THE INFLUENCE OF VARIABLE VANE ANGLE AIR SWIRLER ON REDUCING EMISSIONS FROM COMBUSTION PROCESS

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ABSTRACT

The effect of varying the vane angle on reducing emissions such as oxides of nitrogen (NO_x) and carbon monoxide (CO) from combustion processes is presented. In this paper, a liquid fuel burner system with different radial air swirler vane angles has been investigated using 163 mm inside diameter combustor of 280 mm length. A radial flow air swirler with straight vanes having 40 mm outlet diameter was inserted at the inlet plane of the combustor to produce swirling flow.

All tests were conducted using kerosene as fuel. Fuel was injected at the back plate of the swirler outlet using central fuel injector with two fuel nozzles pointing axially outwards. The swirler vane angles and equivalence ratios were varied. Tests were carried out using four different air swirlers having 30°, 40°, 50° and 60° vane angles, respectively. NO_x reduction of more than 27 percent was obtained for the swirler with vane angle of 60° compared to 30° vane angle. CO emissions were also reduced by 38 percent for 60° vane angle compared 30° vane angle This was achieved at equivalence ratio of 0.95. This paper demonstrated that NO_x emission decreases with increase in vane angle of radial air swirler.

1.0 INTRODUCTION

Swirling flow is a main flow produced by air swirled in gas turbine engine. Such flow is the combination of swirling and vortex breakdown. Swirling flow is widely used to stabilize the flame in combustion chamber. Its aerodynamic characteristics obtained through the merging of the swirl movement and free vortex phenomenon that collide in jet and turbulent flow. This swirl turbulent system could be divided into three groups and they are jet swirl turbulent with low swirl, high jet swirl with internal recirculation and jet turbulence in circulation zone. Each and every case exists due to the difference in density between jet flowing into the combustion chamber and jet flowing out into the atmosphere from the combustion chamber.

When air is tangentially introduced into the combustion chamber, it is forced to change its path, which contributes to the formation of swirling flow. The balance in force could be demonstrated by the movement of static pressure in the combustion chamber and can be calculated by measuring the distribution of the tangential velocity. Low pressure in the core center of the swirling flow is still retrieving the jet flow in the combustion chamber and thus, produces the not-so-good slope of axial pressure. Meanwhile at the optimum swirl angle, the swirl finds its own direction and as a result, swirl vortex is formed.

The recirculation region in free swirl flow is shown in Figure 1. It is assumed that the flow is axially symmetrical, thus only half of the flow characteristics are discussed. The recirculation region is in the *OACB* curve. The point *B* is known as stagnation point. The flow outside of the *OACB* curve is the main flow, which drives the recirculation along the *AB* solid curve. The ultimate shear stress could happen at points near to point *A*, along the boundary of recirculation. The condition of zero axial velocity is represented by hidden curve *AB*. Every velocity component decreases in the direction of the tip. After the stagnation point, the reverse axial velocity will disappear far into tip, the peak of velocity profile will change towards the middle line as an effect of swirling decrease.

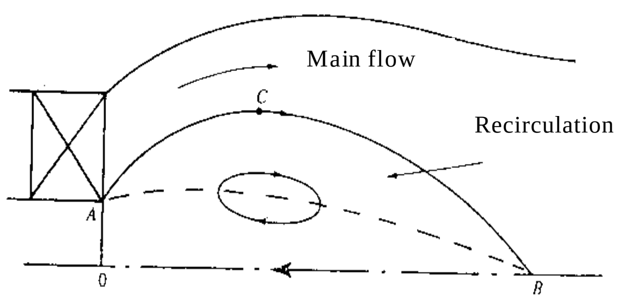

Figure 1 Recirculation zone in swirling

As the level of applied swirl increase, the velocity of the flow along the centerline decreases, until a level of swirl is reached at which the flow becomes stationary. As the swirl is increased further, a small bubble of internal recirculating fluid is formed. This, the vortex breakdown phenomenon, heralds the formation of large-scale recirculation zone that helps in stabilizing the flame. It has been suggested (Beer,1972;Thring,1971) that the large torroidal recirculation zone plays a major role in the flame stabilization process by acting as a store for heat and chemically active species and, since it constitutes a well-mixed region, it serves to transport heat and mass to the fresh combustible mixture of air and fuel.

