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THE EFFECT OF SWIRL NUMBER ON REDUCING EMISSIONS FROM LIQUID FUEL BURNER SYSTEM

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ABSTRACT

Combustion implicates harmful effect to the environment because of the emissions produced. The release of gaseous emissions such as oxides of nitrogen (NO_X), and carbon monoxide (CO) into the atmosphere creates major environmental problems. These gaseous emissions affect plants, human being and animals. High concentration of emissions brings fatal effects to life form. A liquid fuel burner system with different radial air swirler vane angles with 280 mm inside diameter combustor of 1000 mm length has been investigated. All tests were conducted using diesel as fuel. A radial flow air swirler with curved blades having 50 mm outlet diameter was inserted at the inlet plane of the combustor to produce swirling flow. Fuel was injected at the back plate of the swirler outlet using central fuel injector with single fuel nozzle pointing axially outwards. The swirler vane angles and equivalence ratios were varied. Tests were carried out using eight different air swirlers having 10°, 20°, 30°, 40°, 45°, 50°, 60° and 70° vane angles. NO_X reduction of more than 26 percent was obtained for the swirl number of 1.427 compared to 0.046. A turning point occurs at this stage where the emission of NO_X suddenly increases about 23 percent when swirl number of 1.911. CO emissions were reduced by 33 percent, 40 percent and 48 percent reduction in carbon monoxide (CO) emission for swirl number of 0.978, 1.427 and 1.911 respectively compared to swirl number of 0.046. Meanwhile, CO_2 have a stable distribution of emissions for the whole range of equivalence ratios. However, CO_2 emission increases when higher vane angle swirlers were used. CO_2 emissions of about 11.6 percent, 11.7 percent and 15.5 percent decrease for swirl number of 0.978, 1.427 and 1.911 respectively, compared to swirl number of 0.046 at the equivalence ratio of 0.833.

Keywords: *Combustion, Air Swirler, Swirl Strength, Flame Stabilizing, NO_X Emission.*

1.0 INTRODUCTION

Burners are usually used in industrial applications such as starters for boilers, district heating and cooling and also for domestic central heating system. However, conventional burners, operating at or above stoichiometric air/fuel ratios or lean condition, produce high flame temperatures that resulted in the production of nitrogen oxides, which is then emitted to the atmosphere [1]. However, lowering NO_X emission by reducing flame temperature will lead to reduced flame stability or increase in Carbon Monoxide (CO) emission [2]. Therefore, a method must be sought that resulted in the reduction of peak temperature period and will reduce the formation of NO_X.

Global environmental problems such as greenhouse warming, acid rain and hole in the ozone layer have become serious problems all over the world. Where acid rain is essentially a regional phenomenon, green house warming is a global problem and is difficult to solve. In recent years, an increasing awareness of the environmental impact of combustion devices has led to legislation concerning their exhaust emissions. The role of NO_X formation in ozone has been the subject of many recent debates. NO_X emissions from combustion devices would also deplete the stratospheric ozone layer and this would increase ultraviolet radiation to the earth's surface and with it the occurrence of skin cancer in the population [3].

Basically there are two techniques of controlling NO_X in burner applications: those that prevent the formation of nitric oxide (NO) and those that destroy NO from the products of combustion. The methods that prevent the formation of NO involved modifications to the conventional burner designs or operating condition. In this research, the burner will be designed to incorporate swirling flow to enhance turbulence and hence helps in mixing of fuel and air prior to ignition. Swirling flow induces a highly turbulent recirculation zone, which stabilises the flame resulting in better mixing and combustion [4]. It has been suggested that the large torroidal 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 the fresh combustible mixture of air and fuel [5].

The present work will be carried out on an experimental rig using single radial swirler as an air register and a throat for pre-combustion for the liquid fuel burner. The level of swirl or swirl strength can be represented in terms 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 researches that studied on 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.

