FLAME STABILITY AND FUEL EFFICIENCY OF GAS DIFFUSION FLAME ON THE BACKWARD FACING STEP

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ABSTRACT

Propane and butane injection into the recirculation zone in the fuel area with backward-facing step has a significant effect to the diffusion flame with the characteristic stability which depends on the velocity of the free air stream, the injection position from the step and the injection position to step height ratio. The test result shows that there are two main stable diffusion flames: a stabilized flame in the recirculation zone and a stabilized flame in the shear layer region. There is a decrease of the fuel efficiency due to the effect of the greater ratio of the injection position to the step height and the farther injection position from the steps. The effect of the free air stream velocity is much more significant the injection location near the steps.

Key words : fuel efficiency, propane, butane, diffusion flame

I. INTRODUCTION

In the propulsion system application, the flow velocity is so high and turbulent with high velocity combustion that a specific mechanism called flame holding is needed. A little hot pilot flame or recirculation flow mechanism can be used to stabilize the flame in the flow. According to Srehlow[1] recirculation flow can be formed at the back of bluff body, V-gutter and at the back of canal with sudden expansion backward facing step. For the jet combustion chamber, turbulent recirculation flow formed near the step edge is considered as the best flame holder candidate since it gives a big pushing power and a little pressure loss. Diffusion flame can be stable by injecting the fuel to recirculation flow field with low velocity near the step, although the main air flow has a supersonic velocity.

The previous research is a lot about the role of flow field structure at the backward facing step flow, injection and the mixture of fuel into flow field in flame stabilization mechanism focused on propulsion system application.

Karagozian[2], on his research about flame stabilization flame mechanism and the role of flame injection scheme into flame holding area at the high velocity fuel system, tried to use some fuel injection scheme at the backward-facing step including parallel injection, swirl jet parallel, faced down injection and backward-facing step. Lee[3] with his research at supersonic flow field of NASA said that in the supersonic flow field the position where the fuel and air mix really influence the ignition ability and combustion efficiency. The trial also shows that backward-facing step can increase flame stabilization at the supersonic combustion. Smith[4] , on his research about press distribution, average velocity, turbulence intensity, gas composition, static temperature and static pressure distribution at the wall in the cylindered sudden expansion combustor with the use of hydrogen fuel, showed that the size and recirculation area position changed significantly due to the chemical reaction. The intensity of maximum turbulence is almost the same with or without reaction.

Harinaldi et al.[5] investigated the mixing process between injected gas and the airflow behind sudden-expansion of a step of in a cold condition using an alternative diagnostic method based on flow visualization. In the recent work, the experimental investigation was expanded by introducing heated gas injection in effort to a more reasonable approach in modeling the mass and heat transport that occur in the combustor[6]. Since the formed flow field is very complicated, the flame stabilization mechanism at the backward facing step can't be explained thoroughly. Recirculation field is the area that includes reattaching flow formed at the down stream of the step. The recirculation area has flow characteristic with low velocity although the main stream has the high velocity. This characteristic can form diffusion flame by injecting the fuel into the recirculation flow (see Figure 1).

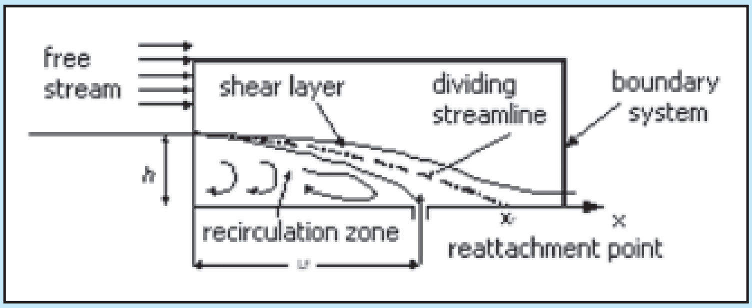

Figure 1
Flow field at backward facing step

The aim of this research is to gain a new basic experimental data about the stabilization characteristic of flame combustion and fuel efficiency in recirculation flow by using propane and butane fuel. It is also expected that this research can get the clearer correlation between practical parameters in producing the effective mixture condition of the fuel and the air that will increase flame stabilization.

