Noxious Emission Reduction from Liquid Fuel Burner via Air Staging Method

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Abstract: Combustion implicates harmful effect to the environment due to the emissions produced. The release of gaseous emissions such as oxides of nitrogen (NO_X) and carbon monoxide (CO) into the atmosphere create major environment problems. These gaseous emissions affect plants, human being and animals. High concentration of emissions brings fatal effects to life form. Air staging or two-stage combustion, is generally described as the introduction of additional/secondary air into the boiler or furnace. Staging the air into the burner (internal air staging) is generally one of the design features of low NO_X burner. Staged combustion is the technique in which a high temperature, fuel rich primary zone is generated with a sufficient residence time to minimize the total fixed nitrogen that is formed in the primary zone. The secondary air mixes downstream of the primary zone to complete the combustion. Staged combustion is an effective method of controlling thermal NO_X. A study has been conducted to demonstrate the effectiveness of air staging in reducing emissions from combustion process. A liquid fuel burner system with 280 mm inside diameter combustor of 1000 mm length has been investigated. All tests were conducted using commercial diesel as fuel. The study shows that a much lower NO_X emissions were obtained for the staged combustion when compared to the non-staged combustion. Significant reduction of more than 15 percent of NO_X emissions reduction was obtained.
Keywords: Air staging; NO_X emission; CO emission; Liquid fuel burner

Introduction

The gradual introduction of more stringent limits on NO_X emission by the industrialised countries has recently boost activities in development of reduction method from combustion process. In general, the amount of NO_X emitted from combustion sources rises with excess air and increasing temperature in the NO_X formation process. Even at low levels of excess air the amount of NO_X generated may exceed standard emission limits; consequently other means of control has to be found.

NO_X concentration in the exhaust of a liquid fuel burner [1] exhibit decreasing concentration with increasing excess air. Also, the burner size plays an important role on the concentration of NO_X in the flue gases. Factors, such as the method of firing has little influence on NO_X concentration. Maximum formation of NO in gas turbines occurs when the temperature is at its peak and near equivalence ratio between 0.8 and 1.0 [2]. The most important factor affecting NO formation in gas turbines is flame temperature ($NO_X \propto \exp(0.009\ T)$) [3]; other important factors are residence time and oxygen concentration, and they are significant insofar since they affect flame temperature. Basically there are two techniques of controlling NO_X; those which prevent the formation of nitric oxide (NO) and those which destroy NO from the product of combustion. The method that prevent the formation of NO involved modification of the conventional burner designs or operating condition, such as lean primary zone, rich primary zone, rich lean, or reduced residence times, since the main factors governing formation of NO are temperature and oxygen availability.

Combustion control mainly involves any of three strategies a) reducing peak temperature in the combustion zone b) reducing the gas residence time in the high temperature zone and c) reducing oxygen concentrations in the combustion zone. These changes in the combustion process can be achieved through combustion process modifications, which usually include low NO_x burners, staged combustion, flue gas re circulation, reburning, reduced air preheat and firing rates, water or steam injection and low excess air firing. These modifications are able to reduce the NO_x emissions by 50 to 80% [4]. The suitable modification depends on the type of boiler and fuel firing method.

Staged combustion involves introducing either the combustion air or fuel into the flame in different stages. With air staging a portion of the combustion air, typically about 50 to 75 % is supplied to a primary combustion zone with all of the fuel. This produces a fuel rich zone and due to this substoichimetric combustion condition, the formation of thermal and fuel NO_X is inhibited. The remainder of the air is injected downstream, forming a secondary flame zone, where the combustion is completed. NO_X formation in this secondary flame zone is also reduced due to reduction of flame temperature, which occurs due to the mixing of inerts form the primary flame zone. NO_X reduction attainable with this method usually ranges from 30 to 40% lower, than that resulting from conventional single stage combustors [5]. Staging requires rapid mixing of fuel and air and generally longer residences times to ensure the burnout of CO and hydrocarbon in the final fuel lean stage [6]. Air staging can control both thermal and fuel NO_X, however it is more effective in reducing fuel NO_X and in fact, is the best method for controlling the conversion of fuel bound nitrogen to fuel NO_X emissions. Figure 1 shows a comparison of NO_X emissions from a conventional, non-low NO_X burner, a staged air low NO_X burner under similar operating conditions. The study was conducted by Waibel [5] using natural gas firing with 15% excess air in a 770 °C (1043 K) firebox.