The level of swirl or swirl strength can be represented in term of swirl number. Determining the swirl number is of great importance in burner design since it contributes to the correct setting for the swirl vanes. Past researchers have studied the effect of varying the vane angle, which in turn vary the swirl number, on combustion performance. Drake and Hubbard (1963) studied the effect of swirl on completeness of combustion and discovered that there was an optimum swirl vane setting. Claypole and Syred (1981) investigated the effect of swirl strength on the formation of NO_x. They varied the swirl number from 0.63 to 3.04 using natural gas (mainly methane). At swirl number of 3.04, much of the NO_x in the exhaust gases was recirculated into the flame front. The total emissions of NO_x were reduced, however, at the expense of reduced combustion efficiency.

Mohd-Jaafar *et al*., (1998) investigated the effect of using swirling flows on reducing NO_x. The radial air swirler vane angles were varied from 28.9^o to 84.5^o and tested using natural gas only and found out that 25 percent and 33 percent NO_x emissions reduction were achieved at burner pressure loss of 40 mm and 10 mm H_2O, respectively. These were achieved not at the expense of increased unburned hydrocarbon (UHC) and carbon monoxide. When it was tested at burner pressure loss of 10 mm H_2O, these emissions were reduced rather then increased. It was found that for burner pressure loss of 10 mm H_2O that the optimum vane angle was 51.1^o and for the burner pressure loss of 40 mm H_2O tests the optimum vane angle was 74.3^o.

Al-Kabie (1989), on the other hand, demonstrated that there is no significant effect on NO_x emissions by varying the vane angle from 20^o to 60^o, hence varying the swirl number from 0.41 to 3.25, respectively. However, at very high swirl number of 3.25, NO_x emissions were considerably higher than the rest at all associated equivalence ratio for two different inlet air temperature of 400 and 600 K. This may be due to increased residence time in the rich stabilizing shear layer and hence increased NO_x emissions. The same effect was demonstrated when he switched from natural gas to propane.

Another way to increase the strength of swirl without changing the vane angle is to decrease the vane depth of the swirl. Kim (1995) studied the effect of decreasing the vane depth of a small radial swirler with 40 mm outlet diameter having a vane angle of 45^o. The effect of increasing the swirl number in this way was seen clearly, especially at 740 K, on decreasing the emissions of NO_x. Combustion efficiencies were also improved as the swirl strength increased. Increasing the swirl strength also extend the lean flammability limits.

Other earlier researchers who studied the effect of varying the swirl strength were mainly interested on the flow pattern and temperature profiles resulted from varying the swirl strength. They were emphasizing the effect of swirl on the generation of torroidal central recirculation zones and flame geometry rather than the effect of swirl strength on emissions formation. Mestre (1974) on the other hand, compared the effect of swirling and non-swirling system on combustion. He demonstrated that the existence of swirl help improve combustion efficiency, decrease all pollutants and increase flame temperature. It was observed that during the presence of swirl, a shorter blue flame was observed indicating good mixing while non-swirling system showed a longer yellow flame indicating that there is still some fuel left unvaporized.

In the present study, the effect of using three different swirler vane angles to vary the swirl strength was investigated. The air swirlers were changed by dismounting it from the combustor test rig and replaced with different vane angle air swirler.

2.0 EXPERIMENTAL RIG SET-UP

The general rig set-up for the liquid fuel burner tests is shown in Figure 2. The rig was placed horizontally on a movable trolley. The air is introduced through the inlet pipe and flows axially before entering the combustor through the radial swirler of 40 mm outlet diameter where the amount of air entering the combustor is controlled by the air swirler minimum area.

