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The Effect of Radial Swirl Generator on Reducing Emissions from Bio-Fuel Burner System

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Abstract - **A liquid bio-fuel burner system with various radial air swirlers attached to combustion chamber of 280 mm inside diameter and 1000 mm length has been investigated. All tests were conducted using crude palm oil as fuel. A radial flow air swirler with curved blades having 50 mm outlet diameter was inserted at the inlet plane of the combustor to produce swirling flow. Fuel was injected at the back plate of the swirler outlet using central fuel injector with single fuel nozzle pointing axially outwards. The swirler vane angles and equivalence ratios were varied. Tests were carried out using four different air swirlers having 45°, 50°, 60°and 70° vane angles. NOx emissions reduction of about 12 percent was obtained at swirl number of 1.911 as compared to 0.780 at the same equivalence ratio of 0.83. In addition, emission of carbon monoxide decreased as the swirl number increased. The results shows that a proper design of air swirler has great effect on mixing process and hence the combustion and emission.**

Keywords- **Swirler, Pressure drop, Swirl number, Combustion, NOx emission.**

I. INTRODUCTION

The primary purpose of combustion is to raise the temperature of the airflow by efficient burning of fuel. From a design viewpoint, an important requirement is a means of relating combustion efficiency to the operating variables of air pressure, temperature, mass flow rate and to the combustor dimensions. Unfortunately, the various processes taking place within the combustion zone are highly complex and a detailed theoretical treatment is precluded at this time. Until more information is available, suitable parameters for relating combustion performance to combustor dimensions and operating conditions can be derived only through the use of very simplified models to represent the combustion process. One such model starts from the well-established and widely accepted notion that the total time required to burn a liquid fuel is the sum of the times required for fuel evaporation, mixing of fuel vapor with air and combustion products, and chemical reaction.

The combustion chamber is the place where two major events take place; at the inlet fuel will mix completely, or to a sufficient degree, with air. In some combustors fuel mixes with air before combustors, however, in order to achieve a smooth burning, air and fuel should be mixed before burning. Depends on when fuel will mixes with air, Second event is burning. In the combustion chamber, due to the high temperature, the gaseous mixture which consists of fuel and air will ignite and raise the temperature. Rise in temperature will increase the volume which will drive the fluid forward. There are number of facts that make this part of gas turbine important. In order to make this clear, we will address problems in a poorly designed combustion chamber.

Ying huang (2005) For each swirl number, calculations were performed for about four flow-through times (around12 m/s) after the flow field had reached its stationary state to obtain statistically meaningful data for analyzing the flow dynamics. Three distinct recirculation zones are observed in the low-swirl number case with S = 0.44, including a separation wake recirculation zone (WRZ) behind the centre body, a corner recirculation zone (CRZ) due to the sudden enlargement of the combustor configuration, and a central toroid recirculation zone (CTRZ) resulting from vortex breakdown. The wake recirculation zone, however, disappears at the high swirl number of SN = 1.10. If there is no swirl, only the wake and corner recirculation zones exist. As the swirl number increases and exceeds a critical value, vortex breakdown takes place and leads to the formation of a central recirculation zone. As the swirl number increases further, the central recirculation zone moves upstream and merge with the wake recirculation zone. To mohiko Furuhata et al. (2007) Studied a low NOx combustor for kerosene-fuelled micro gas turbine based on a new concept was proposed, and the combustion

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characteristics of the prototype combustor were investigated. The new concept combustor consisted of primary and secondary combustion zones, and they were connected by a throat. A swirler was set between the primary and secondary combustion zones. In order to enhance the recirculation of burned gas in the primary combustion zone, the combustion air was introduced through the swirler and forced to flow upward to the combustor bottom, from where fuel spray was supplied through a nozzle. An optimum configuration of the primary combustion zone such as length of primary zone, swirler vane angle, diameter of throat, etc.

were investigated to achieve high combustion stability and low emission in wide ranges of fuel flow rate and excess air ratio. The result shows that when the length of primary zone was 109 mm, the lean combustion limit was higher and CO and NOx concentrations at the combustor exit were lower than those in the other lengths. In the case of 175 mm, the flame in the primary zone changed to luminous flame and the CO and NOx concentrations in exhaust gas were increased. Ishak et al. (2009) conducted experimental investigations and developed a liquid bio-fuel burner system with various radial air swirler attached to combustion chamber of 280 mm inside diameter and 1000 mm length has been investigated. All tests were conducted using crude palm oil as fuel. A radial flow air swirler with curved blades having 50 mm outlet diameter was inserted at the inlet plane of the combustor to produce swirling flow. Fuel was injected at the back plate of the swirler outlet using central fuel injector with single fuel nozzle pointing axially outwards.

