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Experimental Study on the Production of CO-NO-HC Emissions in the Radial Swirling Flow Combustion System

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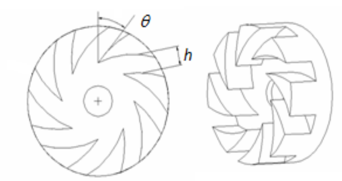
Graphical abstract



Abstract

The main purpose of this paper is to evaluate the production of CO-NO-HC emissions while varying the swirl angle of curve vane radial swirler. 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. Therefore designing an appropriate air swirler is a challenge to produce stable, efficient and low emission combustion inside a burner system. Four radial curve vane swirlers with 30º, 40º, 50º and 60º vane angle corresponding to swirl number of 0.366, 0.630, 0.978 and 1.427 respectively were used in this analysis to show the effect of vane angle on emission production at end of combustion chamber. Pollutant NO reduction of more than 10 percent was obtained for the swirl number of 1.427 compared to 0.366. CO emissions were reduced by 20 percent, 25 percent and 38 percent reduction in carbon monoxide (CO) emission for swirl number of 0.630, 0.978 and 1.427 compared to swirl number of 0.366 respectively. Meanwhile, there was a small decrease in unburned HC emissions when increasing the swirl number for the whole range of equivalence ratios. Results show that the swirling action is augmented with the increase in the vane angle, which leads to better performance of CO-NO-HC emission production inside liquid fuel burner system.

Keywords: Combustion; air swirler; swirl strength; flame stabilizing; CO-NO-HC emission

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 [1]. Its aerodynamic characteristics obtained through the merging of the swirl movement and free vortex phenomenon that collide in jet and turbulent flow. Air swirlers are used as a flame holder by imparting swirl to the incoming air.

Swirl does not only help to stabilize the flame but also to produce other effects which are beneficial to the combustion system. These effects primarily include promoting fuel and air mixing and assisting the control of combustion temperatures and emissions. This is because of the strong shear regions, high turbulence and rapid mixing rates produced by the swirling vortices and the resulting toroidal recirculation zone. The various characteristics of swirl combustion are discussed extensively in the literature [2, 3].

The presence of swirl results in setting up of radial and axial pressure gradients, which in turn influence the flow fields. In the case of strong swirl, the adverse axial pressure gradient is sufficiently large to generate reverse flow along the axis and generating an internal circulation zone [4-7]. In addition, swirling flows are used to improve and control the mixing process between fuel and air streams and enhance heat release rate [8].

The swirl number is usually defined as the fluxes of angular and linear momentum and it is used for characterising the intensity of swirl in enclose and fully separated flows. The parameter can be given as [8]:

$$\mathrm{S} = \frac{\mathrm{G}_{\phi}}{\mathrm{G}_{\chi} . r_o} \tag{1}$$

where G_{ϕ} is the axial flux of angular momentum:

$$\mathrm{G}_{\phi} = 2\pi \int_0^{\infty} \rho U_x U_{\theta} r^2 dr \tag{2}$$

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

$$\mathrm{G}_{\chi} = 2\pi \int_0^{\infty} \rho U_x^2 r dr + 2\pi \int_0^{\infty} p r dr \tag{3}$$

In the above, r_o is the outer radius of the swirler and U_x and U_θ are the axial and tangential component of velocity at radius r.

Since the pressure term in Equation (3) is difficult to calculate due to the fact that pressure varies with position in the swirling jet, the above definition for swirl number can be simplified by omitting this pressure term. Swirl number can be redefined as:

$$S' = \frac{G_\phi}{G'_x r_o} \tag{4}$$

Where

$$G'_x = 2\pi \int_0^\infty \rho U^2{}_x r dr \tag{5}$$

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 that the swirl number may be satisfactorily calculated from geometry of most swirl generator [8]. This research aims to evaluate the combustion characteristics using liquid fuel burner while varying the blade angle in order to investigate the effect of pollution formation and performance.

2.0 EXPERIMENTAL

The schematic drawing of radial swirler designs are shown in Figure 1. Table 1 shows the various dimensions of the radial swirler used in the present work. They were manufactured from mild steel in various angles to investigate the effect of swirl number on the overall performance of the swirler.