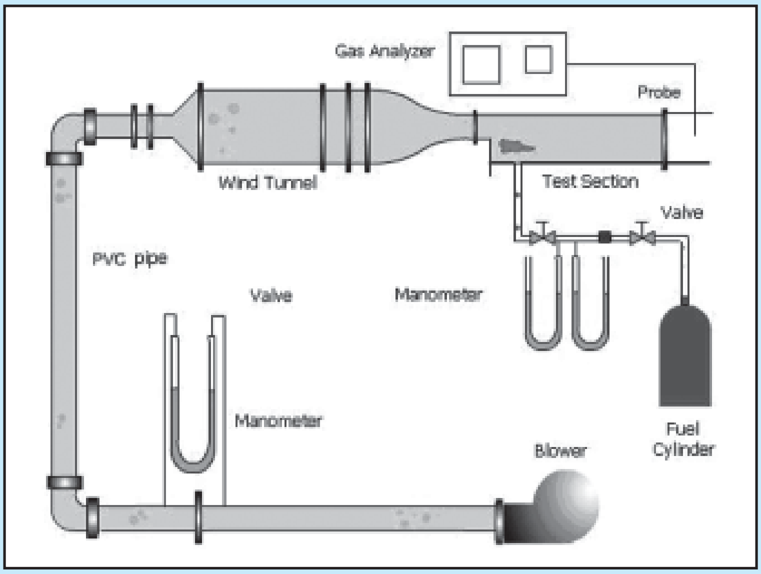

Figure 2
Experiment set-up

II. EXPERIMENT SET-UPS

The test equipment consists of three parts: air supply system, fuel supply system and combustion chamber. The air is supplied by blower in which the air velocity can be arranged with the suction valve arrangement, and then the air is flowed to the small scaled-wind tunnel to give the same flow at the side of combustion chamber entrance. See Figure 2 for the scheme of the equipment set-up. The air flow velocity is measured by capillary manometer calibrated by hot wire anemometer (Lutron AM-4204). The propane and butane is supplied from fuel tank and the capacity is arranged through flow meter with the capillary manometer system calibrated by wet gas meter (Shinagawa WE-25 A)

The combustion chamber is designed in such away that forms the steps with the height easily arranged. The injection slot sizes 1x80 mm is placed in a specific distance from the steps. To measure CO2 and O2 from the gas emission of the combustion, a gas analyzer (ECOM-AC) is used.

A. *Fuel Efficiency Measurement*

As there is no standard formulation to analyze diffusion combustion, an approach is taken in this test. The approach used is the combustion that meets stochiometry formula occurring at the specific area at diffusion flame (local stochiometry combustion). Therefore the fuel efficiency is the comparison of actual fuel mass and stochiometry fuel mass formulated as follow:

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$$\eta_{bb} = \frac{M_{f\,akt}}{M_{f\,sto}} \quad (1)$$

Data taken is the CO_2 and O_2 concentration at the exhausted gas. The flame stability test is carried out only by observing visually toward the stable diffusion flame. The experimental uncertainty for fuel efficiency measurement were estimated approximately ± 5%

B. *Parameter and Experiment Condition*

The experiment is used with condition shown by Table 1.

III. RESULT AND DISCUSSION

A. *Stable Flame Configuration*

The result of the observation shows that there are two kinds of dominant flames clearly seen at the Figure 3 (a) and 3 (b).

At the Figure 3(a) the flame is larger, accumulated near the steps and irregularly changing depending on space and time. This flame shows that the mixture of fuel and air more possibly occurs at the recirculation area where the influence of recirculation flow field is very strong. The dominant yellow of this flame shows that there is more fuel concentration at the mixture of the fuel and the air. The perfect combustion occurs when it is closed to the stabilization limit point signaled by the dominant blue. Since the flame shape is influenced very much by the recirculation flow field, the flame is categorized as a recirculation stabilized flame that tends to occur at the injection closer to the step (*lf/h*=2).

Figure 3(b) shows a different stable flame along the ending steps up to the reattachment zone or shear layer. It can be assumed that the mixture of air and fuel can cause accumulated combustion along the shear layer where the flow zone is influenced very much by the shear layer. The stable flame shape is irregularly unfluctuated depending on space and time and dominated by blue. The result shows the mixture of fuel and air in the composition closed to stochiometry, so that the combustion process is more perfect since the area has high turbulence characteristic for the better fuel and air mixture. Since the flame shape is really influenced by the shear layer flow zone, the flame is categorized as the shear layer stabilized flame that tends to occur at the farther injection (*lf/h*=4).

