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Effect of Varying the Retainer Angle on the Performance of Oil Burner

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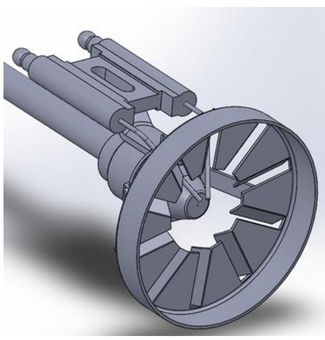
Graphical abstract



Abstract

A research has been done to observe the effect of varying the retainer angle on the performance of oil burner in terms of exhaust gas emissions and temperatures. Retainer was a flame stabilizer used to stabilize the flame, improve mixing between air and fuel and affect the formation of emissions such as carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_X), and sulfur dioxide (SO2). These emissions can cause harm to the world ecosystem. One of the methods to reduce emissions was by varying the retainer's blade angle to certain angle that complete the combustion with high efficiencies and less emissions. In this research, an oil burner with four different retainer angles has been investigated using a combustor of one meter length. Tests were conducted using diesel as feedstock. Four different retainer angles used are 15°, 30° (baseline), 45°, and 60° with swirl number 0.2016, 0.4344, 0.7524, and 1.3032. From the experiment, data shown that swirling flow affect the formation of recirculation zone thus provides the aerodynamics blockage to stabilize the flame and emissions reduced due to varying the retainer angles and the best retainer angle was achieved by consider the exhaust gas emission reduction.

Keywords: Retainer; gas emission; oil burner; combustor; diesel; swirl

1.0 INTRODUCTION

Oil fuel burner have been used a lot at this time in the fast growing country especially Malaysia. The main fuel that is being used by the burner nowadays is diesel. But there are advantages and disadvantages by using this kind of fuel. One of the advantages is the low cost and easily to produced and obtained. The disadvantage is it produces high emission that can cause a lot of pollutants such as global warming, acid rain, ozone depletion, and photochemical smog and so on [1].

Mostly a burner will generate the heat and transfer it to energy [2] that can be used to run some appliances such as turbines system or boiler. But the burner also will generate a lot of emissions that can give a lot of bad effects to the ecosystem and the life on earth. These gases from emissions include carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and others [3].

As such, a detailed research on decreasing those emissions must be studied. One solution that can control or decreasing the emission was by knowing the parameters that is involved in a burner [4]. One method that is suitable to control the emission is by using the axial swirl or commonly known as retainer [5]. This axial retainer usually has several blades with a same angle for all that blades. For this research, the retainer angles were varied to certain angles, i.e. 15º, 30º, 45º and 60º in order to give effects on the flame stabilization. Flame stabilization was important to the combustion system because it will effects all the emissions, fuel consumption and energy produced [5-6]. This research is to find the optimum angle for the retainer vanes in order to produce a low emission burner for all the emissions. This condition can be achieved by studying the burner performance. This method can also determine the performance of oil burner through equivalent ratio as the mixture of air and fuel will generate the lean mixture, stoichiometric or rich mixture of fuel.

Retainer or air swirler is a part of oil-fired burner that produces vortex or back circulation [7] in combustion chamber in order to make sure complete combustion can be reached. Effective retainer can make higher vortex or back circulation in combustion chamber that will help fuel burning more effective and reduces the gas emissions. In this experiment, four angles has been tested in order to find the best angle on producing good vortex for combustion and give low emissions better than the original retainer. Four angles that were tested are 15, 30, 45 and 60 degrees. There are many types and shapes of retainers being used in the burner. Figure 1 shows the retainer geometry attached to the fuel nozzle and ignitor. The important aspects that characterize the types of retainer are the air flow needed, the pressure needed and the pressure drop of the retainer [7].

