Full Paper

EMISSION CHARACTERISTICS OF LIQUEFIED PETROLEUM GAS COMBUSTION IN A PREMIXED SWIRL BURNER

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ABSTRACT

Liquefied petroleum gas (LPG) is widely used as a fuel in domestic and industrial heating appliances throughout the world because its combustion products are relatively clean. However, due to its direct association with people, its combustion pollutants are of great concern. To this end, a study was carried out to investigate the effects of swirl intensity and equivalence ratio on emission produced during combustion of liquefied petroleum gas under fuel-lean conditions in a premixed swirl burner. Experiments were carried out using liquefied petroleum gas whose composition is 75% butane, 25% propane and air as charge. Tests were done for vane angles between 35 and 60^o in steps of 5^o. Employing EGA4 gas Analyzer in measuring NO_x and CO_x emission level, it is shown that emission levels were strongly influenced by swirl intensity and equivalence ratio that strongly decrease pollutant emissions. Between equivalence ratio of 0.65 and 0.90, NO_x emission of less than 5ppm and CO emission of less than 60ppm were achieved. Result also showed that at temperature ranges between 927^{o}C and 1012^{o}C, NO_x and CO emission generated from combustion of LPG were low.

Keywords: *Swirl number; Equivalence ratio; Emissions; Swirl burner; Liquefied petroleum gas*

1. INTRODUCTION

The release of gaseous emissions such as oxides of nitrogen (NOx) and carbon monoxides (CO) into the atmosphere creates major environmental problems which negatively affect plants, human beings and animals. These harmful emissions had driven combustion engineers to employ various combustion methods or post combustion techniques for achieving acceptable emission levels in burner systems. As far as low emission is concerned, gaseous fuels such as liquefied petroleum gas, LPG, appear to be capable of performing a prominent role. LPG is used as a fuel in domestic and industrial heating appliances and burns cleanly with no soot and very few sulphur emissions. This is more so when equipment for its combustion is efficient. Combustion efficiency is achieved due to the fact that the combustor is such that provides or generates high turbulence that provides for very good mixing between well atomized fuel and the oxidant. This good mixing provided by high aerodynamics flow will give good combustion, generates high temperature for total release of the fuels net calorific value and low pollutant emission. Where this turbulence and proper mixing fails to exist due to design shortcomings, the combustion of fuel is inefficient leading to high emission of pollutants in the flue gas. Hence, the injection of fuel and oxidant through the swirler will impart turbulence on the charge and combustion efficiency will be obtained.

LPG is produced in oil refineries and in gas processing plants and represents a modest part of the refinery output (typically 2–3 percent) but significant in gas processing plant. Commercial grade LPG is primarily a mixture of butane and propane and the ratio of these constituents can vary widely. According to [5], the LPG mix that is normally specified for the Nigerian domestic market is one that is butane rich, that is, 7:3 or 3:1 butane: propane mix. LPG combustion emissions may contain considerable amounts of CO, UHCs and NO_x emissions which can accumulate quickly and reach concentrations which are dangerous to humans. In the light of recommendations of [3] that, long term exposure to nitrogen oxide should not exceed 3ppm while a short term to 5ppm is recommended. As for CO, exposure to 300ppm is the limit for a short time of 15 minutes and any period greater than this may be very dangerous which could lead to death. The current study has been carried out to investigate emissions characteristics of LPG as obtained in a premixed swirl burner, varying operating conditions such as swirl intensity and equivalence ratio.

The results obtained in this work will help us to understand what parameters dominate emissions from the combustion of liquefied petroleum gas. Furthermore, the results will be of great importance in design, operation concepts and real applications in the manufacture of gas burners, burning liquefied petroleum gas.