Drake and Hubbard [6], studied the effect of swirl on completeness of combustion and discovered that there was an optimum swirler vane setting. Claypole and Syred [7] 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 Nazri *et al.* [8] investigated the effect of using swirling flows on reducing NO_X. They varied the radial air swirler vane angles from 28.9^o to 84.5^o and tested using natural gas only and obtained 25 percent and 33 percent NO_X emission reduction at the burner pressure loss of 40 mm and 10 mm H_2O, respectively. These were achieved not at the expense of increased in unburned hydrocarbon (UHC) and carbon monoxide. In fact, when tested at burner pressure loss of 10 mm H_2O, they found that these emissions were reduced rather than increased. They also found that for the burner pressure loss of 10 mm H_2O, the optimum vane angle was 51.1° and for the burner pressure loss of 40 mm H_2O, the optimum vane angle was 74.3°.

Mohd. Radzi *et al.* [9] investigated the effect of swirling flow with angle from 50° to 80°. Results revealed that of the same equivalence ratio, NO_X emissions dropped for about 46% for swirler vane angle of 60° as compared to swirler angle of 50°. A turning point occurs at this stage where the emissions of NO_X suddenly increase by about 46 percent when replaced with 70° swirler vane angle. Meanwhile, NO_X emissions keep on increasing to more than 30 percent for swirler vane angle of 80° compared to 70° at the same equivalence ratio.

Al-Kabie [10], demonstrated for swirl number varying from 0.41 to 3.25 that at very high swirl number of 3.25, NO_X emissions were considerably higher than the rest at all associated equivalence ratios for two different inlet air temperature of 400 and 600 K. This may be due to increased residence time in the rich stabilising 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 swirler. Kim [11] studied the effect of decreasing the vane depth of a small radial swirler with 40 mm outlet diameter having a vane angle of 45°. 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 extended 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 resulting from varying the swirl strength. They emphasised 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 [12] on the other hand, compared the effect of swirling and non-swirling system on combustion. He demonstrated that the existence of swirl helps improve combustion efficiency, decreases all pollutants and increases flame temperature. He also observed that during the present of a swirl, a shorter blue flame was observed indicating a short time for peak temperature resulting in good mixing while non-swirling system showed a longer yellow flame indicating a long time peak temperature and there is still some fuel left unvaporised.

A series of combustor tests were conducted by Mularz [13] to evaluate three improved designs of swirl-can combustor models, using axial swirlers and their objectives were to obtain low levels of exhaust pollutants while maintaining high combustion efficiency at combustor operating conditions. He came with an opinion that swirl-can modules consisted of three components; a carburettor, an inner swirler and a flame stabilizer. The functions of the module were to mix fuel and air, swirl the mixture, stabilize combustion in its wake and provide large interfacial mixing areas between the bypass airs around the module and combustion gases in its wake. They found that swirl-can combustor model performed with high combustion efficiency at all conditions tested.

Meanwhile, Ballal and Lefebvre [14] in their study stressed that for a premixed flame the weak extinction limits were governed mainly by inlet air temperature, to a lesser extent by air velocity and turbulence level and were almost independent of pressure.

2.0 EXPERIMENTAL SET-UP

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.