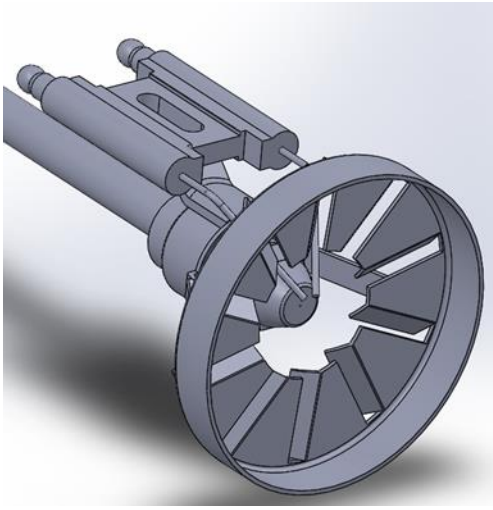


Figure 1 Retainer

The function of the recirculation zone is to mix, partly burn and prepare the fuel for rapid combustion within the remainder of the burning zone [8]. Ideally, at the end of the burning zone, all fuel should be burnt so that the function of the dilution zone is solely to mix the hot gas with the dilution air. The mixture leaving the chamber should have a temperature and velocity distribution acceptable to the guide vanes and turbine. The air swirler adds sufficient swirling to the inlet flow to generate central recirculation region (CRZ) which is necessary for flame stability and fuel air mixing enhancement [9]. Systematic study of swirling flow is an efficient and effective approach for investigating complex flows and correlating combustion dynamics to fluids dynamics [10]. As shown in Figure 2, the low pressure area in the middle of the vortex will induce back the whirl [5].

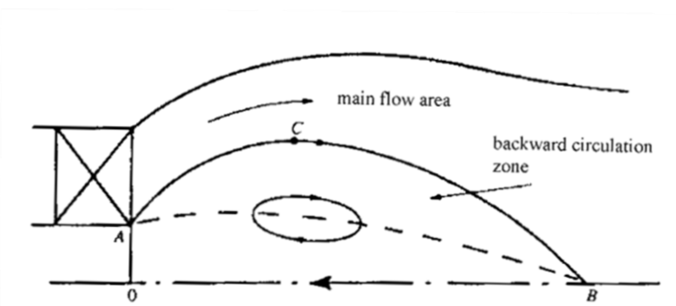


Figure 2 Recirculation zone [5]

With the aid of swirl vanes surrounding the fuel nozzle, strong vortex flow occurs in the combustion air in the combustion region. A low-pressure region is created at the combustor axis which causes recirculation of the flame toward the fuel nozzle [11-12]. At the same time, radial holes around the liner supply air to the center of the vortex, making the flame grow to some extent. The size of the backward circulation zone happened in the estuary of the retainer. So, the increasing of the backward circulation zone size is very important since it is the main factor to achieve a best combustion process [5, 11]. There are 4 main factors that will increase the size of this zone:

1) The increasing in the blade angle
2) The increasing in the blade quantity by decreasing the distance per chord ratio
3) The decreasing in the blade aspect ratio
4) The changing of the blade geometry which is from flat blade to helix blade

The backward circulation zone means the zone where all the component of the combustion process mixes together. Thus, by considering all the factors given, a perfect backward circulation zone will be achieved and produce a perfect combustion process.

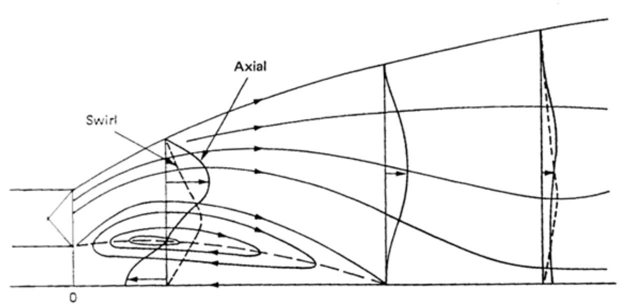


Figure 3 Profiles of axial swirl velocity in swirling flow field [5]

In combustion terms, stoichiometry relates to the amount of oxidizer (air) required to oxidize a fixed amount of fuel. The stoichiometric amount of oxidizer required for the complete combustion of an amount of fuel can be determined using a formula that requires the balancing of the atoms involved in the combustion process [5-7]. The air-fuel ratio is can also be stated as Equivalence Ratio, Φ to indicate if a fuel mixture is either stoichiometric, rich or lean. The equivalence ratio is calculated as per Equation (1).

$$\Phi = \frac{(A/F)_{stoic}}{(A/F)} = \frac{(F/A)}{(F/A)_{stoic}} \quad \text{Eq. (1)}$$