2. EXPERIMENTAL SET UP

The schematic diagram of the experimental set up is shown in Figure 1. The assembly of the experimental set up consists of gas cylinder shut off valve, air compressor control valve, rotameters, connecting flow lines, swirl burner and combustion exhaust chamber. The prototype of low swirl burner used in the experiment (Figure 2) has two premixed zone: the upper premixed and the lower premixed. Fuel and air inlet pipes were connected tangentially and axially into the premixed duct of the swirl burner which has a perforated plate inside to enhance fuel and air mixing. The vane swirler is the major component of the burner. It impacts a swirling motion into the fuel/air mixture to enhance proper mixing of fuel and air before ignition takes place.

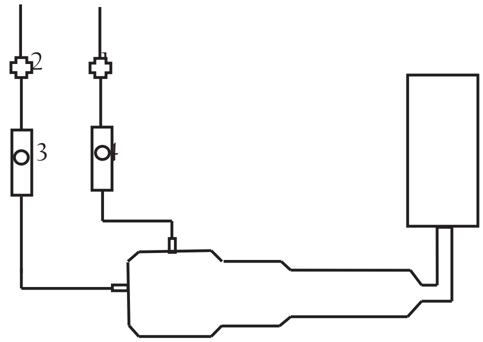

Figure 1. Schematic diagram of the Experimental Set up

1. Gas Cylinder Shut off valve
2. Air compressor control valve
3. Rotameter
4. Rotameter
5. Connecting flow lines
6. Swirl burner
7. Combustion exhaust chamber
8. Sampling point

2.1 Experimentation

Test on the swirl burner were carried out using six swirlers having the same swirl annulus areas and vane lengths but different number of vanes and angles. The dimensions of various swirlers used for the experiments are summarised in Table 1

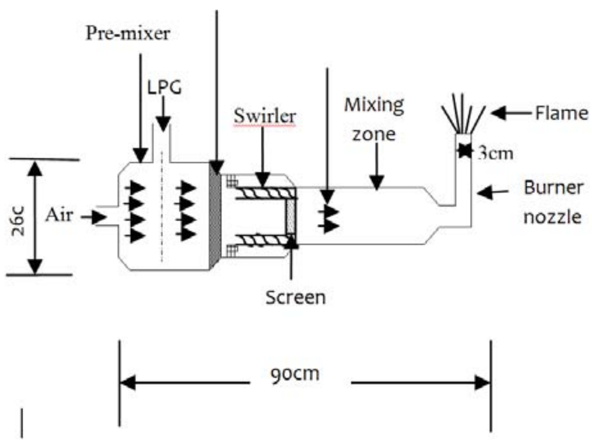

Figure 2. Schematic diagram of prototype low swirl burner used in the experiment

The characteristics swirl number was calculated for all the six swirlers using equation given (1) by [1].

$$S = \frac{2}{3} \tan\alpha \frac{1-R^3}{1-R^2+\left[m^2\left(\frac{1}{R^2}-1\right)^2\right]R^2} \quad (1)$$

Where
S = Swirl number
α = vane angle
R = Ratio of centre channel radius to burner radius,
$R = R_c / R_b$
m = Ratio of mass flow rates through centre channel and swirl annulus. It is the same as the ratio of the effective areas of the centre core and the swirl annulus ($m = m_c / m_a = A_c / A_a$).

Table1. Dimensions of various swirlers used for the experiments

	Swirl angles					
Parameters	35°	40°	45°	50°	55°	60°
Passage width (mm)	27	30	34	39	45	45
Swirl number S_N	0.241	0.289	0.344	0.410	0.491	0.596
Number of vanes	10	9	8	7	6	6
Outlet diameter d_o (mm)	132					
Inlet diameter d_i (mm)	88					
Vane depth L (mm)	25					
Screen holes diameter (mm)	4					
Screen blockage (%)	77.7					

Experiments were carried out using LPG whose composition is 75% butane, 25% propane as fuel and air as charge. Air and fuel were supplied into the pre-mixed duct of the swirl burner through the flow lines. The first step taken in the experiment was to determine the equivalence ratios by measuring the quantity of fuel and compressed air required for combustion using rotameters calibrated in litre per minutes. Variation of the equivalence ratios was obtained by changing fuel flow rate but maintaining constant air flow rate. Each swirler was placed inside the swirl burner to impart a swirling flow to the various air/fuel mixture.