From the stable flame both at the recirculation area and at the shear layer, it shows that there are two mixture areas shown by two different flame col-

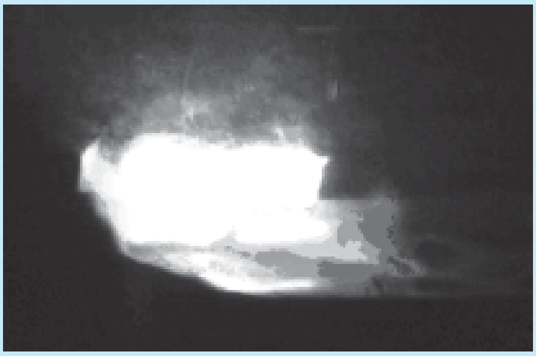

Figure 3 (a)
Stable flame configuration
(velocity, *Uo* = 7,5 m/s, at *lf/h* = 2)

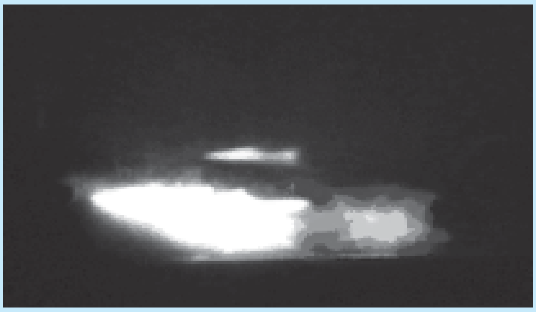

Figure 3 (b)
Stable flame configuration
(velocity, *Uo* = 7,5 m/s, at *lf/h* = 4)

Table 1
Experiment Condition

Step height (*h*)	10 – 40 mm
Injection slot distance from the step (*lf*)	40 – 80 mm
Air free stream velocity (*Uo*)	7,5 – 12 m/s
Fuel	Propane and butane

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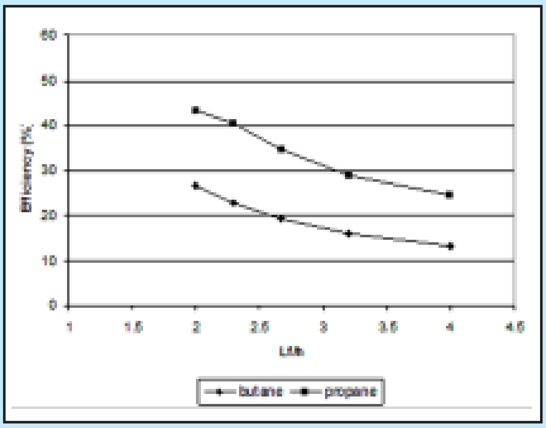

Figure 4
Fuel efficiency, l_f = 40 mm
(at minimum air free stream velocity)

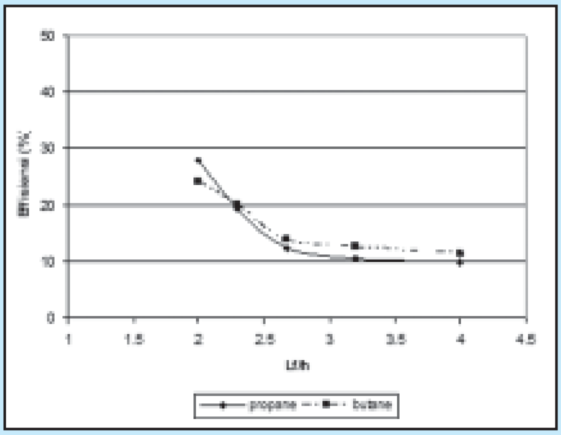

Figure 6
Fuel efficiency, l_f = 80 mm
(at maximum air free stream velocity)

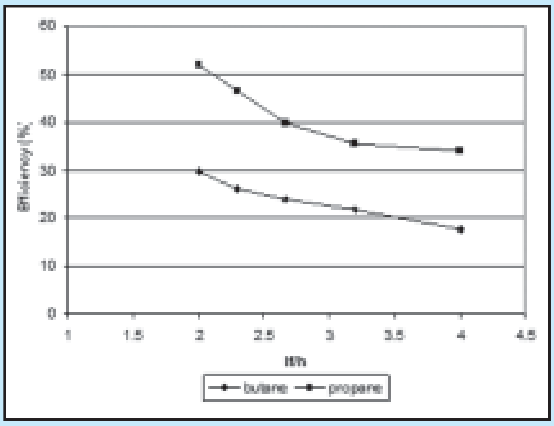

Figure 5
Fuel efficiency, l_f = 40 mm
(at maximum air free stream velocity)

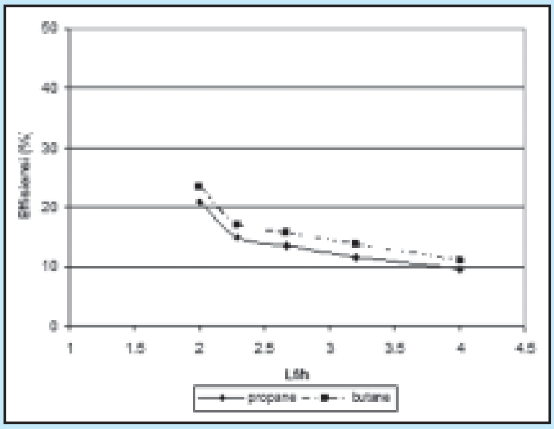

Figure 7
Fuel efficiency, l_f = 80 mm
(at minimum air free stream velocity)

ors. The reddish yellow at the area near the steps shows that at this area the fuel concentration is more than the air concentration. This condition makes the unbalanced mixture to produce perfect combustion. Since the area near injection location is dominated by the blue, it is assumed that there is a mixture of fuel and air closed to stochiometry.

