is the non-slip condition, turn on the energy in the combustion model, a viscous function uses the transition SST Model, Radiation – Discrete Ordinates (DO), and species use non-premixed combustion. The calculation is in a steady state [15, 16]. The validation of this study, the simulation results of the SB mathematics model was considered about the average flame temperature. Validation the simulation results with the previous experimental study results. The comparison of the temperature on the top of the SB at 1.5, 6 and 10 cm height, as shown in Fig. 2. The results found that, the error is 1.98%, 13.76% and 14.38%, respectively [17]. The mixing domain is considered 200 mm height at the top of a burner, as shown in Fig. 3 (a) and (b). The example of the velocity vector and side view temperature distribution, as shown in Fig. 3 (c) and (d).

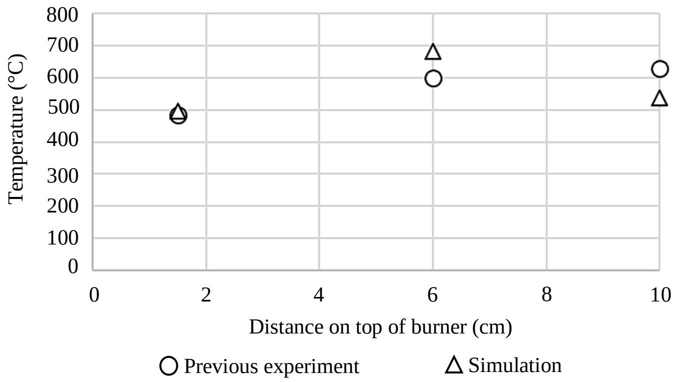
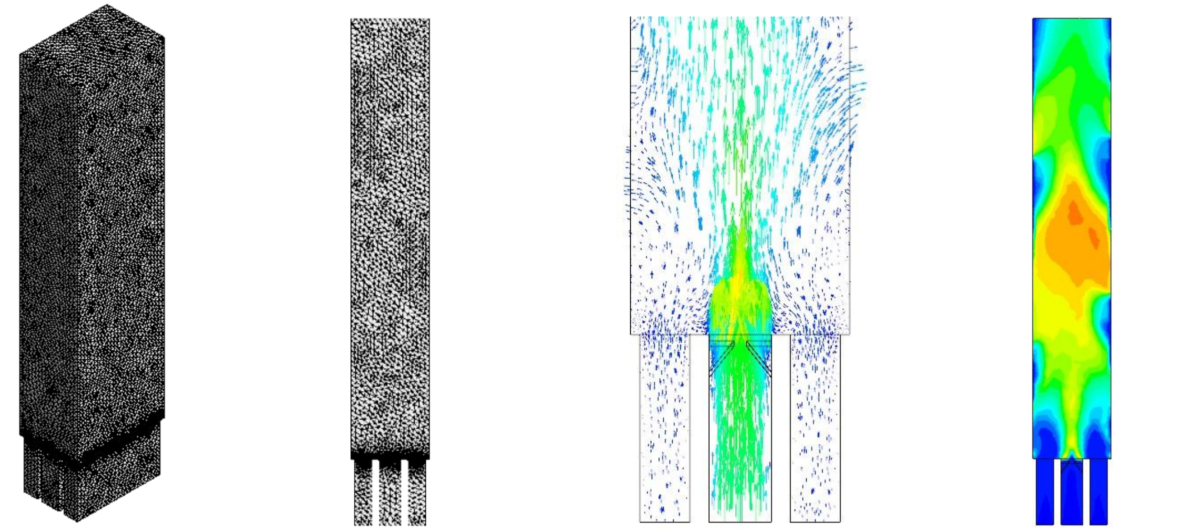


Fig. 2. The temperature of SB previous study comparison with simulation.



(a) Mixing domain (b) Mixing domain on side view (c) Velocity vector d) Side view temperature distribution

Fig. 3. Example of the domain and the results.

4. Results

There are five factors effected to the airflow velocity and the temperature distribution. Then select the best condition from the initial condition and used it to study the next conditions.