When the Φ of a mixture is 1, this means that the mixture is stoichiometric. A mixture is lean when Φ<1 and rich when Φ>1. The air-fuel ration is the single most important factor in determining a system's performance. In order to determine the amount of air to be used in the combustion of diesel, a calculation of the stoichiometric balance of combustion has to be done. Using the molecular composition of diesel [13] as $C_{10.8}H_{18.7}$, the stoichiometric balance of combustion is as follows:

$$C_{10.8} + 15.475(O_2 + 3.76N_2) \rightarrow 10.8(O_2 + 18.7/2)H_2O + 3.76N_2 \quad \text{Eq. (2)}$$

Using the atomic weight of the molecules into consideration (C=12, H=1, O=16 and N=14), we obtained:

$$148.3g + 2124.408g \rightarrow 10.8(O_2 + 9.35)H_2O + 3.76N_2$$

In which the mass of air needed for stoichiometric combustion 2124.40 g for 148.3 g of diesel to be combusted. Using the air-fuel ratio formula, the air-fuel ratio obtained is $(F/A)_{stoic}$ = 0.07.

Experimental studies show that swirl has large-scale effects on flowfields: jet growth, entertainment and decay and flame size, shape, stability and combustion intensity are affected by the degree of swirl imparted to the flow. This degree of swirl is usually characterized by the nondimensional number representing the ratio of axial flux of swirl momentum to the axial flux of axial momentum times the equivalent nozzle radius. This parameter, denoted by the symbol S_N, is called the swirl number and has been used extensively to designate the strength of the swirl [5, 11]. From the calculation of the swirl number, we can see that the angle of spread of the jet increases with the swirl number. Corresponding to this increase in the spread of the jet, the entrainment increases causing faster decay of the velocity and nozzle fluid concentration with distance from the orifice.

Swirling action is augmented with the increase in the swirl number, which leads to increase in the turbulence strength, recirculation zone size, and amount of recirculated mass [14]. The mixing of air-fuel can be enhanced by increasing the velocity and species gradient in this zone. One way to achieve this is the use of swirling air flow that can be obtained by using swirl generators. Swirl flows have been widely employed in many engineering applications [15]. In high-intensity combustion systems, the use of swirl has the following effects such as too reduce combustion lengths by producing higher rates of entrainment of the ambient fluid and fast mixing near the exit nozzle and on the boundaries of recirculation zones and to improve flame stability due to the formation of torroidal recirculation zones in strongly swirling zones. On the other hand, the increase in the swirl number results in more losses in the total pressure which will affect the combustion performances [16]. Equation (3) can be used to determine the swirl number.

$$S_N = \frac{2}{3}\left[\frac{1-\left(\frac{D_{hub}}{D_{sw}}\right)^3}{1-\left(\frac{D_{hub}}{D_{sw}}\right)^2}\right]\tan\theta \qquad \text{Eq. (3)}$$

Swirl numbers for various blade angles based on Equation (3) are shown in Table 1.

Table 1 Swirl number for various angle of retainer

Blade Angle, θ	15°	30°	45°	60°
Swirl Number, S_N	0.2016	0.4344	0.7524	1.3032

* D_{hub} = 30 mm
* D_{sw} = 70 mm

2.0 EXPERIMENTAL

The experiment was conducted at the Combustion Laboratory in the Faculty of Mechanical Engineering. For this experiment, the measured parameters are air mass flow rate while fuel mass flow rate was set constant. Fuel mass flow rate will be set constant at 0.0032 kg/s (0.2 L/m) while the air will be varied for different mass flow rate. The retainer angles were also varied. Experiment equipments can be divided in to three sections, which are combustion chamber, combustor and instrumentation to measure the values from experiment such as temperature and exhaust gas emissions. A Baltur burner with model number BT14GW was used for this project. Combustion chamber is annulus type with outlet diameter about 400 mm and the thickness about 30 mm. The combustion chamber used in the experiment is an open-ended combustion chamber with openings at every 100 mm for placement of measurement devices such as thermocouples. The combustion chamber is made of concrete lined/refractory materials with mild steel sheeting. The experiment apparatus is set up as shown at Figure 4.

