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Experimental Analysis on the Formation of CO-NO-HC in Swirling Flow Combustion Chamber

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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. Swirling flow generates central recirculation region (CRZ) which is necessary for flame stability and enhances fuel air mixing. Therefore designing an appropriate air swirler is a challenge to produce stable, efficient and low emission combustion inside burner system. Four radial curved vane swirlers with 30°, 40°, 50° and 60° vane angles corresponding to swirl numbers of 0.366, 0.630, 0.978 and 1.427 respectively were used in this experiment to measure the vane angles effect on emission production in the combustion chamber. Emission measurements were conducted at 5 axial distances from the burner throat, and at 5 locations along the radius starting the central axis at each section. It was found that at the core near the throat, CO and HC concentrations are low due to high available O_2 and high fuel mixing rate producing efficient combustion. This is due to the high shear region created the high swirl flow.

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

1.0 INTRODUCTION

The use of swirling flow in the combustor is known to improve the length and the stability of the flame [1]. One common method of generating swirling jets is by employing a vane swirler. Employing swirlers on the combustion affects emissions, combustion performance, flame stability and many other factors. Swirling flow also allows the use shorter and bigger diameter combustor.

Swirl also promotes fuel and air mixing and assists in 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 literatures [2, 3].

The presence of swirl also 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 generate an internal re-circulation zone [4-7]. In addition, swirling flow also helps improve and control the mixing process of fuel and air streams and enhance heat release rate [8].

The geometric swirl number (S_N) has been formulated by Al-Kabie [9] and given as;

$$S_N = \frac{\sin\theta}{1+ 1/\tan\theta}\left[\frac{A_a}{C_c A_{th}}\right] \tag{1}$$

Where

A_a is the swirler exit area,
A_{th} is the swirler minimum throat area,
C_C is the swirler contraction coefficient.

Value for C_C, the swirler contraction coefficient, C_D, the swirler discharge coefficient and hence the swirl number was obtained using the following Equation (2) and Equation (3). The discharge coefficient in term of swirler pressure drop and air mass flow rates can be obtained as;

$$C_D = \frac{\dot{m}}{A_{th}\sqrt{2\rho\Delta P}} \tag{2}$$

Where

$\dot{m}$ is the volumetric air flow rates
ΔP is the pressure drop

An expression for contraction coefficient in term discharge coefficient, throat area and swirler exit area can be obtained as follow;

$$C_C = \frac{C_D}{1 + \left(\frac{C_D A_{th}}{A_a} \right)} \tag{3}$$

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 [10].

This paper evaluates the detail internal emissions measurement from a swirl burner using liquid fuel, near the burner throat while varying the blade angle in order to investigate the effects of pollution formation.

2.0 EXPERIMENTAL SETUP

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 [11]. In the present analysis, the stoichiometry condition is applied for all cases.

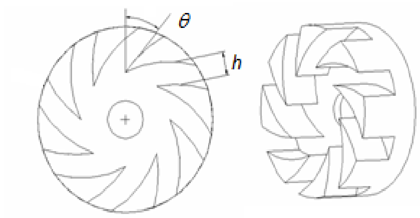

Figure 1 Schematic of radial air swirler design

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 (numerical calculation)	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			