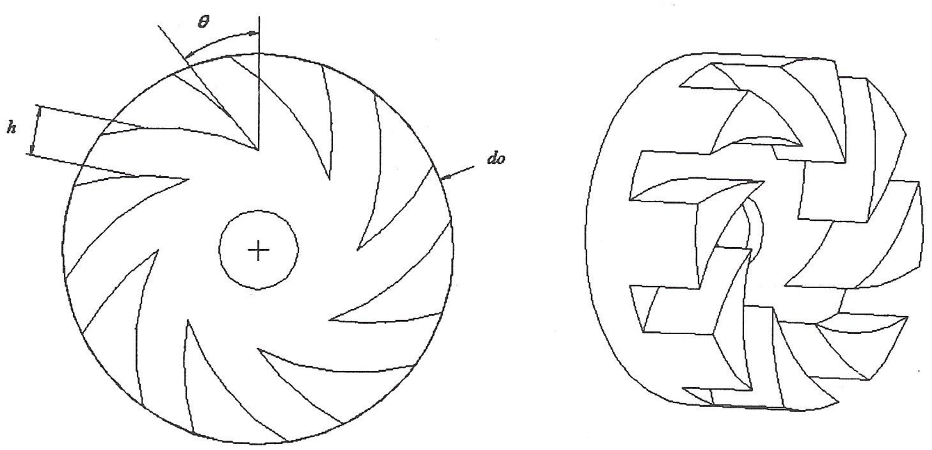

Figure 1: Schematic diagram of radial swirler design

Table 1: Dimensions of various radial swirler

Swirler angle / Parameter	0°	10°	20°	30°	40°	45°	50°	60°	70°
Passage width, h (mm)	12	16	15	13.6	12.3	12	11.2	9.6	8.8
Swirl number, S_N	0	0.046	0.172	0.366	0.630	0.780	0.978	1.427	1.911
No. vane, n	8								
Outlet diameter, d_o (mm)	98								
Inlet diameter, d_i (mm)	50								
Vane depth, L (mm)	25								

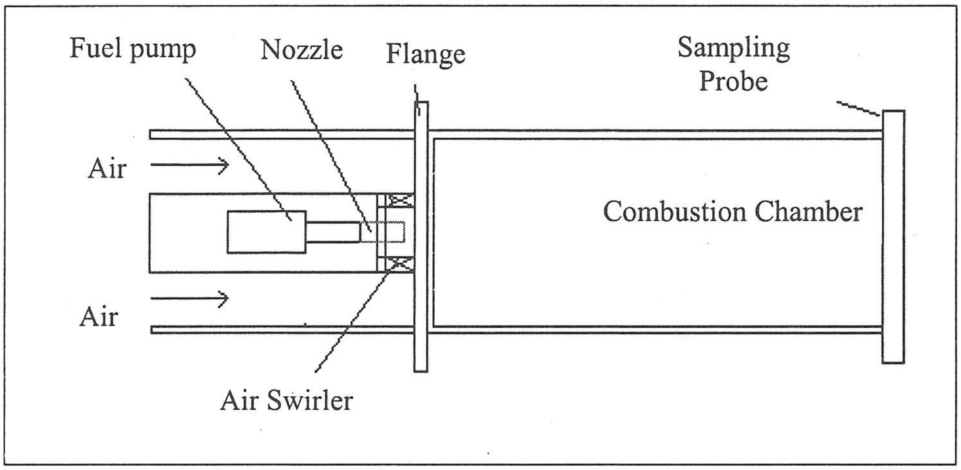

Figure 2: Schematic diagram of the liquid fuel burner experimental rig

The exhaust sampling probe is mounted at the end pipe. 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.

3.0 RESULTS AND DISCUSION

In order to achieve better mixing between fuel and air in liquid fuel burner, turbulence flow must be generated to promote mixing. Turbulence energy is created from the pressure energy dissipated downstream of the flame stabilizer. Figures 3 to 5 show the effect of increasing the swirl number on exhaust emissions from burner system. Tests on exhaust emission were carried out using eight swirler vane angles of 10°, 20°, 30°, 40°, 45°, 50°, 60° and 70°.

Figure 3 shows vast reduction in oxides of nitrogen (NO_X) emissions when the vane angle was increased from 10° to 60° (S_N 0.046 to S_N 1.427). This was apparent for the whole range of operating equivalence ratios. Emissions level of below 35 ppm was obtained for all range of operating equivalent ratios. For swirl number of 1.427, NO_X emissions reduction of about 26 percent was obtained at equivalence ratio of 0.83 compared to the swirl number of 0.046 at the same equivalence ratio. A turning point occurs at this stage where the emissions of NO_X suddenly increase about 23 percent when replaced with swirler of 1.911 swirl number. This proved that swirl does helps in mixing the fuel and air prior to ignition and hence reduced NO_X 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.

