THERMAL CHARACTERIZATION OF STRAIGHT AND CURVE EDGE BLADE LIQUID FUEL SWIRL BURNER

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Abstract

Accurate monitoring and controlling of the temperature in the combustion chamber can raise the burner efficiency, combustion intensity, fuel consumption and reduce pollutant emission. However, except combustion is accurately monitored and controlled, high concentration of pollutant gases and products like carbon monoxide (CO) and soot can form in the combustion chamber. This paper compares the combustion thermal profiles in a liquid fuel swirl burner using developed straight edge and curve edge blade swirlers at (20, 30, 40, 50 and 60)° for 6, 8, 10 and 12 number of blades in order to optimize the temperature of the burner. Measurements were made in straight and curve blades liquid fuel swirl burner in order to study and compare the thermal characteristics of the straight and curve edge blades in optimizing the combustion dynamics. Similarly, measurements were made for burner without swirl generator and the combustion temperature assessed. Thermal profile was measured in the direction of flow via the six axial ports at distance ((d) = 150, 350, 550, 750, 950 and 1150 mm) from the burner exit using Chromium-Zinc thermocouple. Results showed that the wavelength and oscillation of temperature decay in the same type of blade followed the same trend and the peak of combustion intensity is nearer the nozzle for curve edge blades than the straight edge blade. Six (6) blades performed best with the highest temperature in all the ports, while 12 blades gave the least performance. Findings further show that curve edge blade swirlers gave better performance than straight edge blade swirlers with highest temperature of (1065 and 1015) °C, respectively. Hence, it is recommended especially where high temperature and stability application is desirable.

Keywords: liquid fuel, combustion, curve edge blades, straight edge blades, thermal profile.

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1. Introduction

The quest for fuel swirl burner technology with efficient air-fuel mixture for optimized combustion performance without compromising the global yearning for stringent clean, low emissions and sustainable alternative fuel is attracting a renewed research interest in the design of improved fuel swirl burner [1–13]. Swirling flow as a flame stabilization technique in fuel swirl
burner technology has been of immense application in the power plants, refinery burners, and internal combustion engines [14].

Several studies on the effect of different parameters on the efficiency and performance of Liquid Fuel Swirl Burner (LFSB) have been reported. In [15], bio-oil was blended with surfactants containing biodiesel, alcohol, and amine. At a specific flow rate, it was found that flames resulting from emulsified bio-oil with surfactants containing biodiesel offered the least NOx and CO emissions. In the final remark of the authors in the paper, flow rate was considered more crucial in influencing emission levels of NOx and CO emissions when compared to the effect of fuel type. The emulsification and combustion characteristics of LFSB using different methanol-in-canola oil blends at various conditions swirl number and equivalence ratio were investigated by [4]. The three different fuels studied were pure canola oil, 89–9 canola oil emulsion and 85–12.5 canola oil emulsion. The chamber was equipped with a twin fluid atomizer and a radial vane swirler. It was shown that the blend of canola oil and methanol to the blend exhibited improved combustion characteristics in comparison with pure canola oil. It was also reported that the observed increase in vorticity at substantial swirl angle enhanced air-fuel mixing which in turn reduced emission levels. The variation effect of swirl angles on the possibility of enhancing emission reduction efficiency was examined by [16]. It was found that as the swirl angle increased, the emissions of NOx and CO diminished. The reduction in emissions was attributed to the mixing enhancement and shorter resident time. [17] studied the effect of atomizing air swirl intensity on the combustion and emissions characteristics of LFSB. The adopted atomizer design provided opportunity for changing the atomizing air swirl angle. The authors compared performance characteristics of three cases of swirl angles (15, 30 and 45°). The outcome of the study revealed that increase in atomizing air swirl angle enhanced inflame temperature and decreased emission level (associated with CO as well as NOx).