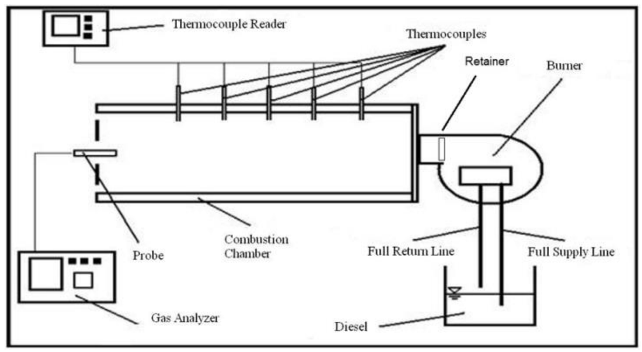
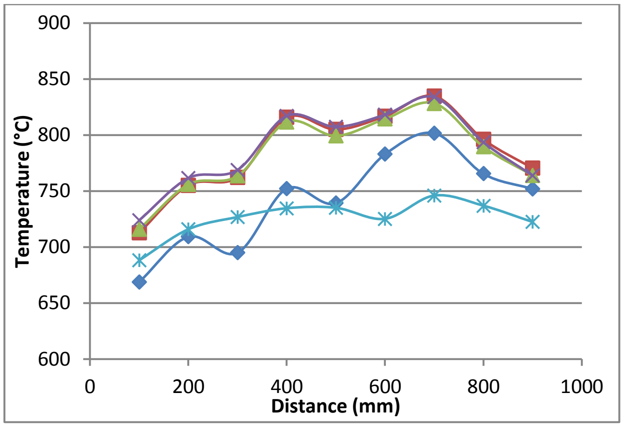


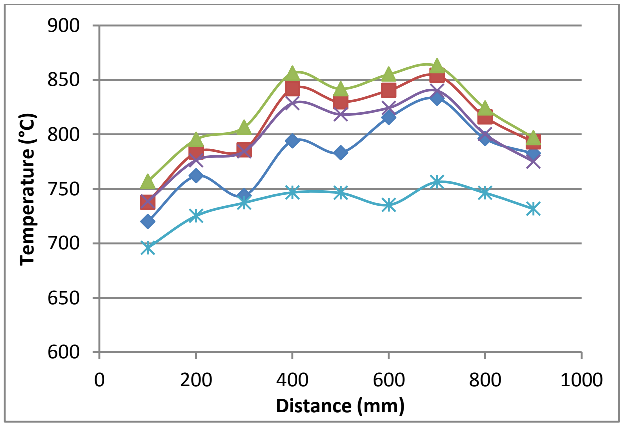
Figure 4 Schematic of experimental setup

3.0 RESULTS AND DISCUSSION

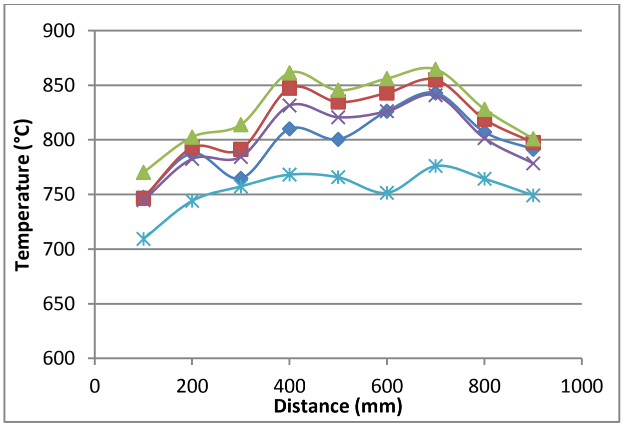
Figures 5(a), 5(b), 5(c), 5(d) and 5(e) show the temperature distribution at different distance from combustion chamber entrance. At Φ=0.833, for baseline, the highest temperature is at 748.3ºC while retainer with 60 degree was 842.6ºC. While at Φ=0.881 for baseline, the highest temperature is at 758.3ºC while retainer with 45 degree was 861.9ºC. For Φ=0.986, the highest temperature for baseline is 775.1ºC while for retainer with 45 degree was 868.4ºC. While for Φ=1.185, the highest temperature for baseline is 813.6ºC while for retainer with 45 degree was 864.2ºC. Meanwhile for Φ=1.391, the highest temperature for baseline is 852.6ºC while for retainer with 30 degree was 889.2ºC.