Table 2. Flow rates

Volume (L/mins)		Excess air ratio	Equivalence ratio
Air	Fuel		
309.4	10.00	0.06	0.94
309.4	9.50	0.12	0.90
309.4	9.00	0.18	0.85
309.4	8.50	0.25	0.80
309.4	8.00	0.33	0.75
309.4	7.50	0.42	0.71
309.4	7.00	0.52	0.66
309.4	6.50	0.63	0.61

The various air/fuel mixtures were burnt inside the swirl burner. Pollutant emissions were sampled inside 31cm cylindrical combustion exhaust chamber for different swirlers and air/fuel mixtures; and analyzed by an EGA4 combustion gas analyzer capable of measuring oxides of nitrogen (NO_X) and carbon monoxide (CO).

3. Results And Discussion

3.1. Effect of Swirl on NO_x Emissions

Figure 3 shows the effect of increasing swirl number on NOx emissions. The graphs show vast reduction in oxides of nitrogen (NOx) emissions when the vane angle was increased from 35o to 60o (SN 0.241 to SN 0.596). Emissions level of below 5ppm was obtained for all range of operating equivalence ratios ($0.61 \leq ø \leq 0.95$). This agrees with the fact that combustion processes operating under fuel lean conditions will have very low emissions and high efficiency [2]. While temperature is the most important factor for gaseous fuels, there are number of different factors involved in NOx reduction; Lowering the flame temperature less than 1400°C [4]. NOx emissions in this study are reduced for all range of operating equivalence ratio because flame temperatures are low (560oC ≤ Tf ≤ 1096oC), reducing thermal nitric oxide formation. For swirl number of 0.491, NOx emissions of 0.33ppm was obtained representing a total NOx reduction of 93.4% at equivalence ratio of 0.90. This reduction was higher when compared to swirl number of 0.241 at the same equivalence ratio. A turning point occurs where the NOx emissions suddenly increased to 1.13ppm (about 22.6%) when replaced with swirler of 0.596 swirl number. However, the effect of swirl number on NOx emissions was clearly seen when replaced with swirler of swirl number 0.241, 0.344 and 0.410. NOx emissions were higher with these swirlers than others which shows that the lower the swirl number, the higher the emission of NOx

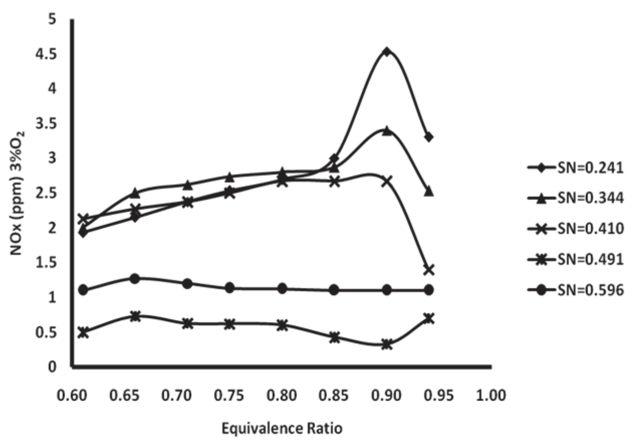

Figure 3. NOx emissions as a function of equivalence ratio for various swirl number