Meanwhile, considerable research efforts on the effect of geometry on temperature profile and thermal efficiency have been well documented. In [2], oscillating combustion technology was implemented in LFSB by introducing a hardware configuration capable of creating oscillations in the fuel flow. The authors examined temperature distribution and radiative heat transfer characteristics in LFSB based on oscillating combustion mode of operations. It was shown that the breakup of thermal boundary layer yielded enhanced heat transfer rate in the oscillating combustion system. Favourable thermal profile and general improvements in the performance characteristics of the system were observed. The authors attributed the foregoing to oscillations in the fuel flow by the oscillating valve. Further, a study on thermal efficiency of LFSB using pulsation arising from back-flow tendencies at different heights of burner has been reported [18]. The thermal efficiencies at various geometries of the LFSB were examined. It was revealed that the head loss to backflow increases with higher values of heights. With the nozzle diameter of 0.35 mm, it was reported that optimum thermal performance was realized at 54.0 mm burner’s height. The influence of swirling flow patterns on the thermal performance of a domestic single ring burner has been investigated [19] using three different flow patterns namely; swirl flow, star pattern swirl and the radial flow. Findings revealed that swirl flow pattern exhibited thermal efficiency of 60.4 % at minimal CO emissions, which was observed to be the most improved thermal efficiency in comparison to the other two flow geometries. The effect of various geometry of swirl vanes (twist, curved and skewed) on flame visualization and temperature distribution on co-flow burner was examined by [20]. Although the flow rate of fuel was observed to influence flame visualization and temperature distribution, the skewed swirl vane yielded the most enhanced highest flame shape and temperature profile when compared to twist and curved swirl vanes. In a study carried out by [21], a cylindrical single chamber flameless liquid fuel swirl based combustion reactor was proposed. This LFSB design utilizes maximum swirling effect and multiple air injection to increase fuel residence time as well as mixing time for achieving flameless mode. Although with different equivalence ratios, the authors’ work revealed similar temperature profile inside the combustion chamber. However, the peak temperature was found to be largely directly proportional to the equivalence ratio. Some other recent studies have also provided insights on the crucial influence of burner’s geometry on temperature and thermal characteristics of LFSB [22–25].
Despite all the previous studies, there are yet some unresolved issues especially on the use of various blade geometries at various swirl angles in altering the combustion characteristics. The present work focuses on the effect of selected geometries at various swirl angles as well as for various number of blades on thermal profile of LFSB. Effort is made to characterize temperature distribution and thermal characteristics of LFSB when straight edge and curve edge swirlers are incorporated in the combustion chamber. The present work will provide more insight on the effect of these swirlers on the dynamics of combustion which is of practical important.

2. Materials and methods

The experimental model liquid fuel swirl burner used for this research consists of a high pressure liquid pump atomizer with swirl before the nozzle operating at a pressure above 10 bar. A single output centrifugal blower (powered by 2850 rpm, 0.5 hp, 3 phase electric motor) with a 2-inch gate valve for varying the air flow-rate was used. The burner is made of mild steel but the combustion chamber is made from stainless pipe steel type 304 of thickness 4 mm with dimension 108×420 mm per modular section. It has five modules; each module has a flange machined with projection that exactly fits with the recess on the adjacent module to prevent leakages. The base module has a hinge which was fastened to the burner body by 1 M10-6H bolt and nut. Each module has ports for measurement probes. The modular combustion chamber enables the monitoring and evaluation of the flame length velocity and pressure drop. The blades/vanes were also made using mild steel welded to the centre core on a rod whose base has been threaded for fastening to the burner with M10-6H nut. Fig. 1 shows the schematic diagram of the liquid fuel swirl burner (All dimensions in millimetre). With the control switch on, the centrifugal blower was put on first and set at a constant air flow rate, followed by the atomizer to supply diesel at a particular flow rate and fire was introduced in front of the burner for ignition till combustion took place and the first module of the combustion chamber was fixed followed by the rest. Measurements were made for 6, 8, 10 and 12 straight edge blade swirlers at swirl angles of (20, 30, 40, 50 and 60)°. Similarly, measurements were made under the same experimental conditions for 6, 8, 10 and 12 curve edge blade swirlers at swirl angles of (20, 30, 40, 50 and 60)°.

The ambient temperature was 37 °C, conventional diesel was used as the fuel to fire the liquid fuel swirl burner and the combustion temperatures of the six axial ports with distance (d) from the burner exit (where d = 150, 350, 550, 750, 950, 1150 mm) were taken. Temperature measurements were also taken radially from the centre of the chamber in steps of 9 mm towards the outer surface interacting directly with the environment and axially at specific distance from the burner exit. The time taken for each temperature measurement was 5 minutes for stability. The measurements were repeated three times and the uncertainty was less than ±5 %. The burner was fired with swirl generator. In addition, the burner was also fired without swirl generator in order to provide a reference against which the effect of swirl can be assessed.