The general set-up for liquid fuel burner tests is shown in Figure 2. The rig was placed horizontally on a movable trolley. The air is introduced into the liquid fuel burner and flows axially before entering radial 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 was cooled by convection from the ambient air. Industrial ring blower was used for air supply at below 0.5% pressure loss. Equivalence ratios are defined as the actual air-fuel ratio to the stoichiometric air-fuel ratio [9].

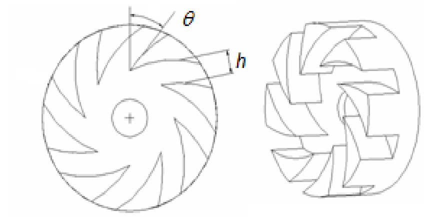


Figure 1 Schematic of radial air swirler design

Table 1 Dimensions of various radial swirler

Swirler angle	30º	40º	50º	60º
Passage width, h (mm)	13.6	12.3	11.2	9.6
Swirl number, S_N	0.366	0.630	0.978	1.427
No. vane, n		8		
Outlet diameter, d_o mm)		98		
Inlet diameter, d_i (mm)		50		
Vane depth, L (mm)		25		

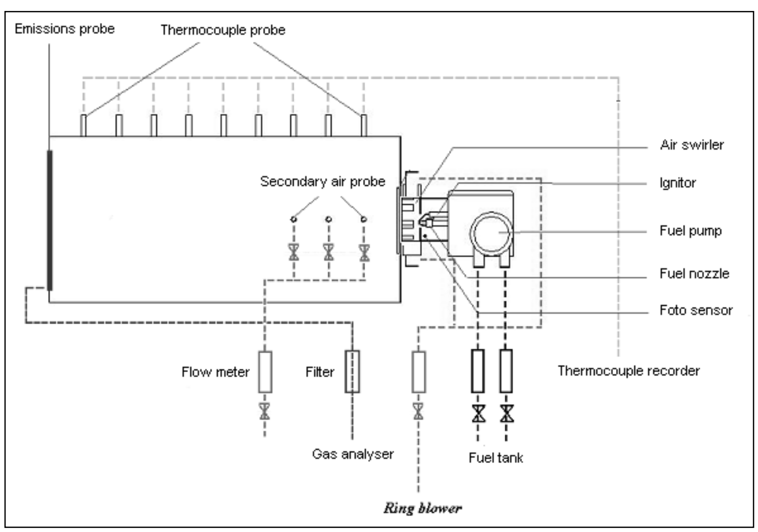


Figure 2 Schematic diagram of the liquid fuel burner experimental rig

The exhaust sampling probe is mounted at the end of the combustion chamber that situated L/D=3.57 from the burner throat. The gas analyser used in these tests was the portable Kane May model 9106 gas analyser capable of measuring oxides of nitrogen, sulphur dioxide, carbon monoxide and carbon dioxide. Table 2 shows gas analyser specifications and range. The measurement of Combustion Efficiency (η) is referred to British standards [10].

Table 2 Gas analyser specifications

Parameter	Resolution	Accuracy	Range
Oxygen (O_2)	0.1%	±0.2%	0-25%
Carbon monoxide (CO)	1ppm	±20ppm	0-10,000ppm
Nitrogen Oxide (NO)	1ppm	±5ppm	0-1000ppm
Hydrocarbon (HC)	1ppm	±5%	0-100,000ppm

3.0 RESULTS AND DISCUSSION

In order to achieve better mixing between fuel and air in liquid fuel combustor, turbulence flow must be generated to promote mixing. Turbulence energy is created from the pressure energy dissipated downstream of the flame stabilizer. Figure 3 to 6 shows the effect of using the different swirl number, S_N and various fuel blends on exhaust emissions from combustor system.

Figure 3 shows that the pollutant nitrogen oxides, (NO) emission increase with respect to equivalence ratio for all swirlers. Emissions level of below 35 part per million (ppm per volume) was obtained for all range of operating equivalence ratios. Swirler with S_N -0.366 give the higher range of pollutant NO compared to other swirler. This experiment also shows the vast reduction in pollutant NO emissions when the vane angle was increased from swirl number, S_N- 0.978 to 1.427. This was apparent for the whole range of operating equivalence ratios. Pollutant NO emissions reduction of more than 10 percent was obtained for the swirler with S_N -1.427 compared to S_N -0.978 at 0.8 equivalence ratio. This proved that swirl does help in mixing the fuel and air prior to ignition and hence reduced pollutant NO 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. This suggested that higher swirler vane angle enhances better mixing than the lower ones due to improve upstream mixing the fuel and air prior to ignition and hence reduced pollutant NO emissions.