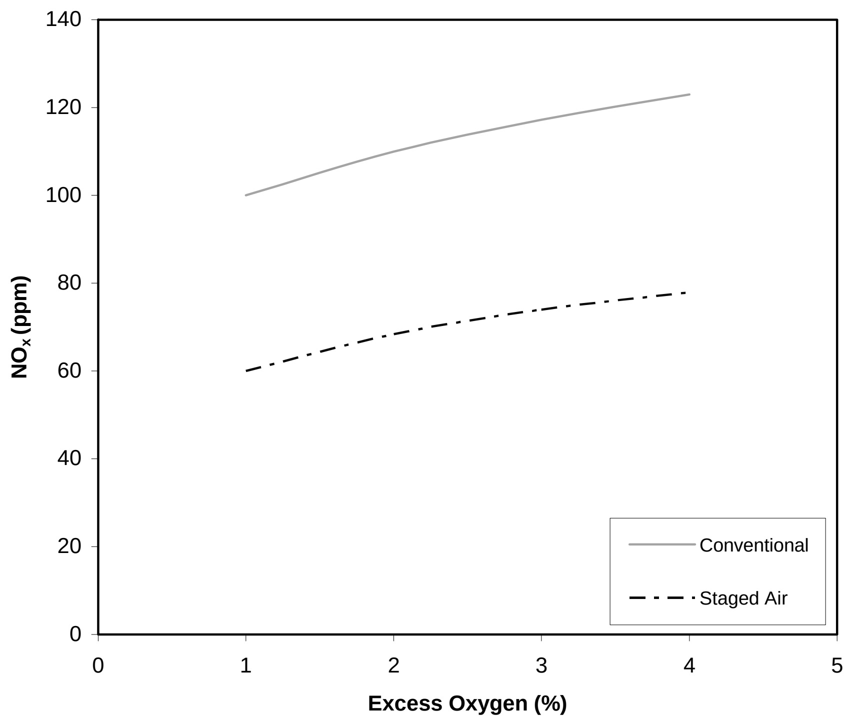

Figure 1 Comparison of conventional burner and burner with staging operation [5].

Air staging can be applied in several ways, which include introducing of over fire air (OFA), burner out of service and biased firing. Only conventional OFA alone can reduce NOx emissions by 30% and advanced OFA has potential to reduce them further [7]. However, a possibility of corrosion and slagging exists in case OFA. Capital costs for conventional and advanced OFA range from $5 to $10 per kW of the burner capacity [8].

In the present work, the method that destroys NO from the product of combustion is employed. Primary zone combustion followed by secondary air injection for combustion reaction in the second stage zone, which destroys first stage NO_X. The secondary air into the combustion chamber was introduced to reduce the CO and smoke emissions. The Air Fuel Ratio (AFR) will increase by supplying additional air into the combustion chamber. This will reduce the emission from the combustion process by burning the emission gases off which is the main purpose of the air staging technique.

Experimental set up

The general rig 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 the combustor through the radial air swirler of 8 blades as turbulence generator where the amount of air entering the combustor is controlled by the air swirler minimum area. Tests were conducted using commercial diesel as fuel. Fuel was injected at the back plate of the 45^o vane angle swirler outlet using central fuel injector with single fuel nozzle pointing axially outwards.

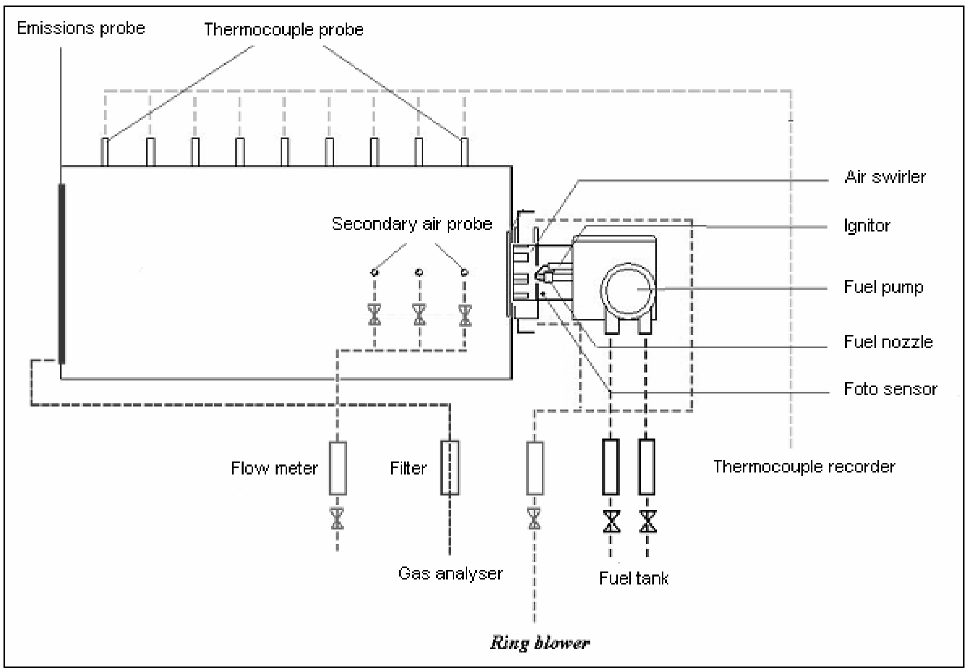

Figure 2 Schematics diagram of the liquid fuel burner

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. Secondary air was introduced at 200 mm downstream of the fuel nozzle with 10 mm inside diameter mild steel tube. The air staging experiments were carried out with secondary air to total air ratio various from 0 to 0.4 or 0 to 40% of primary air are diverted to secondary air.