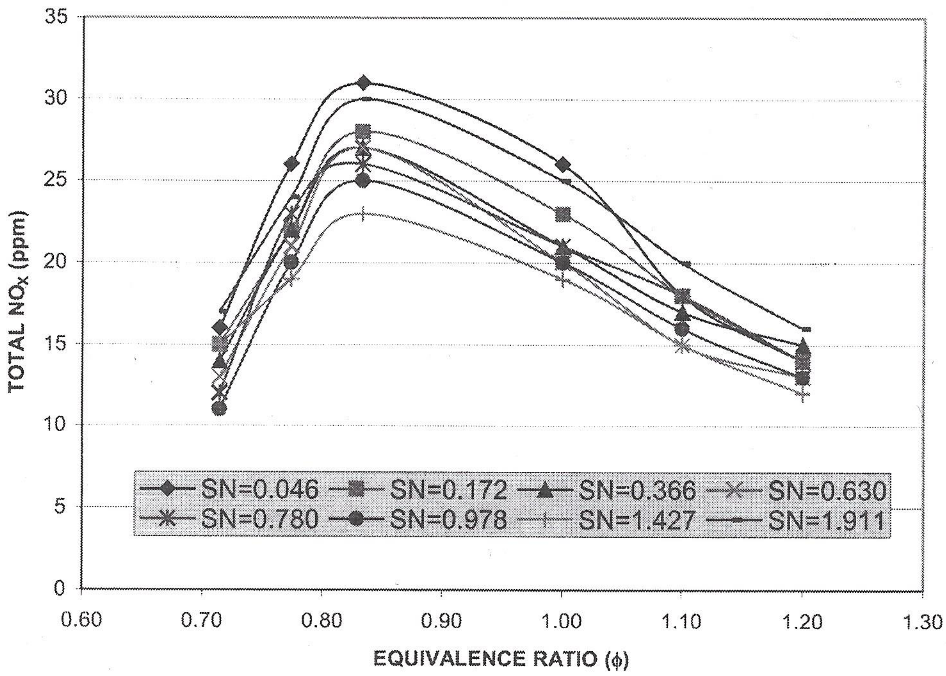

Figure 3: NO_X vs equivalence ratio for various swirl number

Figure 4 shows carbon monoxide emissions versus equivalence ratio for all swirl number. There was a 33 percent, 40 percent and 48 percent reduction in carbon monoxide (CO) emission for swirl number 0.978, 1.427 and 1.911 respectively compared to swirl number of 0.046 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 NO_X will tend to increase CO since both emissions were on the different side of the balance [15]. Nonetheless, the increase was quite high, which indicates that there is some fuel escaped unburned, which was the product of incomplete combustion.