Figure 4 shows carbon monoxide emissions versus equivalence ratio for all swirl number. There was a 20 percent, 25 percent and 38 percent reduction in carbon monoxide (CO) emission for swirl number 0.630, 0.978 and 1.427 compared to swirl number of 0.366 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 pollutant NO will tend to increase CO since both emissions were on the different side of the balance [11]. Nonetheless, the increase was quite high, which indicates that there is some fuel escaped unburned, which was the product of incomplete combustion.

Figure 5 shows a plot of unburned Hydrocarbon (HC) emissions versus equivalence ratio for all air swirlers. There was a decrease in unburned Hydrocarbon (HC) emissions when increasing swirl number. This was seen throughout the whole range of operating equivalence ratios. Anyway the increasing was very small compared to the reduction of pollutant NO emissions that was obtained.

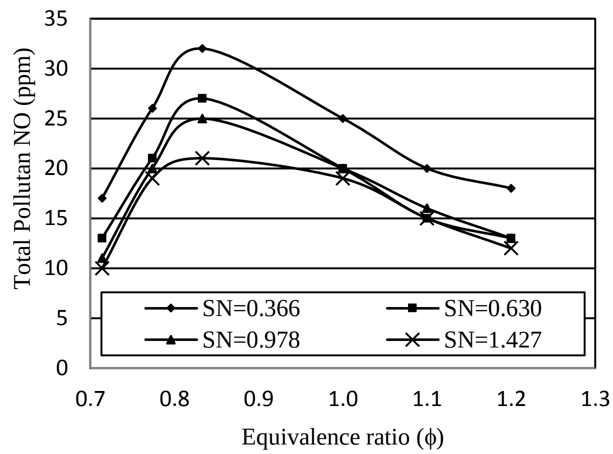


Figure 3 Pollutant NO vs Equivalence ratio for various swirling angle

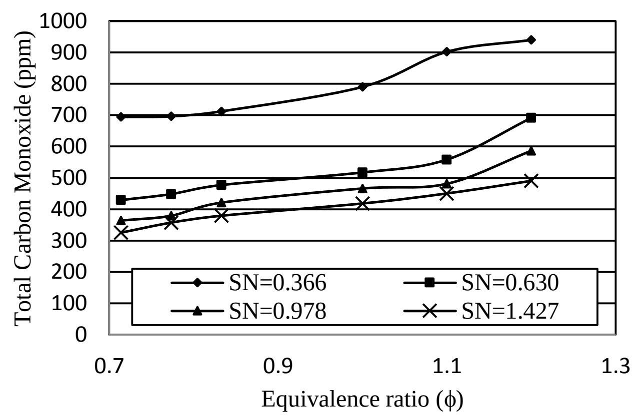


Figure 4 CO vs Equivalence ratio for various swirling angle

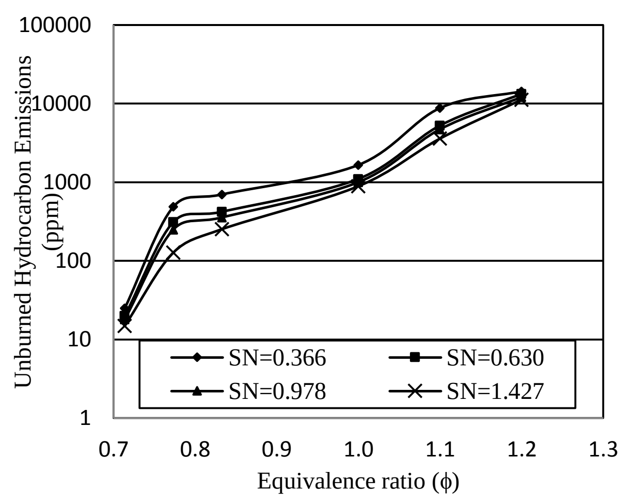


Figure 5 unburned Hydrocarbon (HC) emissions vs Equivalence ratio for various swirling angle

Figure 6 shows a plot of Combustion Efficiency (η) versus equivalence ratio for all air swirlers. The Combustion Efficiency (η) around 70-77 percent was obtained for all the combustion range. There was an increase in Combustion Efficiency when increasing the swirl number S_N-1.427 compared to S_N-0.978. This was seen throughout the whole range of operating equivalence ratios.