The swirler vane angles and equivalence ratios were varied. Tests were carried out using four different air swirler having 45°, 50°, 60°and 70° vane angles. NOx emissions reduction of about 12% was obtained at swirl number of 1.911 as compared to 0.780 at the same equivalence ratio of 0.83. In addition, emission of carbon monoxide decreased as the swirl number increased. The results shows that a proper design of air swirler has a great effect on mixing process and hence the combustion and emission. Shang Yong et.al (2010) studied A concept of forced swirl combustion chamber in diesel engine is proposed. It can be used to enhance the intensity of swirl flow in the cylinder and accelerate the rate of air-fuel mixture process by designing the special structure in the combustion chamber Firstly, the calculative result of double swirl combustion chamber by CFD code FIRE is calibrated by the method of Validation & Verification with experiment data.

By the effect of the special structure of the ridge and slope in partial swirl combustion chamber, the rate of air-fuel mixture and combustion process has been accelerated twice by comparing with the calculative result of these two combustion chambers. At the same time, the utilization of air in squish zone has been improved. The characteristic of double-peak has appeared within main combustion duration on the instantaneous heat release rate curve of partial swirl combustion chamber. The result of calculation shows that NOx and soot mass fraction of partial swirl combustion chamber is lower than that of double swirl combustion chamber by 8.2 and 7.4 % respectively, and indicated heat efficiency is 2.2 % higher.

II. SWIRL NUMBER

The swirl number is usually defined as the fluxes of angular and linear momentum (Beer and Chigier, 1972) and it isused for characterising the intensity of swirl in enclose and fully separated flows.The parameter can be given as (Beer and Chigier, 1972).

$$S' = \frac{G_\phi}{G_\chi . r_o}$$

where Gφis the axial flux of angular momentum:

$$G_\phi = 2\pi \int_0^\infty \rho U_x U_\theta r^2 dr$$

and Gx is the axial flux of momentum (axial thrust):

$$G_\chi = 2\pi \int_0^\infty \rho U_x^2 r dr + 2\pi \int_0^\infty p r dr$$

In the above, ro is the outer radius of the swirler and Ux and Uθ are the axial and tangential component of velocity atradius r. The swirl number should, if possible, be determined from measured values of velocity and static pressure profiles.However, this is frequently not possible due to the lack of detailed experimental results. Therefore, it has been shown(Beer and Chigier, 1972) that the swirl number may be satisfactorily calculated from geometry of most swirl generator.

III. EXPERIMENTAL SET UP

The drawing for radial air swirler is shown in Figure 2. Table 1 shows the various dimensions of radial air swirler usedin the present work. The air swirlers are made from mild steel. They were manufactured in various angles to investigatethe effect of pressure loss and combustion performance due to swirl number on the overall performance of the airswirler.The general set-up for liquid bio-fuel burner tests is shown in Figure 3. The rig was placed horizontally on a movabletrolley. The air is introduced into the liquid bio-fuel burner and flows axially before entering radial through the airswirler of 8 blades where the amount of air entering the combustor

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is controlled by the flame swirler minimum area.The rig is equipped with a central fuel injector. The inside diameter of the combustor is 280 mm and the length is 1000mm. The combustor was cooled by convection from the ambient air. Industrial ring blower was used for air supply atbelow 0.5% pressure loss.

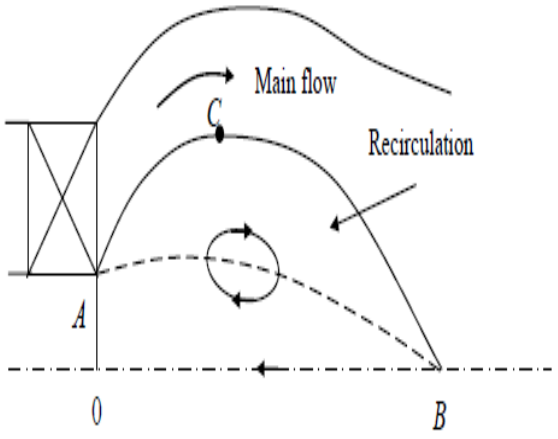

Fig.1. Recirculation zone in swirling flow.