3.2. Effect of Swirl on CO Emissions

Figure 4 shows the profile of carbon monoxide emissions with equivalence ratio for all swirl numbers. The emissions data trend is typical of those measures in pool heater with low swirl burner [1]. In this study, CO emissions of less than 300ppm were obtained for all range of operating equivalent ratios. According to [3], human beings are in serious danger when exposed to carbon monoxide. For exposure to 300ppm of CO, only a short time of 15 minutes is recommended and any period greater than this may be very dangerous and may lead to death. Hence, every burner design aims at CO emission that is below this level and the present work meets this requirement. For swirl number of 0.491, CO level was drastically reduced reaching 45ppm at $ø = 0.66$ representing a total CO emission reduction of 85%. The Health and Safety Executive [3] also specify that for long time exposure of 8hours day working periods, CO level should not be above 50ppm. This result of 45ppm strongly comply with this exposure limits at this equivalence ratio combustion. However, at equivalence ratio of 0.90, CO emission was higher for swirl number 0.241, 0.344 and 0.410indicating poor combustion efficiency resulting from poor mixing of combustion reactants in comparison with swirl number of 0.491 and 0.596 at the same equivalence ratio. There was 55.3% and 82.1% reduction in carbon monoxide (CO) emissions for swirl number 0.596 and 0.491 respectively at $ø = 0.90$. From these results, it should be noted that NO_x and CO emissions were strongly influenced by swirl intensity imparted by the swirler.

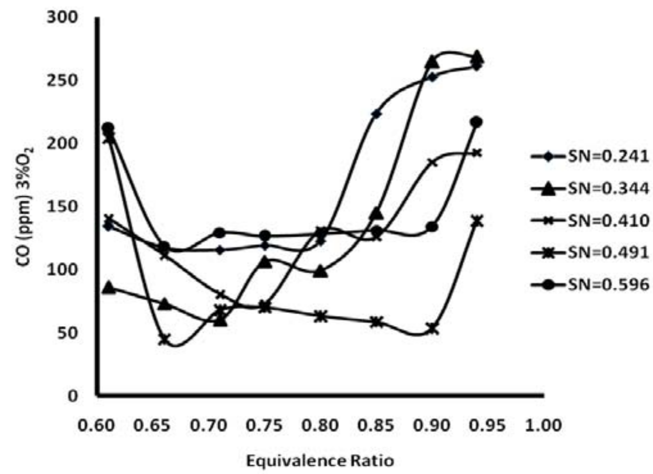

Figure 4. CO emissions as a function of equivalence ratio for various swirl number

3.3. Effects of Fuel/air Mixture on Emission Characteristics

Figure 5 shows NO_x emissions measured at the exhaust associated with flame temperatures as a function of equivalence ratio at $S_N = 0.491$. High excess air supplied to the swirl burner (lean fuel regime) at the onset of combustion process causes NO_x emissions to rise to a peak of 0.73ppm at ø of 0.66. Here, NO_x emissions were mainly formed from nitrogen supplied from the combustion air. As combustion reaction continues, NO_x emissions decrease from 0.7ppm to 0.3ppm, representing 57% of NO_x reduction with increase in equivalence ratio and consequently decreased with flame temperature up to 970°C though above ø of 0.90, there was a sharp rise in NO_x emission. NO_x emissions are generally reduced due to reduction in flame temperature. The swirl burner ensures lower NO_x emission levels in all operating equivalence ratio ($0.60 \leq ø \leq 0.95$) with NO_x emissions of 0.3ppm at $ø = 0.90$. Further increase in NO_x emissions above $ø = 0.90$ indicate combustion incompleteness as oxygen in the oxidizers supplied to the burner was not enough to completely burn the fuel. The results here as well as the previous ones are very significant in the light of recommendation of long term exposure to nitrogen dioxide level of only 3ppm and a short term of 5ppm [3].

Figure 6 shows CO emissions as a function of equivalence ratio with varying flame temperature. With increasing equivalence ratio from ø of 0.61 to ø of 0.66, CO emissions decreased rapidly from 204ppm to 45ppm representing 77.9% of CO emission reduction. Above this regime, increment in CO emissions from 45ppm ($ø = 0.66$) to 70ppm ($ø = 0.75$) is an indication of combustion inefficiency. The reduction of CO emissions to 54ppm at ($ø = 0.90$) indicates good combustion efficiency with increase in flame temperature to 1012°C at the same equivalence ratio. After this point, CO emissions steeply increased putting into evidence possible combustion inefficiency with subsequent temperature decrease approaching stoichiometric value.