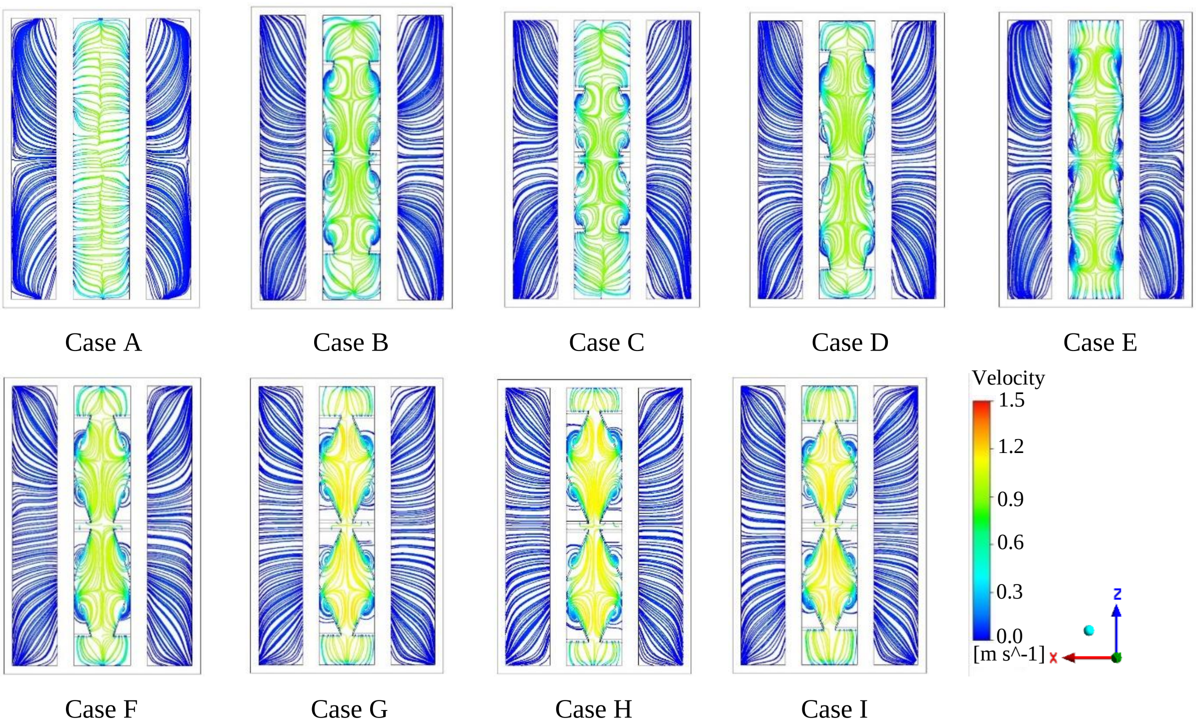


Fig. 4. Air and fuel velocity streamline at the top of the exit channel.