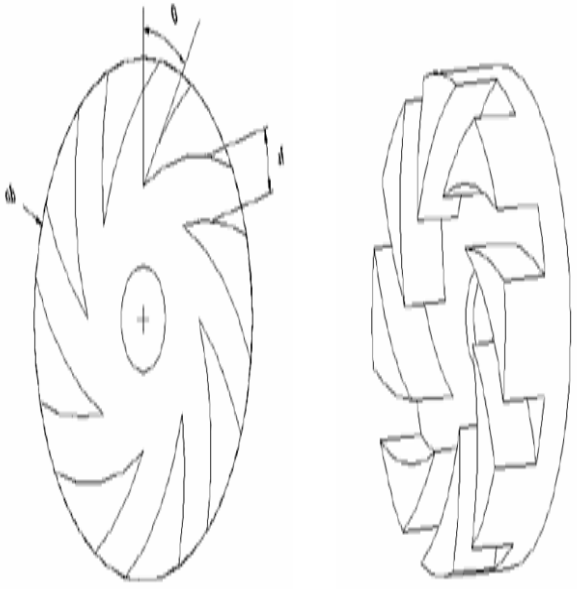

Fig.2. Schematic of Radial Air Swirler Design.

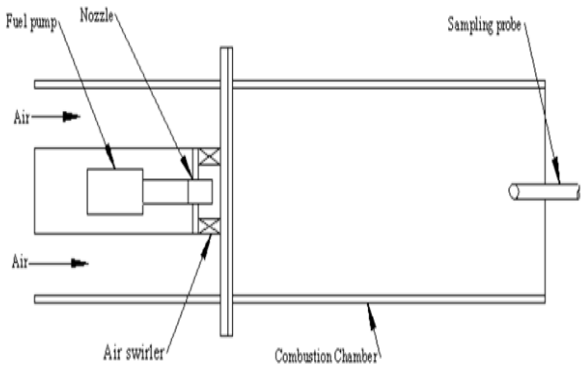

Fig.3. Schematic Diagram of the liquid bio-fuel burner experimental rig.

Table I: Dimensions of Various Radial Air Swirler

Swirler angle / Parameter	45°	50°	60°	70°
Passage width, h (mm)	12	11.2	9.6	8.8
Swirl number, S'	0.780	0.978	1.427	1.911
No. of vane, n	8			
Outlet diameter, do (mm)	98			
Inlet diameter, di (mm)	50			
Vane depth, L (mm)	25			

IV. RESULTS AND DISCUSSIONS

From Figure 4, it can be seen generally that all discharge coefficients were approximately constant with variation in Reynolds number. Thus the value of discharge coefficient may be concluded to be independent of Reynolds number. Inthe case for S = 1.911or 70º vane angle swirler gave the highest CD around 0.68. The CD values were decreased with the decreasing in swirl number (S), with the lowest S = 0.780 having the CD value of around 0.58. This may be attributed to the fact that the excessive swirl was generated by the restriction on swirled exit width.

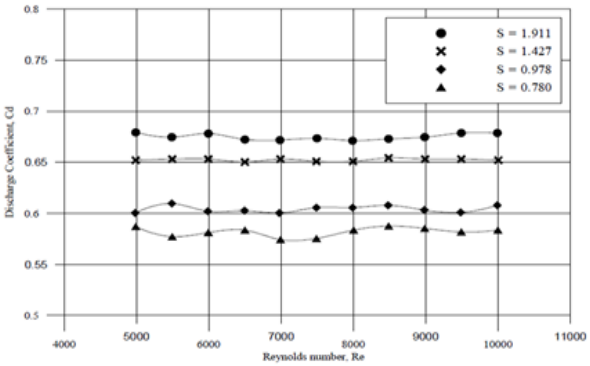

Fig. 4. Discharge Coefficient vs. Reynolds Number for Various Swirl Numbers.

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Figures 5 and 6 show the effect of increasing the swirl number on exhaust emissions from burner system. Tests on exhaust emission were carried out using four swirler vane angles of 45, 50,60° and 70.Figure 5 shows vast reduction in oxides of nitrogen (NOx) emissions when the vane angle was increased from 45° to70. This was apparent for the whole range of operating equivalence ratios. Emissions level of below 35 ppm was obtained for all range of operating equivalent ratios. For swirl number of 1.911, NOx emissions reduction of about 12percent was obtained at equivalence ratio of 0.83 compared to the swirl number of 0.780 at the same equivalence ratio. This proved that swirl does helps in mixing the bio-fuel and air prior to ignition and hence reduced NOx emissions. This situation occurs at certain swirler vane angle. However this was achieved at the expanse of increased in other emissions and reduction in combustion stability.