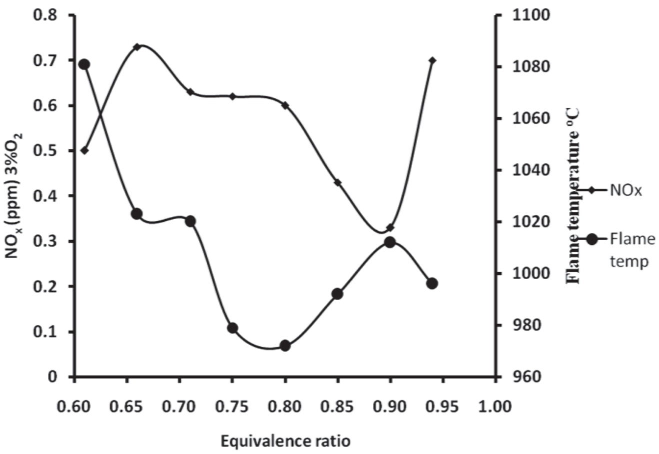

Figure 5. Effects of fuel/air mixture on NOx emissions associated with flame temperature at SN = 0.491

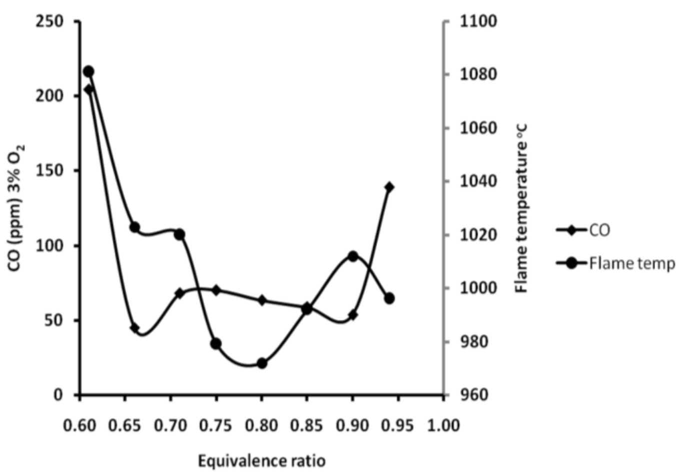

Figure 6. Effects of fuel/air mixture on CO emissions associated with flame temperature at SN = 0.491

Both figures 5 and 6 with respect to the two pollutants NO_x and CO are similar in their trend. As the equivalent ratio increases, the figures indicate a fall in these emission but towards the highest equivalent ratio, greater than 0.90, the mixture of the charge had become rich in fuel. The temperature therefore deeps as the oxygen available is shared for the formation of CO and NO_x and hence incomplete combustion occurs. This as a result leads to increases in these pollutants and the sharp rise shown in the diagram. It should be noted that our measurements globally looks at NO_x emission rather than the many components of NO_x.

4. Conclusions

Combustion implicates harmful effect to the environment because of the pollutant emissions produced. Numerous articles have attested to the prominent role of lean premixed combustion and swirling flow as an important control technology option for reducing pollutant emissions and swirl burner is not an exception to this. This study has shown that NOx and CO emissions were strongly influenced by swirl intensity imparted by the swirler. NOx emission of 0.3ppm and CO emission of 54ppm were obtained at swirl number of 0.491 and equivalence ratio of 0.90 representing 93.4 and 84% of total NOx and CO emission reduction, respectively. The temperature ranges between 960oC and 1012oC at which NOx and CO emission generated from combustion of LPG are less than 5ppm and 60ppm, respectively, indicating a strong potential for achieving low emissions while maximizing power produced from combustion of the fuel. The results obtained in this work will be of great importance in design, operation concepts and real applications in the manufacture of gas burners burning liquefied petroleum gas.

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