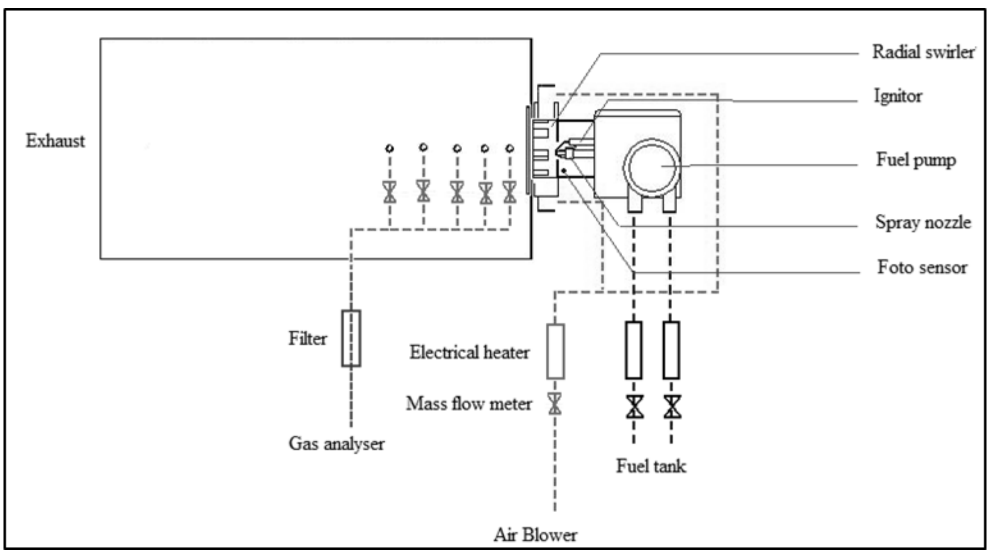

Figure 2 Schematic diagram of the liquid fuel burner experimental rig

The exhaust sampling probe is mounted transverse downstream of the swirler in the expansion chamber at various cross section stations (z/D = 0.2 to 1.0) from the burner throat as shown in Figure 3. 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 emissions results are referred to British standards[12].

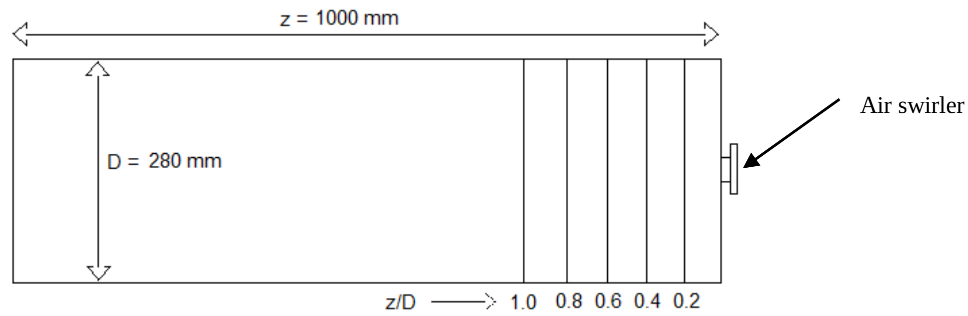

Figure 3 Details of position of transvers measuring stations indicated by cross section lines (z/D = 0.2 to 1.0) from the swirler throat

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, turbulent flow must be generated to promote mixing. Turbulent energy is created from the pressure energy dissipated downstream of the flame stabilizer. Transversal profiles of gas-phase carbon monoxide (CO), oxide of nitrogen (NO), hydrocarbon (HC) and excess of oxygen were obtained from the experiment at chamber radial distance of 56mm (z/D=0.2), 112mm (z/D=0.4), 168mm (z/D=0.6) and 224mm (z/D=0.8) from the swirler throat exit position. In total, four radial swirler produced flames were investigated at ambient air and pressure producing swirl numbers (S_N) of 0.366, 0.630, 0.978 and 1.427. Figures 4 to 7 show the effect of using the different swirl numbers, S_N on the formation of emissions in the combustor system.

Figure 4 shows the CO formation along the chamber radial distance. For low swirl, CO concentration at the core is very low immediately after the swirler throat, after that the formation increased at the flow progresses along the combustor axis. This value of CO concentration is due to the condition that the flame occurred after z/D=0.2. After combustion, the CO concentration increased which can be seen from z/D=0.4. It should be noted that the swirl in the chamber produced a secondary re-circulation zone near the wall of the chamber where the flow actually reversed. This brought back the CO from the cone (centre core) at axial distances far from inlet back to the plane z/D=0.2. That is why the CO concentration in this area is higher compared to the cone area. As the flow progress in axial direction, the CO at the cone slowly increased until it has a constant distribution radially, starting at z/D-0.6.

As the swirl number increased, the CO concentration at the cone increased as well. But it is still lower that the concentration at the near wall region. For SN=1.427, the CO concentration at z/D=0.2 was 230ppm at core. This value does change along the radius until r/R=0.2, when it starts to increase and stabilized at 330ppm at r/R=0.3. As the flow progressed along the axis, the concentrations increased but tend to constant at all radial positions.

Figure 5 shows the NO formation along the chamber radial distance. The formation of NO is normally associated with high combustion temperature. In this work, the NO formation is affected by two mechanisms, namely the high temperature and availability of oxygen (O_2). In the core region high temperature due to the flame encouraged the NO formation, which starts to be significant from z/D=0.4. The concentration continue to increase until z/D=0.8 after which point the concentration of NO had stabilized. At the near wall region, the NO formation is lower than the core as the temperature is lower at this region because it is far from the core flame. These condition and explanation agree with the finding of previous researcher [13, 14] which stated that the combustion inefficiency was higher near the combustor wall regions.