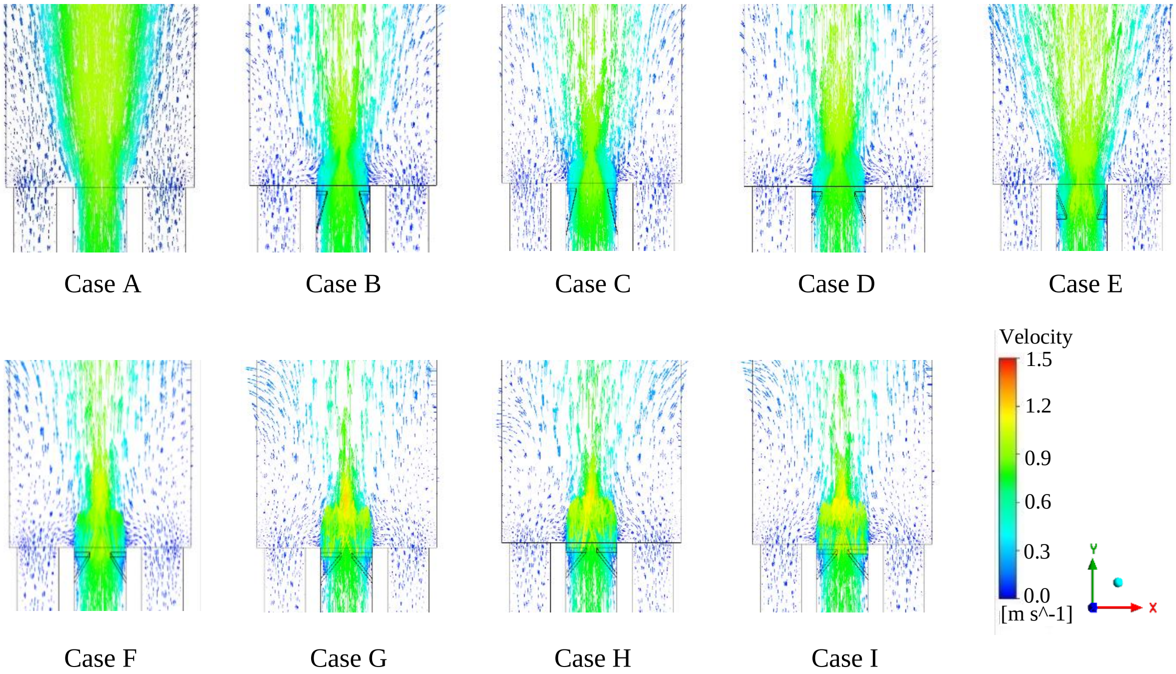


Fig. 5. Air and fuel side view velocity vector.

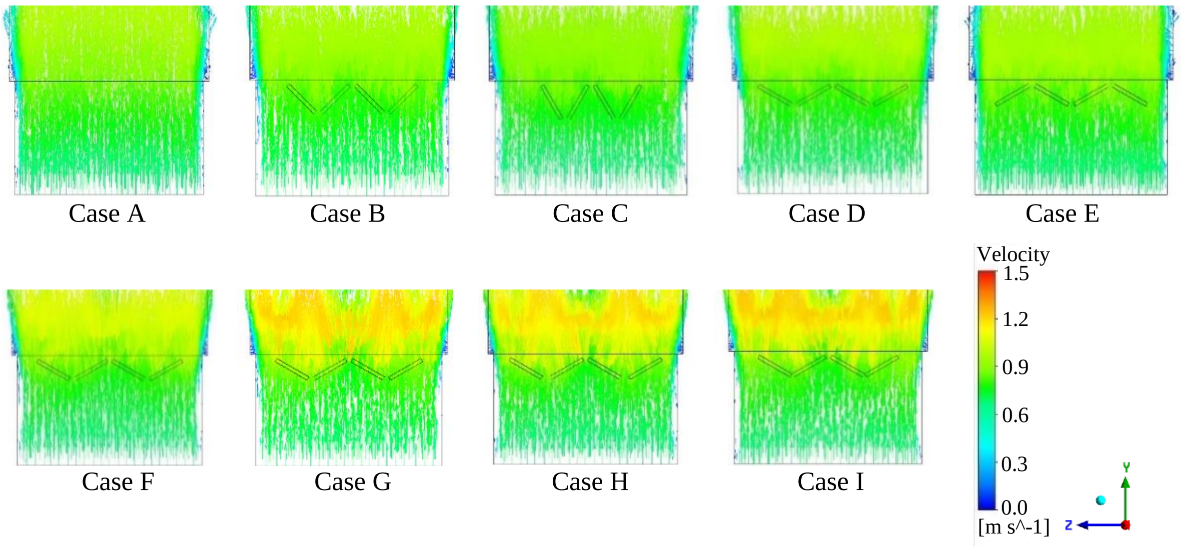


Fig. 6. Air and fuel front view velocity vector.