At the beginning, the dominated color is more to occur if the fuel injection is greater. But when the stabilization limit of color composition from the diffusion flame is more dominated by the blue, it is believed that the fuel and air concentration is balanced enough to create a perfect combustion.

B. *Fuel Efficiency*

The Figure 4 – 7 show the fuel efficiency of propane and butane. The data is taken at the minimum and maximum free stream velocity at the point closed to fuel stabilization limit. These figures show the fuel efficiency with the fuel injection position *lf*=40 mm and *lf*=80 mm at the different injection relative position; 2; 2,29 ; 2,67; 3,2 and 4.

1. The Step Height Influence

It is proved that there is a same pattern on each fuel that fuel consumption efficiency is really influenced by the injection location. At *lf*=40 mm that has

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lower step height, the fuel consumption efficiency score tends to be higher that the *lf*=80 at either minimum or maximum air free stream velocity.

At the *lf*=40, the circulation area formed at each *lf/h* tested is influenced by lower velocity recirculation flow zone so that the fuel entering the flow can mix more with the air at the recirculation area to promote more combusted fuel. This can increase the fuel efficiency value.

At the injection location that is far from the step *lf*=80, the air velocity at this area is still high and influenced by the free stream flow so that there is much fuel eliminated by the stream when the fuel is injected. This can make the fuel entering the circulation area lower and eventually causes the combusted fuel mass lower. With the decrease of combusted fuel, the fuel consumption efficiency at the *lf*=80 becomes lower.

The air free stream velocity entering combustion chamber quite influences the fuel efficiency value. The above figure shows the velocity increase of air free stream. The fuel efficiency is getting greater especially at the relative injection position *lf/h*=2 on each injection location, while for the relative position *lf/h*=4 the influence of air free stream velocity is not too much. The influence of air free stream velocity can obviously seen at the propane with the injection location *lf*=40mm where the fuel efficiency of the propane is greater than other gas fuels for each relative injection location condition and air free stream velocity. This is assumed by the writer that the gas entering the recirculation flow field is more combusted since the propane is more reactive than others. The reactivity of the propane is caused by the short carbon chain that promotes the easy breaking.

For the *lf*=80mm, recirculation flow is more influenced by the flow velocity and high turbulence so the fuel and air mixture is better that the increase of the air free stream velocity can cause more reactive gas to be less combusted.

2. The Influence of the Relative Injection Position

The above figures show that if the observation is focused on the influence of relative injection location, there is a tendency of the fuel efficiency value to decrease with the increase of lf/h. at the *lf/h*=2, the fuel efficiency is greater. This condition, in writer's opinion, is promoted by the recirculation flow field influenced by low velocity recirculation flow. And this condition causes less perfect mixture of fuel and air that can cause more combusted fuel.

At the *lf/h*=4, where the recirculation flow field is much influenced by high velocity shear layer and high turbulence intensity at the area near reattachment zone, the area gives the impact to the better fuel air mixture and less fuel entering the recirculation area that as a result can decrease the fuel efficiency.

IV. CONCLUSION

From the test result of the flame stabilization and propane and butane efficiency in the recirculation area at the backward facing step, it can be concluded that:

1. There are two kinds of backward facing step stable flame: first is recirculation stabilized flame with fluctuative characteristic depending on space and time. This flame tends to occur at the injection near the step (*lf/h*=2) as it gets big influence from the recirculation area; second is shear layer stabilized flame that is more stable, not to fluctuated by the space and time. This flame tends to occur at the injection farther from step (*lf/h*=4) where the shear layer influence is very dominant.
2. The fuel efficiency really depends on the change of the relative injection location *lf/h*. if the *lf/h* is near the reattachment, *lf/h*=4, it means that the combusted fuel is little. The fuel mass is more combusted at the lower relative injection location, *lf/h*=2, as at this area, the recirculation flow velocity is lower.
3. The air free stream velocity influence to the fuel efficiency. For the injection location *lf*=40mm, there is an increase of fuel combusted mass especially for the propane. For the *lf*=80 mm, there is a decrease of combusted fuel mass.

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