The rig is equipped with a central fuel injector. The inside diameter of the combustor is 163 mm and the length is 280 mm. The combustor was cooled by convection from the ambient air. The air entering the combustor was passed through a plenum chamber of the same diameter where the air swirler was installed at its exit plane and the fuel was introduced in this chamber.

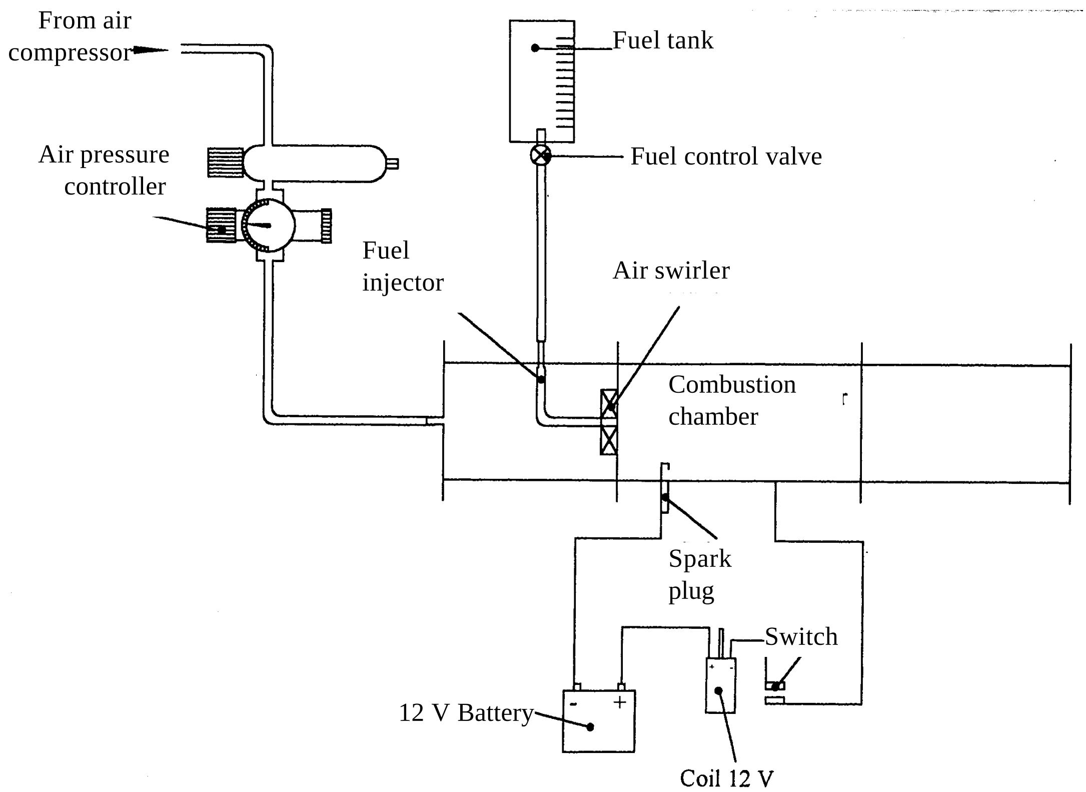

Figure 2 Schematic of test rig set-up

The air swirler used in these tests are of radial flow type with straight vanes. The vane angles are varied from 30^o to 60^o in increment of 10^o. Figure 3 shows the schematic of radial air swirler with 40^o vane angle.