Fig. 1. Schematic diagram of the liquid fuel swirl burner

3. Results and discussion

In order to provide a reference against the effect of swirl and blade types, Fig. 2 shows the distributions of axial temperature without swirl generator at various ports and streamwise locations. Similarly, Fig. 3–6 show the axial temperature distributions of liquid fuel burner with
6, 8, 10 and 12 straight edge blades swirl generator, respectively at angle 20° at various ports and streamwise locations. Further, for comparison with straight edge blade, Fig. 7–10 show the axial temperature distributions of liquid fuel burner with 6, 8, 10 and 12 curve edge blades swirl generator respectively at angle 20° at various ports and streamwise locations. It worth noting that for combustion without swirlers, temperature decreases radially and along the combustion chamber in the flame direction with port 1 having the highest temperature as reflected in Fig. 2. However, the wavelength and oscillation of the temperature changed with straight and curve blade swirlers. This is not surprising, since the introduction of blades will lead to enhancement of turbulent mixing. However, irrespective of the blade types and swirling angles, 6 blade swirlers give the best performance with the highest temperature in all the ports, follows by 8 blade swirlers, then 10 blade swirlers, while the least temperature is observed at 12 blade swirlers. This might be due to the number of 6 blades having more space for the (air and fuel) mixture to enter the premix and combustion chambers. Furthermore, for all blade swirlers, the temperature increases from port 1 to port 3 but started to decrease after port 3, which means combustion improves along the chamber up to port 3 because of proper mixing of fuel and air. Interestingly, the peak of combustion intensity is achieved at port 3 for straight blades and port 2 for curve blades irrespective of the swirl angles. This might suggest that curve blade enhances flame propagation than straight blade.

**Fig. 2.** Distribution of axial thermal profiles of the burner without swirl generator

**Fig. 3.** Distribution of axial thermal profiles of 6 straight edge blade swirler at 20°

**Fig. 4.** Distribution of axial thermal profiles of 8 straight edge blade swirler at 20°
Fig. 5. Distribution of axial thermal profiles of 10 straight edge blade swirler at 20°

Fig. 6. Distribution of axial thermal profiles of 12 straight edge blade swirler at 20°

Fig. 7. Distribution of axial thermal profiles of 6 curve edge blade swirler at 20°

Fig. 8. Distribution of axial thermal profiles of 8 curve edge blade swirler at 20°
For better assessment of the performance of the blade type, number of blade and swirl angle, the effect of swirl angle on optimum temperature of straight and curve blade swirlers are shown in Fig. 11, 12, respectively. Similarly, Fig. 13 depicts the effect of number of blades on optimum temperature for both straight and curve blade swirlers. Interestingly, the distributions (Fig. 11, 12) follow the same patterns.

For instance, at particular swirl angle, as the number of blade increases, the optimum temperature decreases. However, for a particular blade type, as the swirl angle increases, the optimum temperature increases until a threshold is reached before starting to decrease. It should be noted that for the present experiment, the threshold for straight blade swirler is 50° whereas for the curve blade is yet to be determined because at 60° (highest swirl angle), the optimum temperature is still increasing. The present result will suggest that curve blade swirler have tendency of sustaining temperature at higher swirl angles. This is not surprising; the dynamics of the blade geometry should play significant role in the flame phenomena. This is evidenced in Fig. 13, where curve blade shows higher optimum temperatures for all the number of blades considered. Meanwhile, 6 numbers of blades show higher optimum temperature compared to others for both cases. However, curve blade swirler demonstrated highest temperature of 1065 °C and straight blade swirler also demonstrated highest temperature of 1015 °C. This implies that curve blade shows a better performance than straight blade. This study will suggest that for high temperature and stability application, curve blade swirler should be preferred. While the objectives of this present study has been achieved though is limited to the measurement of the temperature profiles taking into consideration effect of the swirler blades and configurations, it would be interesting for further study to simultaneously measure both velocity and temperature in order to understand the flow and thermal fields. In addition, visualization technique and emission characterization should be explored.
Fig. 11. Effect of swirl angle on optimum temperature of straight-edged blade swirler

Fig. 12. Effect of swirl angle on optimum temperature of curve-edged blade swirler

Fig. 13. Effect of blade number on optimum temperature of straight-edged and curve blade swirlers
4. Conclusion

Measurements were made in straight and curve blades liquid fuel swirl burner in order to examine and compare the thermal characterization of the straight and curve edge blades in optimizing the combustion dynamics. This was done through the measurements of radial and axial temperature distributions using Chromium-Zinc thermocouple with an effective range of 0 to 1300 °C for the straight and curve blades swirl generator made up of 6, 8, 10 and 12 number of blades at angles of 20°, 30°, 40°, 50° and 60° incorporated in a developed experimental model liquid fuel burner fired by conventional diesel. Similarly, measurements were made for burner without swirl generator against which the effect of both straight and curve blade swirlers were assessed. It was shown that wavelength and oscillation of temperature function followed the same trend for the same blade type and the peak of combustion intensity was nearer the nozzle for curve edge blades than the straight edge blades. It was shown that 6 blades performed best with the highest temperature in all the ports, while 12 blades gave the least performance. Findings further showed that curve edge blade swirlers gave better performance than straight edge blade swirlers with highest temperature of 1065 °C and 1015 °C, respectively. Hence, curve edge blade swirlers are better in enhancing turbulence in the combustion chamber of a burner leading to higher temperature attainable.

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