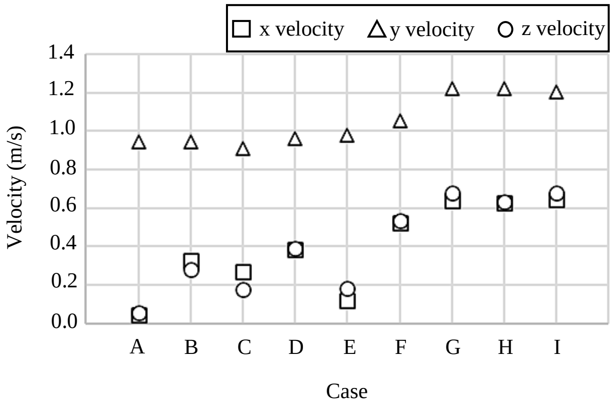


Fig. 7. Air-fuel mixed velocity in x-y-z axis.

The results of this study are VG parameters that were affecting on the airflow velocity and the temperature distribution. The effect of VG on airflow velocity made the small vortex generated, as shown in Fig. 4. And it can lead the fuel to mixed with the air, as shown in Fig. 5-6. When comparison on case A and B, found that case B made the air velocity is higher than case A, as shown in Fig. 7. The temperature distribution has been considered on the top view cross-section at 1.5, 6, and 10 cm height and the middle-side view, as shown in Fig. 8. The complete combustion was occurred because of well-mixed between air and fuel, the reaction has the high temperature. Then the good temperature distribution was occurred. So, the average temperature of each case, as shown in Fig. 9.

4.1 The position of the VG effects on velocity and temperature distribution

Case A without the VG and case B installation the VG on an air port with the initial condition, angle 45°, direction CW, AR=0.2, and S=1 mm, as shown in Fig. 6. The results of case B are the VG made the small vortex occur at the exit of the air port, while case A does not produce the vortex, as shown in Fig. 4. The VG in case B made well-mixed between air and fuel more than case A. It can be seen from the velocity vector of the fuel induced towards the air, as shown in Fig. 5-6, and the velocity is higher than case A, as shown in Fig. 7. Due to the above reasons, case B has a wide yellow and orange area, it means case B has a temperature distribution better than case A on every top view above the burner, as shown in Fig. 8. And it has an average temperature higher than case A, as shown in Fig. 9.

4.2 The angle of the VG effects on velocity and temperature distribution

Installation the VG on an air port with direction CW, AR=0.2, S=1 mm, and the angle case B (45°), C (30°), and D (60°), as shown in Fig. 6. The results found that case C made the small vortex at the exit channel, but smaller than case B and D, as shown in Fig. 4. All three cases made the well-mixed between air and fuel similarly improved, as shown in Fig. 5-6. But case D has the highest airflow velocity, as shown in Fig. 7. And the temperature distribution has a wide yellow and orange similarly. But in case D has the small dark orange areas on the top, as shown in Fig. 8, that means a high-temperature area. Then case D has the highest average temperature, as shown in Fig. 9.

4.3 The direction of the VG effects on velocity and temperature distribution

Installation the VG on an air port with the angle of 60°, AR=0.2, S=1 mm, and the direction case D (CW) and E (CCW), as shown in Fig. 6. The results found that case D made the vortex in the opposite direction from case E, as shown in Fig. 4, and made the airflow velocity vector has a straight direction only. Case E made the airflow velocity vector separate direction like a V-shape, as shown in Fig. 5. Case D has the airflow velocity higher than case E, as shown in Fig. 7. Considering the temperature distribution of case D has a yellow in a wide area. Case E has a yellow area to be separated on the top view at 1.5 cm, similar to case A, as shown in Fig. 8. That means case D has well-mixed between air and fuel better than case E. The combustion immediately after well-mixed on the burner tip, resulting in a short length temperature distribution. However, a mixing of case E is not good, the combustion spreads to the upper zone, resulting in a long length temperature distribution, as shown in Fig. 8 on the middle side view. The length of the side view temperature distribution can be predicted the flame stability, that means case D has more flame stability than case E.