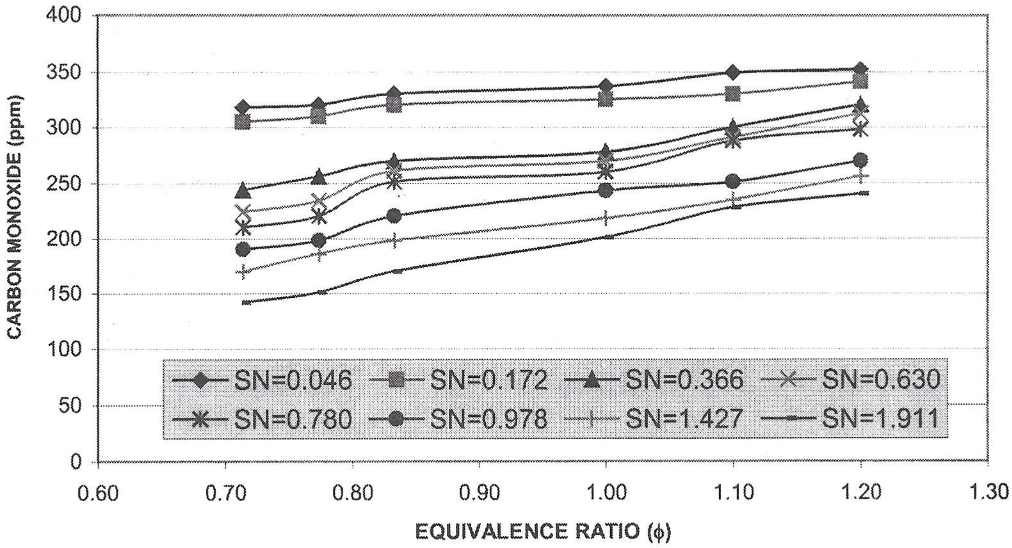

Figure 4: CO vs equivalence ratio for various swirl number

Figure 5 shows a plot of carbon dioxide (CO_2) emissions versus equivalence ratio for all air swirlers. There was a slight decrease in carbon dioxide emissions when increasing the swirl number. This was seen throughout the whole range of operating equivalence ratios. There was an 11.6 percent, 11.7 percent and 15.5 percent reduction in carbon dioxide emission for swirl number of 0.978, 1.427 and 1.911 respectively compared to swirl number of 0.046 at the equivalence ratio of 0.833. The decrease was very small compared to the reduction of NO_X emissions that was obtained. The increase of carbon dioxide emissions does not contribute to health problems, as carbon dioxide is more stable and non-toxic. However, CO_2 is a greenhouse gas and can contribute to global climate change.

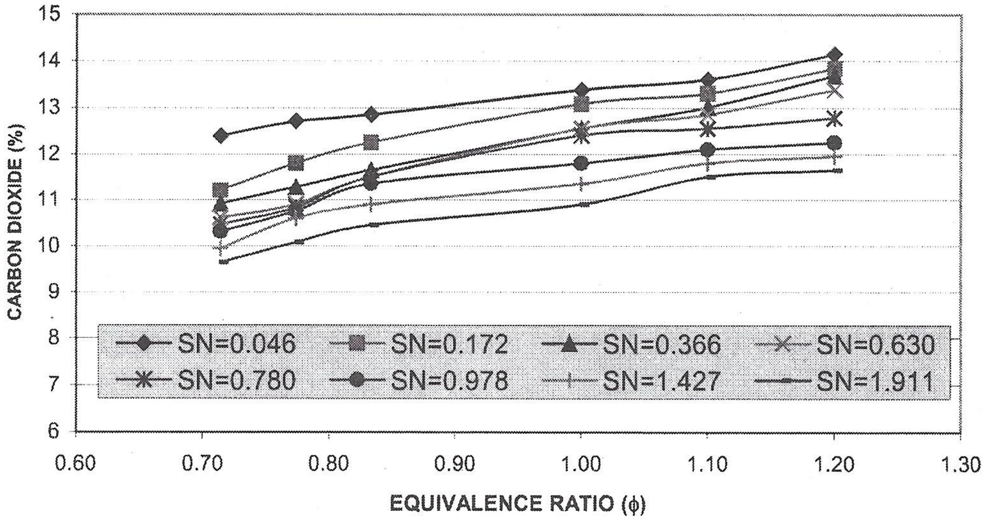

Figure 5: %CO_2 vs equivalence ratio for various swirl number

4.0 CONCLUSION

NO_X emissions reduction of about 26 percent was obtained at equivalent ratio of 0.83 at swirl number of 1.427 as compared to 0.046 at the same equivalence ratio. The emission suddenly increases at swirl number of 1.911. Other emissions such as carbon monoxide and carbon dioxide decreased when using higher swirl number compared to that of the lower swirl number. This shows that swirler does help in mixing the air and fuel prior to ignition. NO_x emissions of less than 35 ppm were achievable over the whole range of equivalence ratios for all swirlers.

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