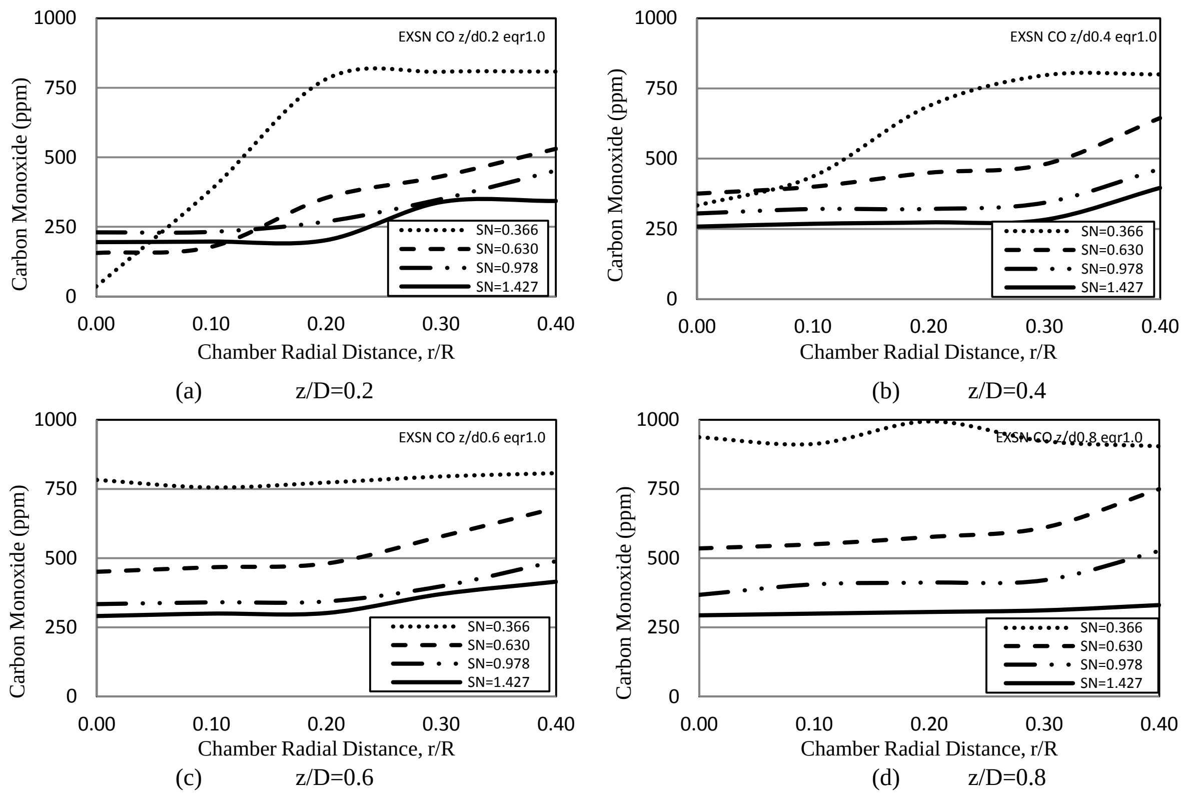

Figure 4 Transversal profiles of experimental mean carbon monoxide (CO) with ambient air inlet

