ISSN: 0128-7680
Pertanika J. Sci. & Technol. 13(2): 139 - 146 (2005)

The Application of Water Cooling on Reducing NO_x from a Gas Burner System

[1]Mohammad Nazri Mohd. Jaafar, [2]G. E. Andrews & [2]M. C. MkPadi
[1]*Department of Aeronautics & Automotive,*
Mechanical Engineering Faculty
Universiti Teknologi Malaysia
81310 UTM Skudai, Johor, Malaysia
[2]*Department of Fuel & Energy, Leeds University*
Leeds LS2 9JT United Kingdom

Received: 15 November 2001

ABSTRAK

Sebuah sistem pembakar yang mengaplikasikan kaedah penyejukan air telah dikaji menggunakan kebuk pembakar dengan garis pusat dalam 140-mm dan panjang 294-mm. Kebuk pembakar diletakkan secara menegak. Kesemua ujian dijalankan menggunakan gas asli sahaja. Pemusar udara bilah lurus yang tetap dengan garis pusat keluaran 76 mm telah dipasangkan di satah masukan ke kebuk pembakar. Sebuah plat orifis dengan garis pusat 59 mm telah dipasangkan di satah keluaran pemusar untuk menggalakkan pembentukan gelora dan membantu dalam percampuran bahan api dengan udara. Bahan api dipancitkan di plat belakang pemusar menggunakan pemancit bahan api pusat dengan lapan lubang bahan api yang mengarah keluar secara jejarian. Semua ujian dilakukan pada kejatuhan tekanan 5-mmH_2O. Pengurangan emisi NO_x sebanyak 21.53 telah dicapai pada nisbah setara hampir stoikiometri (0.88) dan pengurangan sebanyak 35.7% telah dicapai pada nisbah setara 0.42. Emisi lain seperti karbon monoksida adalah di bawah aras 100 ppm kecuali pada nisbah setara di bawah 0.5 yang disebabkan oleh kesan penyejukan. Emisi hidrokarbon tak terbakar juga adalah di bawah 10 ppm kecuali pada nisbah setara di bawah 0.5.

ABSTRACT

A gas burner system applying water cooling has been investigated using a 140-mm inside diameter combustor of 294-mm length. The combustor was placed vertically upwards. All tests were conducted using natural gas only. A fixed straight blade radial swirler with 76-mm outlet diameter was placed at the inlet plane of the combustor. An orifice plate of 59 mm was inserted at the exit plane of the swirler to enhance turbulence and help in mixing of the fuel and air. Fuel was injected at the back plate of the swirler using central fuel injector with eight fuel holes pointed radially outward. Tests were conducted at 5-mmH_2O pressure loss. A reduction of about 21.53% on NO_x emissions was achieved at equivalence ratio of near stoichiometric (0.88) and a reduction of 35.7% was achieved at equivalence ratio of 0.42. Other emissions such as carbon monoxide were well under 100 ppm except below the equivalence ratio of 0.5 due to cooling effect. Unburned hydrocarbon emissions were well below 10 ppm except below the equivalence ratio of 0.5.

Keywords: Oxides of nitrogen, carbon monoxide, unburned hydrocarbons, water cooling

INTRODUCTION

The effects of increased levels of NO_x (oxides of nitrogen) in the atmosphere are far reaching. In the atmosphere nitric oxide (NO) is rapidly oxidised to nitrogen dioxide (NO_2) and in this form plays an essential role in the formation of tropospheric ozone and photochemical smog. NO_2 is further oxidised to form nitric acid that may then be deposited as acid rain (Harrison 1990). At ground level, increased concentrations (above 0.06 ppm) of NO_2 can cause respiratory problem (World Health Organisation 1987).

NO_x emission limits legislation in many parts of the world has substantially complicated the burner design process. Attempts at lowering NO_x emissions by reducing the flame temperature will lead to reduced flame stability or increased carbon monoxide (CO) emissions. Unacceptable stability problems or CO emissions always limit the lowest NO_x emission obtained in a given configuration. Therefore, the process of burner design has become a trial-and-error, multi-parameter optimisation process (Van Der Meij *et al.* 1994).

Generally there are two techniques of controlling NO_x: those which prevent the formation of nitric oxide, NO and those which destroy NO from the products of combustion.

The former approach has been widely applied. The main aim is to reduce the flame temperature thus reducing the formation of NO_x. There are several ways of accomplishing this.

One method is the modification of combustion processes, i.e. either to burn fuel-rich or fuel-lean. The operation of lean burning is to introduce additional air in order to reduce the flame temperature. This would generally cause a significant decrease in the production of NO_x. A reduction of the primary-zone flame temperature on the other hand may increase the emissions of carbon monoxide and unburned hydrocarbon (UHC). The problem with fuel-rich combustion is the formation of soot and CO, even though the stability margin is widened.