4.4 The aspect ratio of the VG effects on velocity and temperature distribution

Installation the VG on an air port with the angle of 60°, direction CW, S=1 mm, and the aspect ratio case D (AR=0.2), F (AR=0.3), and G (AR=0.4). The VG is bigger, it can be observed from Fig. 4-5, resulting all three cases were making the vortex occur at the exit channel are similar. But case G made the highest airflow velocity, as shown in Fig. 4-7. Cases F and G have the temperature distribution with yellow and orange in a similar wide area, because the bigger size of the VG affected to the airflow velocity vector and well-mixed between air and fuel, making the good temperature distribution and look like two loops. The reason above that means case F and G have the temperature distribution is better than case D. But considering in Fig. 8 on the top view at 1.5 cm, case G has a small orange area occur, that means high temperature area, and the combustion immediately on the burner tip, resulting in a short length temperature distribution. But cases F and D have a combustion spread to the upper zone, resulting in a long length temperature distribution, that means case G has more flame stability than cases F and D.

4.5 The distance between the VG effects on velocity and temperature distribution

Installation of the VG on an air port with the angle of 60°, direction CW, AR=0.4 and the distance between VG case G (S=1 mm), H (S=2 mm), and I (S=0 mm). The results show that all three cases have similar airflow velocities, as shown in Fig. 4-7. The distance was increased resulting in temperature distribution on the top view at 6 cm is separated to be two areas, and a short length temperature distribution, as shown in Fig. 8. That means case I has more flame stability than cases G and H.