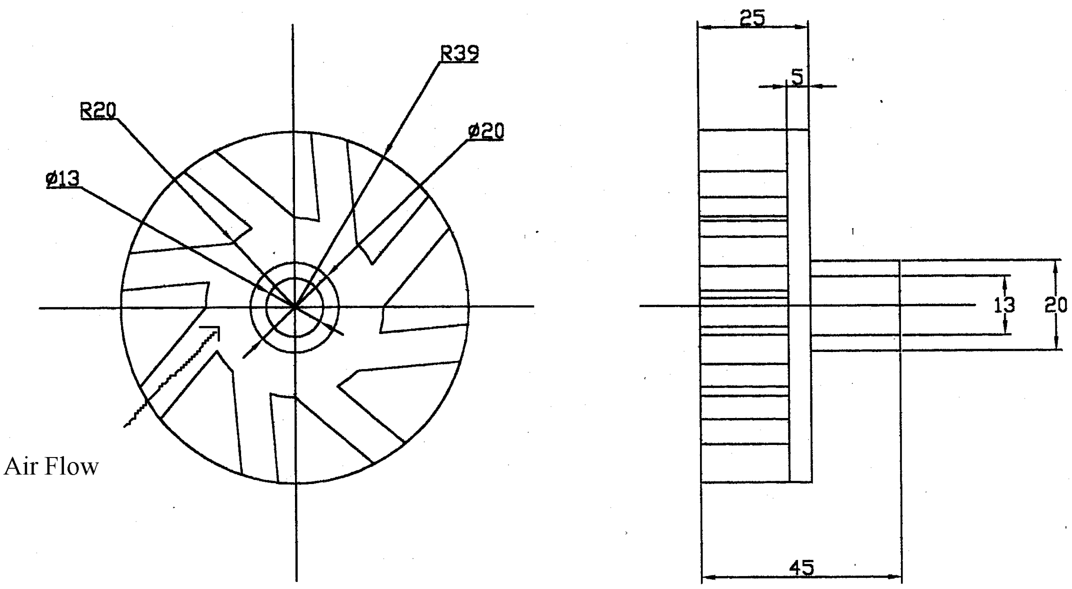

Figure 3 Schematic of 60^o vane angle radial air swirler

3.0 TESTS CONDITION

Tests were carried out at around ambient temperature for inlet air since there was no preheating devices used in these tests. Air was supplied from the main air compressor in the laboratory. The air supply pressure was metered using an air pressure regulator. This air supply was split into two, one to supply air to the combustor and the other to compress the fuel to help in atomising the fuel to smaller droplets.

Kerosene was used as fuel throughout the entire investigation. Swirler vane angles and fuel flow rates were varied to see the effect of lean and rich conditions on emissions formation.

The exhaust sampling probe was mounted at the end pipe. The gas analyzer used in these tests was the portable MSI Dragger gas analyzer.

4.0 RESULT AND DISSCUSIONS

Figures 4 and 5 show the effect of increasing the vane angle on exhaust emissions from liquid fuel burner system. Tests on exhaust emissions were carried out using 4 swirler vane angles of 30°, 40°, 50° and 60°.

Figure 4 shows vast reduction in oxides of nitrogen (NO_x) emissions when the vane angle was increased from 30° to 60°. This was apparent for the whole range of operating equivalence ratios from around 0.83 to 1.06. NO_x concentration of below 18 parts per million (ppm) was obtained for swirlers over the entire range of operating equivalence ratios. This shows that the use of air swirler does helps in mixing the fuel and air thoroughly prior to ignition. This helps to achieve near complete combustion.

As can be seen clearly from Figure 4 that NO_x emissions decreases as the vane angle was increased from 30^o to 40^o. When further increased to 50^o, NO_x emission was further decreased. A NO_x reduction of more than 27 percent was achieved for vane angle of 60° compared to the 30° vane angle at the same equivalence ratio. This is in agreement with all other researchers mentioned previously. However, in this work, it was shown that the vane angles can be increased from 30^o to 60^o without causing any detrimental effect on emissions and flame stability. Hence, the emissions are further reduced and flame are more stable.