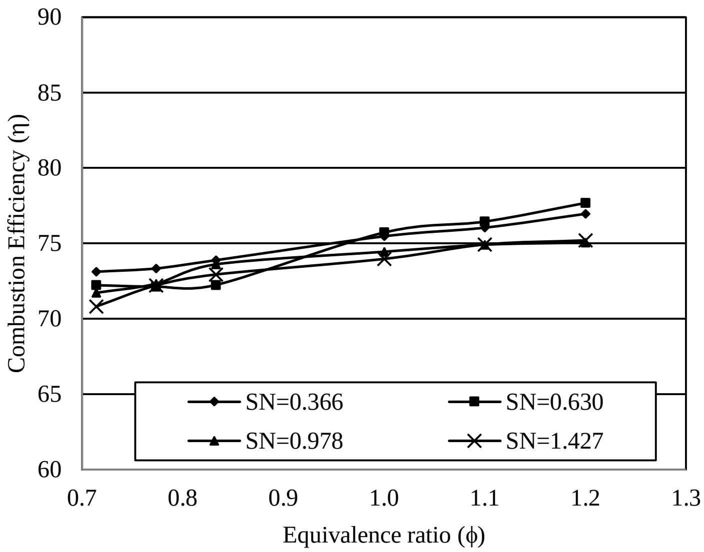


Figure 6 Combustion Efficiency (η) vs Equivalence ratio for various swirling angle

■4.0 CONCLUSION

An experimental investigation of swirl number effect on the CO-NO-HC emissions of liquid fuel combustion has been conducted while varying swirl number condition for lean to rich equivalence ratio. Four radial swirlers with vane angles of 30°, 40°, 50°and 60° which are corresponding to 0.360, 0.633, 0.978 and 1.427 respectively was used in this investigation. Pollutant NO emissions reduction of about 10 percent was obtained at equivalent ratio of 0.83 at swirl number of 1.427 as compared to 0.978 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 swirler enhances the mixing process of the air and liquid fuel prior to ignition. Emissions on other pollutants, such as unburned HC also gave a positive effect when varying the swirl number throughout the whole range of operating equivalence ratios that investigated. Therefore, for the future works in the development of an efficient combustion system, the relationship between the swirler number/swirler angle and the formation of CO-NO-HC must be taken into consideration.

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References

[1] Jaafar, M. N. M., Ishak, M. S. A., Saharin, S. 2010. Removal of NOx and CO from a Burner System. *Environmental Science and Technology*. 44 (8): 3111–3115.
[2] Gupta, A. K., Lilley, D. G. and Syred, N. 1984. *Swirl Flows*. Abacus Press, Tunbridge Wells, England.
[3] Sloan, D. G., Smith, P. J. and Smoot, L. D. 1986. Modelling of Swirl in Turbulent Flow System. *Prog. Energy Combust. Sci*. 12: 163–250.
[4] Lefebvre, A. H. 1983. *Gas Turbine Combustion*. First edition. Hemisphere Publishing Corporation.
[5] Mellor, A. M. 1990. *Design of Modern Gas Turbine Combustor*. Academic Press.
[6] Mohd Jaafar, M. N., Eldrainy, Y. A., Ahmad, M. F. 2009. Investigation of Radial Swirler Effect on Flow Pattern inside Gas Turbine Combustor. *Modern Appl. Sci*. 3(5): 21–30.
[7] Yehia, A. E., Hossam, S. A., Khalid, M. S., Mohd Jaafar, M. N. 2010. A Multiple Inlet Swirler for Gas Turbine Combustors. *Int. J. Mechanical Syst. Sci. Eng*. 2(2): 106–109.
[8] Beer, J. M., Chigier, N. A. 1972. *Combustion Aerodynamics*. Applied Science Publishers Ltd.
[9] Spiers, H. M. 1977. *Technical Data on Fuel*. 7th ed. The British National Committee, World Power Conference, London.
[10] British Standard-BS845. 1987. *Methods for Assessing Thermal Performance of Boilers for Steam, Hot Water and High Temperature Heat Transfer Fluids, Comprehensive Procedure*. British Standard Institution. United Kingdom.
[11] Gupta, A. K., Lewis, M. J., Qi, S. 1998. Effect of Swirl on Combustion Characteristics of Premixed Flames. J. Eng. Gas Turbine and Power. *Trans, ASME.* 120: 488–494.