Reducing Emissions from Bio-Fuel Burner System

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Introduction

Conventional bio-fuel burners, operating at or above stoichiometric air/fuel ratios, produce high flame temperatures that result in the production of nitrogen oxides (NOx), which is then emitted to the atmosphere. However, lowering NOx emission by reducing flame temperature will lead to reduced flame stability or increase in Carbon Monoxide (CO) emission. Basically there are two techniques for controlling NOx in burner applications:

i) prevent the formation of nitric oxide (NO) and
ii) destroy NO from the products of combustion.

In this research, a burner will be designed to incorporate a swirling flow to enhance turbulence and hence aid fuel-air mixing prior to ignition. A swirling flow induces a highly turbulent recirculation zone, which stabilises the flame resulting in better mixing and combustion. It has been suggested that the large toroidal recirculation zone plays a major role in the flame stabilisation 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 fresh combustible mixture of air and fuel.

Most conventional liquid fuel burners employ the axial-flow type swirler. These swirl vanes are usually flat for easy manufacturing process, but curved blade may give better performance in aerodynamic properties. 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 - jet swirl turbulence 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 recirculation region in free swirl flow is shown in Figure 1. Every velocity component decreases in the direction of the tip. After the stagnation point, the reverse axial velocity will disappear far into the tip; the peak of velocity profile will change towards the middle line as the effect of swirling decreases. As the level of applied swirl increases, 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.

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 a fresh combustible mixture of air and fuel.

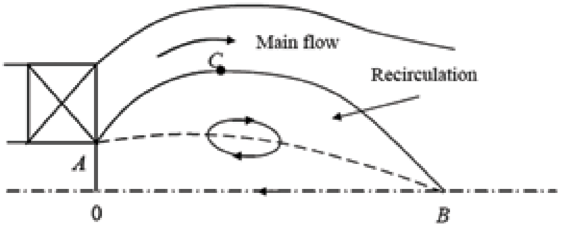

Figure 1. Recirculation zone in swirling flow

A significant improvement in performance is obtained as well as NOx emissions when using radial swirler compared to the axial swirler due to the immediate contact of fuel with turbulent by swirled air as it leaves the fuel nozzle. Aerodynamic curved vanes allow the incoming axial flow force to turn gradually. This inhibits flow separation on the suction side of the vane such that a more complete turning and higher swirl and radial velocity component can be generated at the swirler mouth, with the added advantage of lower pressure loss. The discharge coefficient (CD) for the various radial swirlers, are low, approximately 0.6 compared with the zero angle blade, approximately 0.9. Poor CD is due to the vane angle and not just the 90° inlet and outlet blades. This led to a major consideration of the flow field inside the swirler vane passage as low CD implied that flow separation occurred in the passage in spite of the curved vane.

Experimental set up

The drawing for radial air swirler is shown in Figure 2. Table 1 shows the various dimensions of radial air swirler used in the present work. The air swirlers are made from mild steel and manufactured with various angles to investigate the effect of pressure loss and combustion performance due to swirl number on the overall performance of the air swirler. The rig is placed horizontally on a movable trolley. The air is introduced into the liquid bio-fuel burner and flows axially before entering radially through the air swirler of 8 blades where the amount of air entering the combustor 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 1000 mm. The combustor is cooled by convection from the ambient air. An industrial ring blower is used for air supply at below 0.5% pressure loss.

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			

Table 1. Dimensions of Various Radial Air Swirler

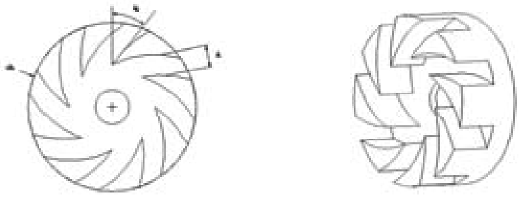

Figure 2. Schematic of Radial Air Swirler Design

Results and discussions

Isothermal performance

In order to achieve better mixing between fuel and air in liquid bio-fuel burner, a turbulent flow must be generated to promote mixing. Turbulence energy is created from the pressure energy dissipated downstream of the flame stabilizer. In the radial swirler with orifice insertion, turbulence can be generated by increasing the aerodynamic blockage or by increasing the pressure drop across the swirler. The CD for a radial swirler is obtained by passing a metered air flow through the radial swirler and flame tube while monitoring the static pressure loss upstream of the radial swirler relative to the atmospheric pressure.

The results for isothermal performance as a function of Reynolds number is generally that all discharge coefficients are approximately constant with variation in Reynolds number. Thus the value of discharge coefficient may be concluded to be independent of Reynolds number. In the case for S = 1.911or 70° vane angle swirler gave the highest CD around 0.68. The CD values decreases with decreasing 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 is generated by the restriction on swirler exit width.

Combustion Performance

Tests on exhaust emission are carried out using four swirler vane angles of 45°, 50°, 60° and 70°. A vast reduction in NOx emissions when the vane angle was increased from 45° to 70° is seen. Emission level below 35 ppm is obtained for all range of operating equivalent ratios. For swirl number of 1.911, NOx emissions reduction of about 12 % was obtained at an equivalence ratio of 0.83 compared to the swirl number of 0.780 at the same equivalence ratio. This proved that swirl does help in mixing the bio-fuel and air prior to ignition and hence reduced NOx emissions. This situation occurs at a certain swirler vane angle. However this is achieved at the expense of increase in other emissions and reduction in combustion stability. CO emissions versus equivalence ratio for all swirl number is a 13 percent, 22 percent and 31 percent reduction in CO emission for swirl number 0.978, 1.427 and 1.911 compared to a swirl number of 0.780 at the equivalence ratio of 0.833. The concentration of CO 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 are on the different side of the balance. Nonetheless, the increase is quite high, which indicates that there is some fuel escaping unburned, producing an incomplete combustion.

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 correspond to CD of 0.780, 0.978, 1.427 and 1.911 respectively. NOx emission reduction of about 12 percent is obtained at an equivalent ratio of 0.83 at a swirl number of 1.911 as compared to 0.780 at the same equivalence ratio. Other emissions such as carbon monoxideCO decreased when using higher swirl number compared to that of the lower swirl number. This shows that the proper design of the swirler enhances 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 are achievable over the whole range of equivalence ratios for all swirlers.

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