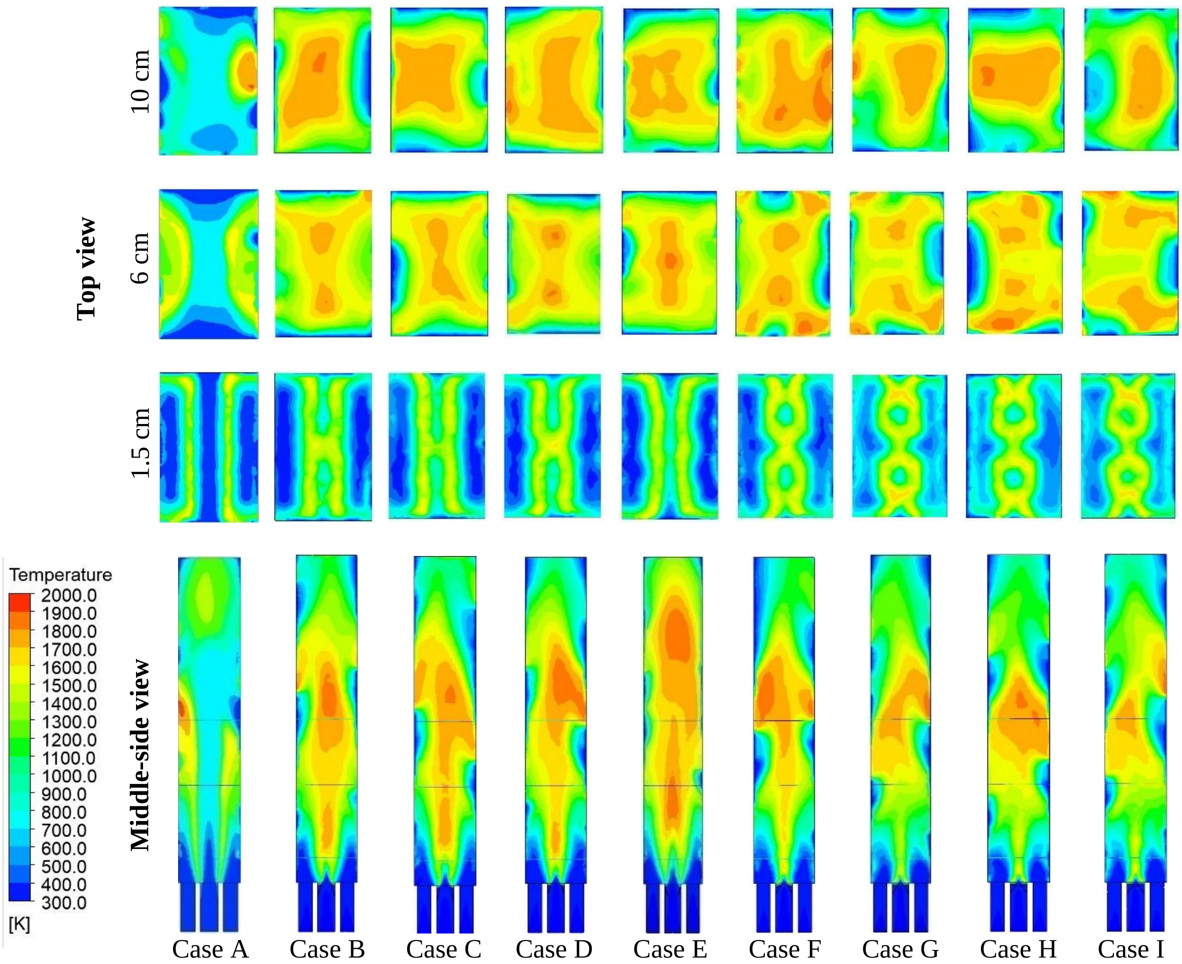


Fig. 8. Top view and side view temperature distribution.

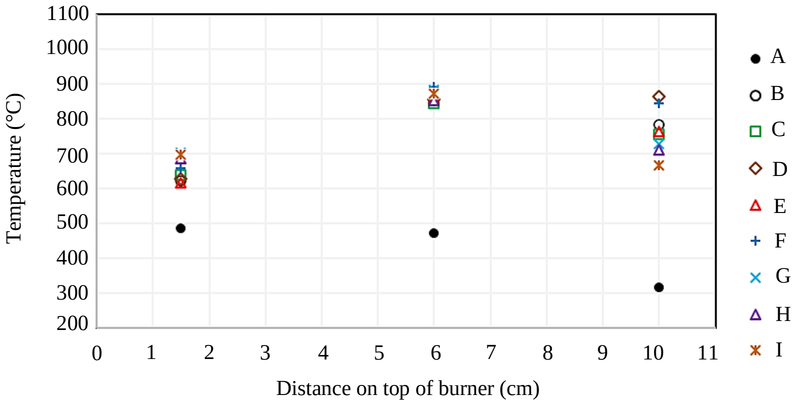


Fig. 9. Average temperature distribution at top view.

5. Conclusion

The VG effects on velocity and temperature distribution of synthetic LPG on an air port of SB was studied by the position, direction, aspect ratio, and the distance between the VG. The non-premixed combustion model was used to study at the stoichiometry via mathematical models. The angle and AR were increased, it made the small vortex change to bigger vortex and made the higher airflow velocity. The effected of the CW direction, it can induce the fuel and air to be well-mixed. Resulting in complete combustion, uniform temperature distribution on top view and high average temperature. And the distance between VG was decreased, made a short length temperature distribution on side view. Meaning to the flame stable.

Then the VG is installed on the air port of SB with an angle of 60°, direction CW, and AR = 0.4, distance S=0 mm, called the VGSB. It was made the vortex occurred at the exit channel, could increase the air velocity, and made well-mixed between air and fuel enhance the flame temperature and more stable flame.

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Nomenclature

Φ	equivalence ratio
A	air channel
AR	aspect ratio (h/L)
BB	bluff-body
CCW	counterclockwise
CW	clockwise
D	direction
F	fuel channel
F.R.	firing rate, kW
h	height, mm
L	long, mm
LHV	low heating value, kJ/kg
LPG	liquefied petroleum gas
$\dot{m}_a$	air mass flow rate, kg/s
$\dot{m}_f$	fuel mass flow rate, kg/s
S	distance, mm

SB slot burner
VG vortex generator
VGSB vortex generator slot burner

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