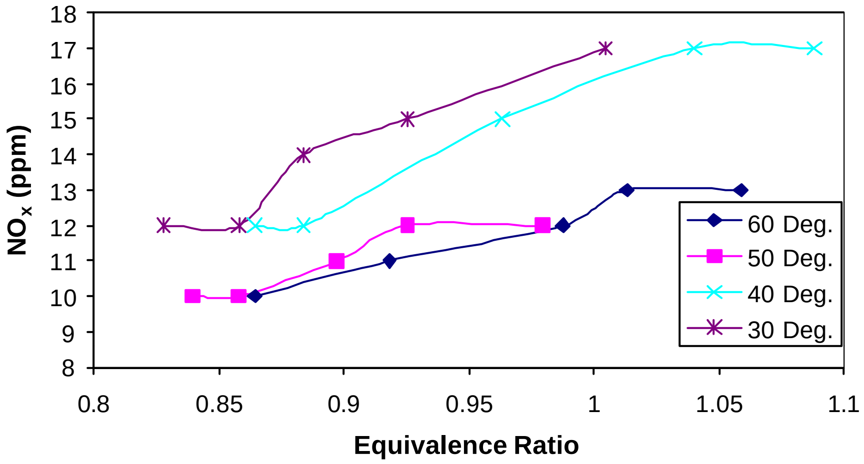

Figure 4 Effect of NO_x emissions on equivalence ratio at different vane angle

Figure 5 shows the effect of carbon monoxide emissions against equivalence ratios for all air swirlers. All swirlers show emissions concentration of lower than 1400 ppm over the entire range of operating equivalence ratios. The trend of CO emissions against equivalence ratio is as expected since CO emissions are higher at leaner condition and decreases towards stoichiometric and starts to increase again.

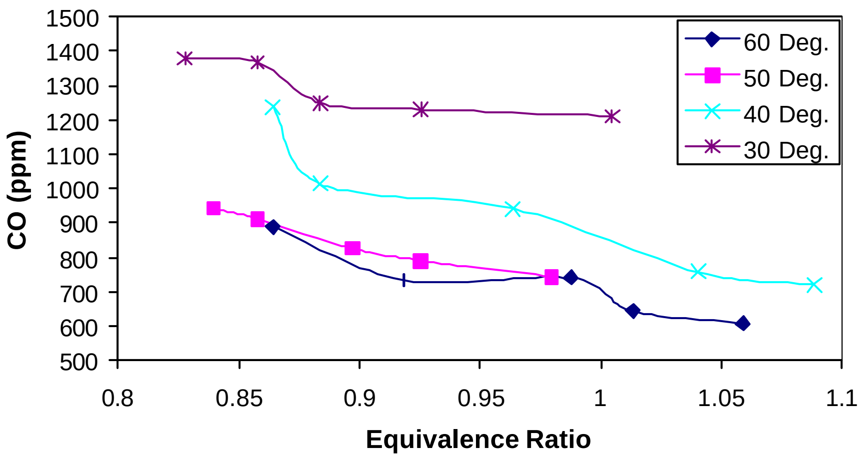

Figure 5 Effect of CO emissions on equivalence ratio at different vane angle

The same trend was observed, ie. CO emissions decrease when increasing swirler vane angles from 30^o up to 60^o. This can be attributed to the turbulent effect generated by the swirling flow resulting in better mixing of fuel and air prior to combustion. This eventually resulted in lower CO concentration since almost complete combustion was achieved. There was a 38 percent decrease in CO emission for vane angle of 60° compared to the 30° vane angle at the same equivalence ratio.

5.0 CONCLUSIONS

An NO_x emissions reduction of about 27 percent was obtained at equivalence ratio of 0.95 when using higher vane angle air swirler compared to that of the lower vane angle air swirler at the same equivalence ratio. Carbon monoxide emissions were also decreased when using higher vane angle air swirler compared to that of the lower vane angle air swirler. NO_x emissions of less than 18 ppm was achievable over the whole range of equivalence ratios when using higher vane angle air swirler.

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