The exhaust sampling probe is mounted at the end pipe. The gas analyzer used in these tests was the portable Kane May gas analyzer capable of measuring oxides of Nitrogen, Unburned Hydrocarbon, Carbon Monoxide and Carbon Dioxide.

Results and Discussion

Figures 3 to 6 show the effectiveness of air staging on reducing exhaust emissions from liquid fuel burner. Tests on exhaust emissions were carried out using various secondary air flow rates at stoichiometric equivalence ratio (ϕ).

Figure 3 shows a large reduction in oxides of nitrogen (NO_X) emissions when air staging is applied to the liquid fuel burner. This is apparent from 20 percent of air staging supplied to a primary combustion zone. Emissions level below 25 ppm was obtained for the whole range of operating air ratio. NO_X emissions reduction of approximately more than 15 percent was obtained at the portion of the combustion air of 20 percent when using air staging as compared to non-air staging test supplied at 200 mm downstream to the combustion chamber.

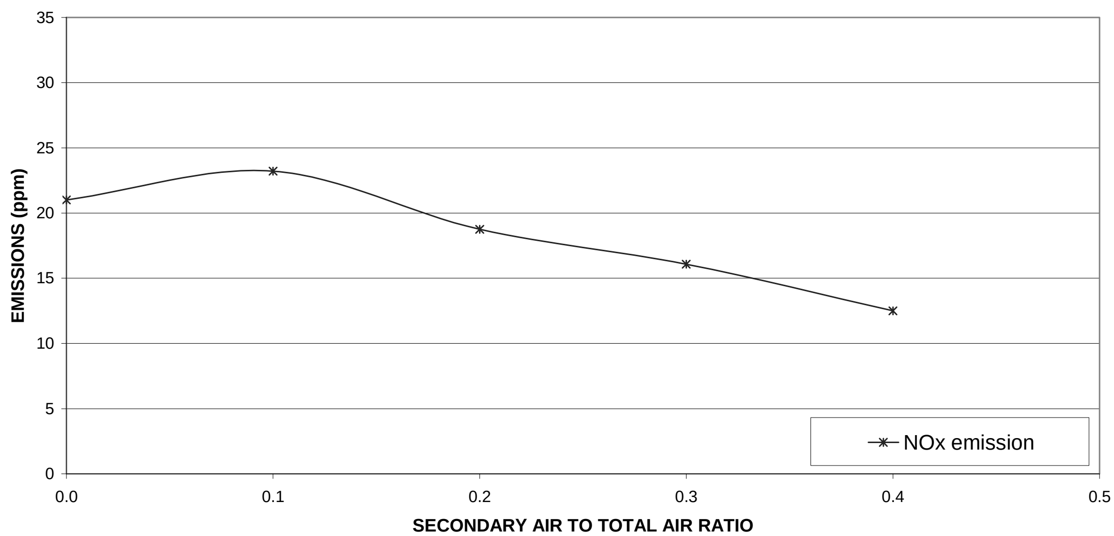

Figure 3 NO_X vs Air ratio

Thermal NO_X produced by oxidation of atmospheric nitrogen in post flame gas can also be reduced by using air staging method. The secondary air will decrease the temperature in the combustor and reduce the NO_X emission. The secondary air also reduces the prompt NO produced by high-speed reaction at the flame front during the combustion by reducing the speed of the flame.

Figure 4 shows the plot of carbon monoxide (CO) emissions at different secondary air to total air ratio. CO emission reduction of more than 10 percent was achieved by using air staging compared to non-air staging test at the portion of the combustion air of 20 percent. CO emission will be emitted from the combustion process due to the lack of sufficient oxygen to complete the reaction from CO to CO_2 and also because of low combustion chamber temperature. When the secondary air is added into the combustor to supply the oxygen to complete the combustion, the combustor temperature will drop and this will cause an increase in CO emission. Anyway, this situation only happens at the beginning of the process.

Figure 5 shows a plot of carbon dioxide (CO_2) emissions versus air ratio when air staging is applied to the liquid fuel burner. There was a slight increase in carbon dioxide emissions when air staging method is applied. This was observed throughout the whole range of operating air ratio. CO_2 increases about 20 percent when 20 percent of air staging supplied to a primary combustion zone. However, this increase is not significant as compared to the reduction of NO_X emissions. When secondary air was introduced, oxygen from the air will complete the combustion and CO will decrease (Figure 4). Furthermore, carbon dioxide emissions are more stable and non-toxic. However, CO_2 is a greenhouse gas and can contribute to global climate change.