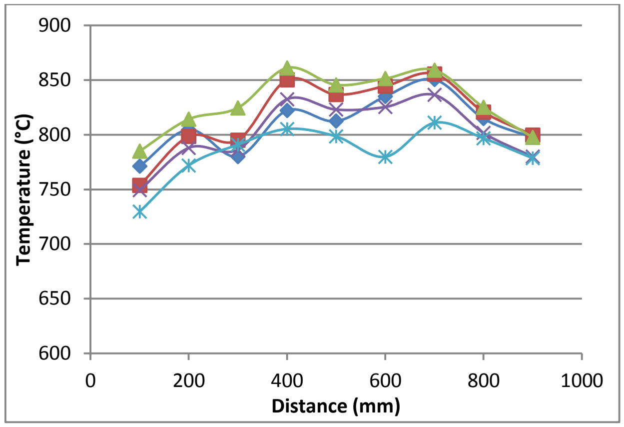
(a) Φ=0.833



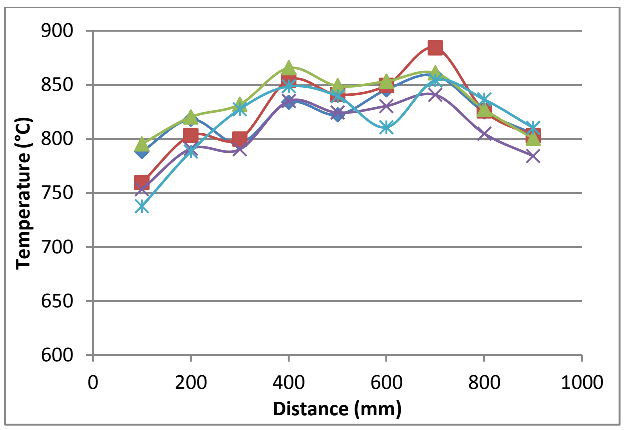
(b) Φ=0.881



(c) Φ=0.986



(d) Φ=1.185



(e) Φ=1.391

Figure 5 Temperature distributions at variable equivalent ratio

Figures 6, 7 and 8 show the effects of increasing the blade angle on exhaust emissions from burner system. Figure 6 shows carbon monoxide emissions plotted against equivalent ratio for all air retainers. There was more than 23 percent decrease in carbon monoxide (CO) emission when increasing the vane angle from baseline to 60° at equivalent ratio of 1.185. The reduction increases when increasing the vane angle from baseline to 45º as much as 17 percent. A CO emissions of greater than 23 percent was achieved at the same equivalent ratio which indicate that swirling flow does help in mixing the fuel and air thoroughly prior to ignition. This is evident throughout the whole operating equivalent ratios and for all retainers. The content of carbon monoxide emission increases with the increase in equivalent ratio after equivalent ratio of 0.986. There are a few factors in production of carbon monoxide but the main factor such as less air supplied will reduce the oxygen and this will limit the oxidation of carbon.