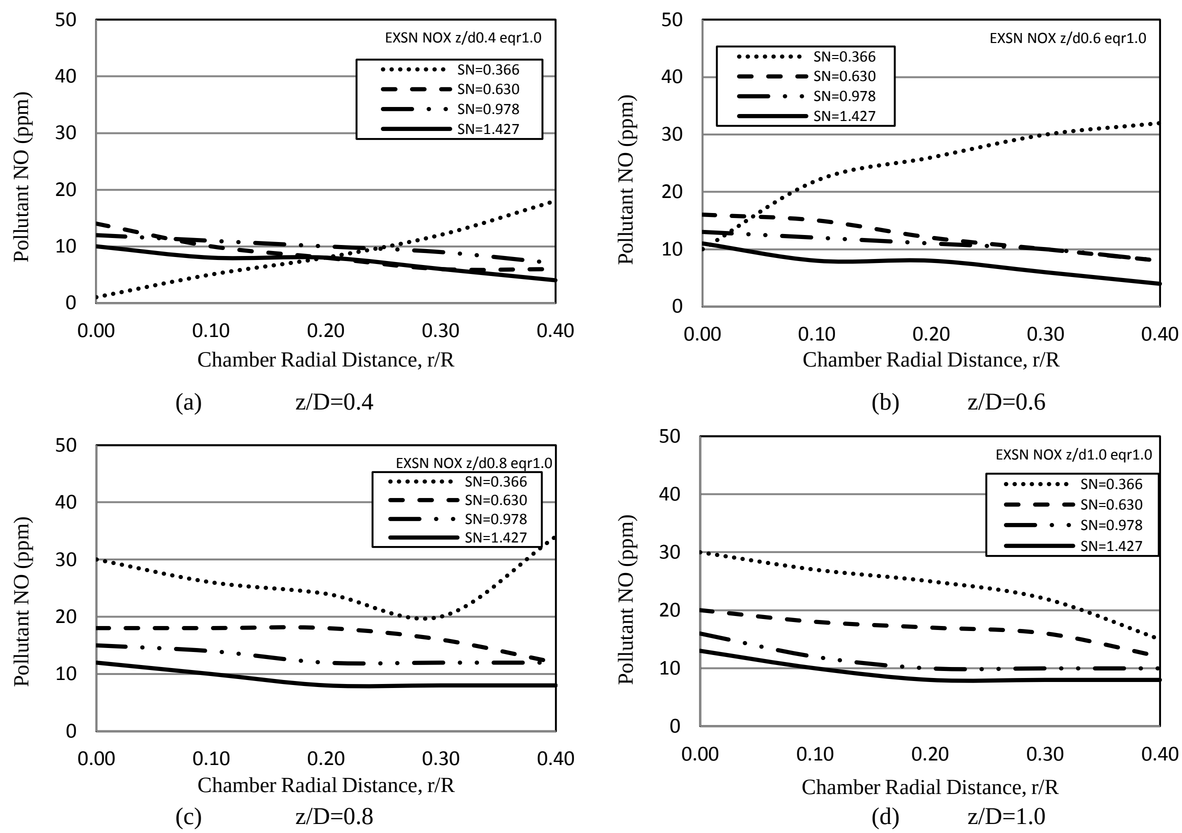

Figure 5 Transversal profiles of experimental mean of pollutant NO with ambient air inlet