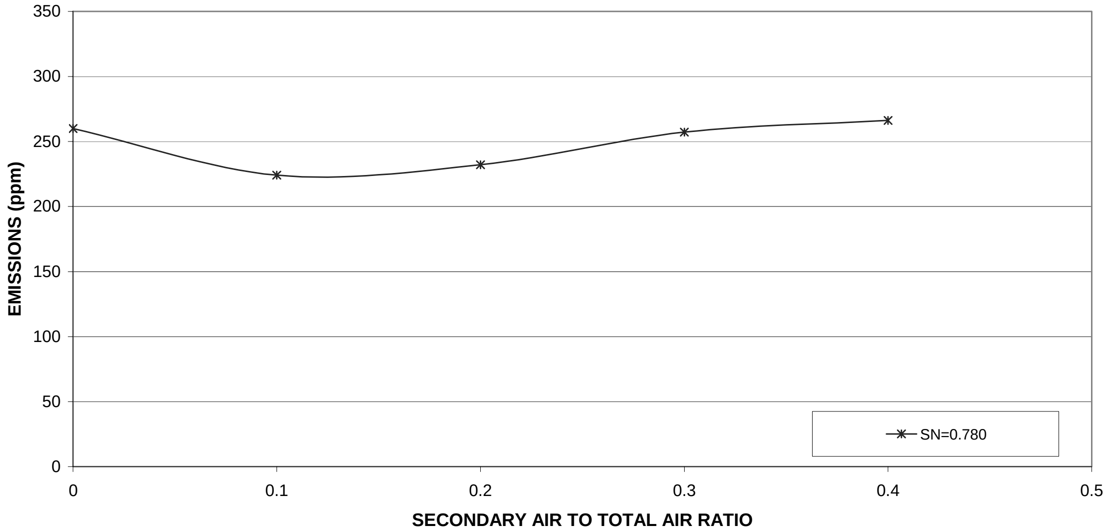

Figure 4 CO vs Air ratio

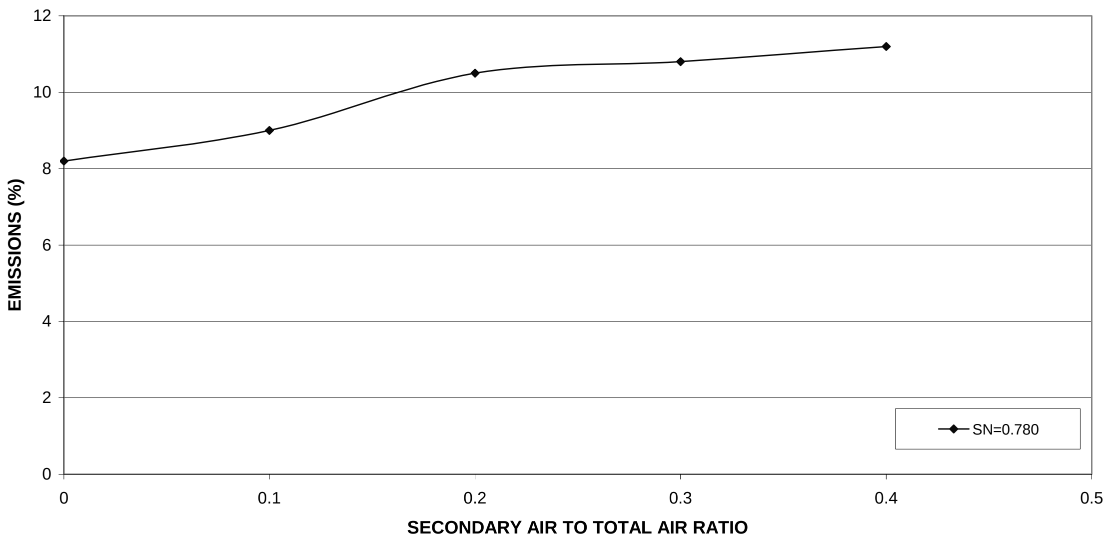

Figure 5 CO_2 vs Air ratio

Conclusion

The use of air staging has been proved to be effective in reducing emissions from liquid fuel burner especially the oxides of nitrogen (NO_X) and carbon monoxide (CO). NO_X emissions reduction of about 15 percent was obtained at the portion of the combustion air of 20 percent air staging compared to the non-air staging test. Other emissions such carbon monoxide also decreased when using air staging method. Air staging method also helps to complete the combustion and increased the formation of carbon dioxide from the liquid fuel burner.

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