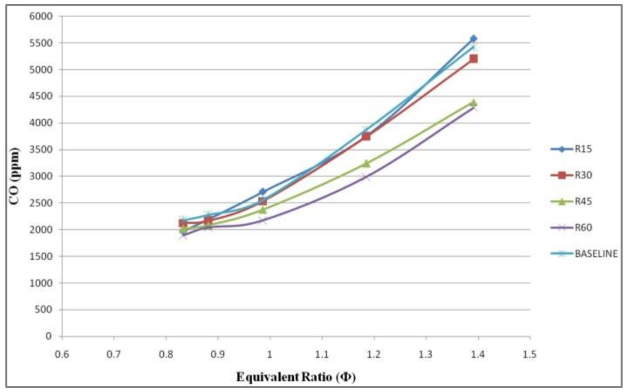


Figure 6 Carbon monoxide emissions at variable equivalent ratio

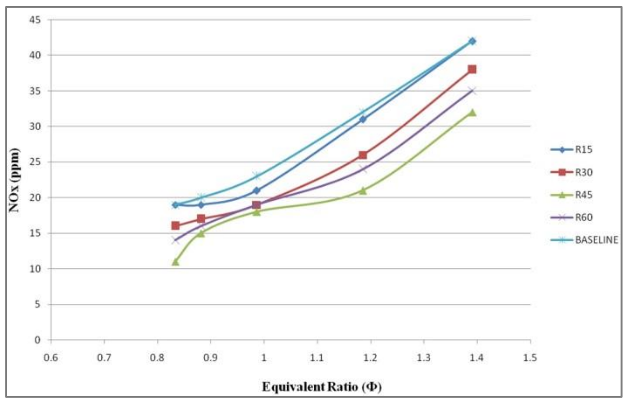


Figure 7 Nitrogen oxide emissions at variable equivalent ratio

Figure 7 shows vast reduction in nitrogen oxide (NO) emissions when the blade angle was increased from 15º to 60º. This was apparent for the whole range of operating fuel flow rates. Emission level below 42 ppm was obtained for all range operating fuel flow rates. For retainer blade angle of 60º, NO emission reduction of more than 25 percent was obtained at equivalent ratio of 1.185 compared to the baseline blade angle air retainer at the same equivalent ratio. Meanwhile, NO reduction of near 35 percent was achieved for blade angle of 45° compared to baseline at the same equivalent ratio. This proved that swirl does helps in mixing the fuel and air prior to ignition and hence reduced NO emissions.

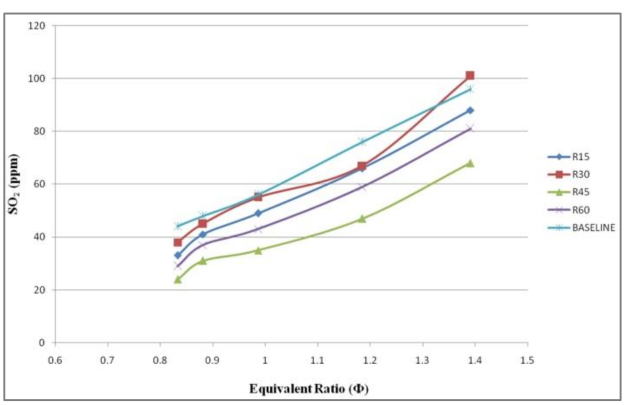


Figure 8 Sulphur dioxide emissions at variable equivalent ratio

Figure 8 shows vast reduction in sulphur dioxide (SO_2) emissions when the blade angle was increased from 15º to 60º. Emission level below 136 ppm was obtained for all ranges of operating fuel flow rates. For retainer blade angle of 45º, SO_2 emission reduction of more than 39 percent was obtained at equivalent ratio of 1.185 compared to the baseline blade angle air retainer at the same equivalent ratio. Meanwhile, SO_2 reduction of near 23 percent was achieved for blade angle of 60° compared to baseline at the same equivalent ratio. This proved that swirl does helps in mixing the fuel and air prior to ignition and hence reduced SO_2 emissions.

■4.0 CONCLUSION

Liquid oil burner using retainer with angles of 15º, 30º, 45º and 60º, corresponding to swirl number of 0.2016, 0.4344, 0.7524 and 1.3032, has been studied and how this retainers can affect the forming emission of nitrogen oxide (NO_X), carbon monoxide (CO), carbon dioxide (CO_2) and sulphur dioxide (SO_2). This short flame will produce the high temperature at the short distance and the increasing of the flame volume at main zone can reduce the emission of carbon monoxide. From the results, for reducing nitrogen oxide emissions, retainer angle with 60º is the best, while for carbon monoxide retainer with angle 30º is the best. For reduce carbon dioxide, retainer with angle of 60º is more effective. Then, for reducing sulphur dioxide, retainer with angle 45º more suitable than others. After the investigations, I can conclude that the optimum retainer angle is 45º because it can reduce nitrogen monoxide and carbon oxide at the same time although not too much. A NO_X emissions reduction of about 35 percent was obtained at equivalent ratio of 1.185 when using higher blade angle retainer compared to that of the lower blade angle retainer at the same equivalent ratio. CO emissions were also reduced greatly, 23 percent reduction was obtained when using higher blade angle air retainer compared to that of the lower blade angle air retainer. NO_X, emissions of less than 42 ppm were achievable over the whole range of operating equivalent ratios when using higher blade angle air retainer at the same fuel flow rate. The retainer is one of the most effective ways to induce flow recirculation inside the primary zone. This type of recirculation provides better mixing, In addition swirling flow is used to control the stability and intensity of the combustion and the size and shape of the flame region which is dependent on the size and shape of the recirculation zone.[10] Therefore, it can be concluded that the mass flow rate (engine load), retainer blade angle and swirl number S_N are one the factor governing the size of the recirculation zone and combustion performances.

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