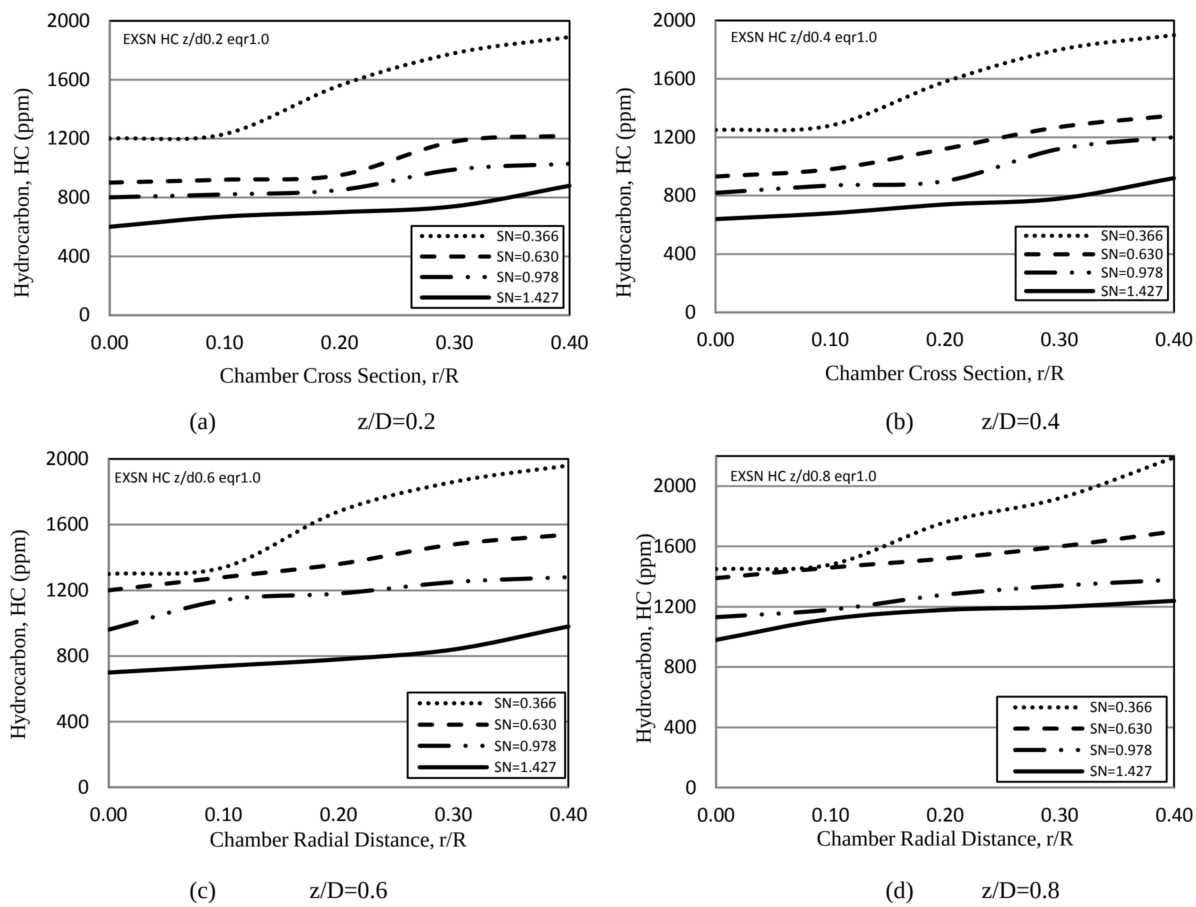

Figure 6 Transversal profiles of experimental mean hydrocarbon (HC) with ambient air inlet

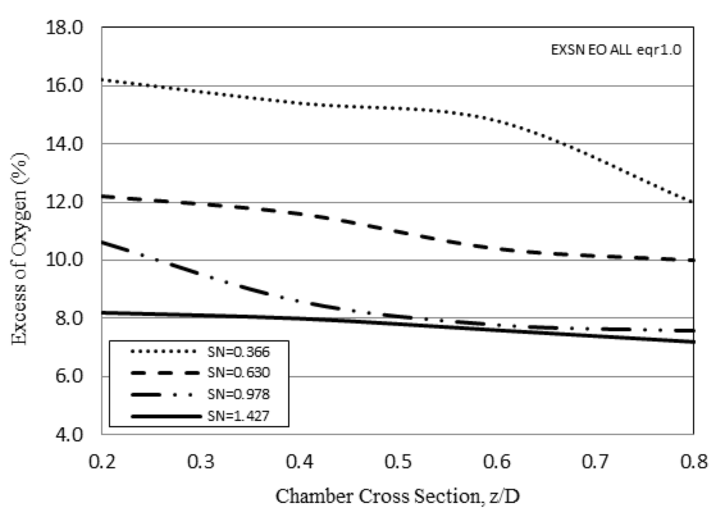

Figure 7 Chamber cross section transversal profiles of experimental mean excess of oxygen with ambient air inlet

Figure 6 shows a plot of Hydrocarbon (HC) formation versus chamber radial distance for all air swirlers. From the figure it can be see that HC concentration are basically inversed to NO formation. HC concentration point to how complete is the combustion. The fact that the HC concentration are lower in the core region compared to the near wall region, point to higher efficiency of combustion at the core. For all swirl condition the HC concentration increase gradually along the flow axis, indicating a continuous formation of HC residue in the chamber.

Figure 7 shows the excess of oxygen (O_2) concentration versus chamber cross section along the combustion chamber. Excess of oxygen was found to be almost constant radially along chamber. As such only the variation along the flow axis is discussed. It was found that for all swirl numbers, the excess of oxygen concentration reduces as the flow progressed axially. For high swirls combustion the excess of oxygen concentration is lower 43% at z/D=0.8 and 33% at z/D=0.2 to the lower swirl cases as 76% at z/D=0.2 and 57% at z/D=0.8. This indicates that the high swirl combustion is more efficient thus uses more oxygen compare to lower swirl combustion.

■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 at stoichiometry condition. 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. The results show that the CO and HC emissions were low in the central core region for all high swirl. Furthermore NO formation is higher at the core as availability of oxygen (O_2) swirl from the swiler throat. It also shows that high swirl combustion is more efficient thus uses more oxygen compare to lower swirl combustion 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] Al-Kabie, H. S. 1989. *Radial Swirlers for Low Emissions Gas Turbine Combustion*. University of Leeds, Dept. of Fuel & Energy: PhD.
[10] Beer, J. M., Chigier, N. A. 1972. *Combustion Aerodynamics*. Applied Science Publisher, London.
[11] Spiers, H. M. 1977. *Technical data on Fuel*. 7^{th}. ed. The British National Committee, World Power Conference, London,
[12] 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,
[13] Syred, N. 2006. A Review of Oscillation Mechanisms and the Role of the Precessing Vortex Core (PVC) in Swirl Combustion Systems. *Progress in Energy and Combustion Science*. 32(2): 93–161.
[14] Liang, H., & Maxworthy, T. 2005. An Experimental Investigation of Swirling Jets. *Journal of Fluid Mechanics*. 525: 115–159.