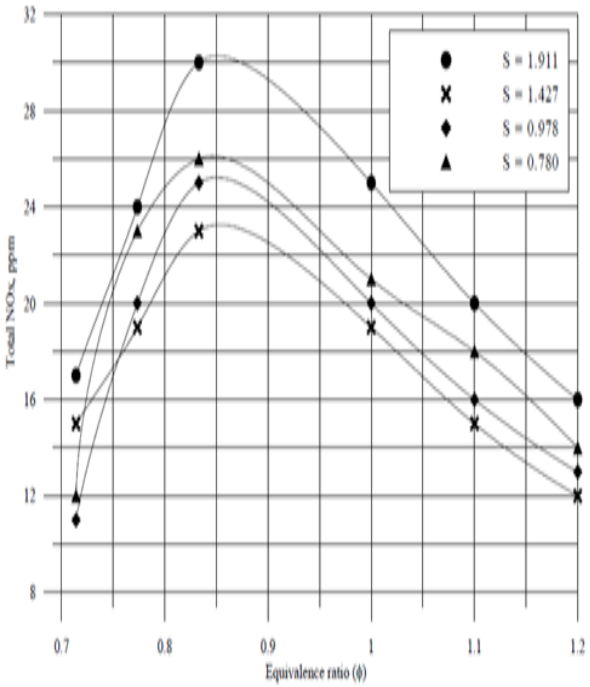

Fig.5. NOX vs Equivalence Ratio for various swirl Number.

Figure 6 shows carbon monoxide emissions versus equivalence ratio for all swirl number. There was a 13 percent, 22percent and 31 percent reduction in carbon monoxide (CO) emission for swirl number 0.978, 1.427 and 1.911 compared to swirl number of 0.780 at the equivalence ratio of 0.833. The concentration of carbon monoxide emission increases with increase in equivalence ratio. This was anticipated due to the fact that any measure of decreasing NOx will tend to increase CO since both emissions were on the different side of the balance (Al-Kabie, 1989). Nonetheless, the increase was quite high, which indicates that there is some fuel escaped unburned, which was the product of incomplete combustion.

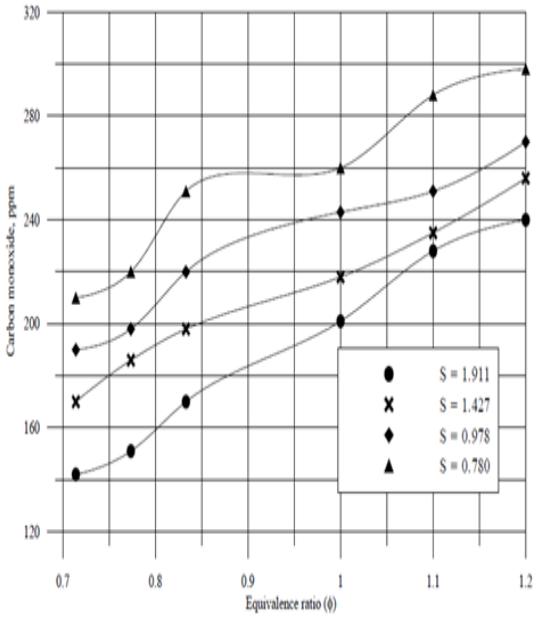

Fig.6. CO vs. Equivalence Ratio for various swirl number.

V. CONCLUSION

An experimental investigation of swirl number effect on the NOx and CO emissions of palm oil combustion has been conducted. Four radial swirlers with vane angles of 45°, 50°, 60°and 70° which are corresponding to 0.780, 0.978,1.427 and 1.911 respectively was used in this investigation. Ox emissions reduction of about 12 percent was obtained at equivalent ratio of 0.83 at swirl number of 1.911 as compared to 0.780 at the same equivalence ratio. Other emissions such as carbon monoxide decreased when using higher swirl number compared to that of the lower swirl number. This shows that the proper design of the swirlerenhances the mixing process of the air and bio-fuel prior to ignition. It can be also concluded that NOx emissions of less than 35 ppm were achievable over the whole range of equivalence ratios for all swirlers.

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