Another method, i.e. steam or water injection has been shown to be very effective in accomplishing the above goal (Shaw 1974). A typical NO_x reduction curve as a function of rate of water injection is shown in *Fig. 1* (Correa 1991). These data were obtained in an aeroderivative inductive gas turbine at full power. Fox and Schlein (1992), testing the FT8 gas turbine combustor, also demonstrated the same effect in their final test run. The FT8 engine is an industrial/marine gas turbine engine that is a derivative of the widely used JT8D aircraft jet engine. However, to avoid detrimental effects on turbine durability, the water has to be purified to a maximum of 2-5 ppm of dissolved solids (Sarofim and Flagan 1976; Correa 1991). Furthermore, there are other complications such as incorporating the water injection system into the combustor design. Another disadvantage of water injection is the undesirable side effects of quenching CO burnout. These drawbacks render water injection method unattractive for smaller gas turbines or where availability of sizeable water supply is difficult. However, it is a feasible technique for burner NO_x control in water heater or steam generator.

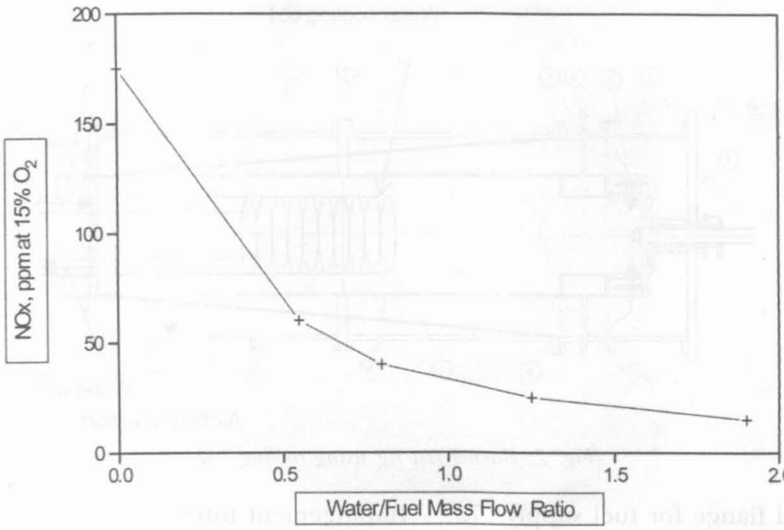

Fig. 1: NO_x as a function of water addition in a gas-turbine combustor running on natural gas at a pressure ratio of 30 (after Correa 1991)

Other methods of NO_x control involve staged combustion, variable geometry combustion, lean premixed prevaporised combustion and catalytic combustion. In the present work, a water cooling comprising of a 6-mm stainless steel tube coil was used to reduce emissions by supplying constant amount of cooling water through it. The cooling coil was placed at a particular distance from the flame.

METHOD

The general rig set-up for burner tests is shown in *Fig. 2*. The air is introduced through the inlet pipe, designated (13) on the diagram and flows downward before entering the combustor through the fixed straight blade radial swirler of 76-mm outlet diameter.

The rig is equipped to be fuelled either by wall or central fuel injector. The central fuel injector is of a simple type with eight holes pointing radially outward. The inside diameter of the combustor is 140 mm and the length is 294 mm. The combustor is enclosed by a 250 mm inside diameter pipe through which air flows. Thus, the air is actually preheated by the combustion inside the burner as it flows through this pipe before entering the combustor through the swirler. However, this preheat cannot be controlled externally. The exhaust sampling probe is mounted at the top of the end pipe to measure all the major exhaust gases such as oxides of nitrogen (NO and NO_2), carbon monoxide and unburned hydrocarbon.

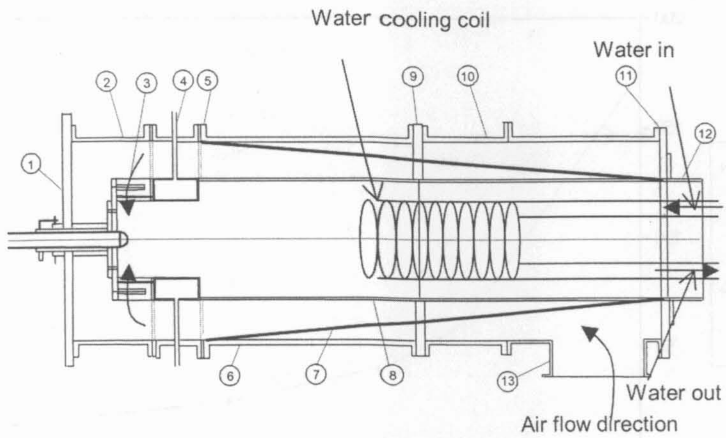

Fig. 2: Burner test rig using cooling coil

1. End flange for fuel supply & swirler support
2. Swirler case pipe
3. Variable swirler
4. Wall fuel injector
5. Flange
6. 250mm-dia. case pipe
7. Impingement tube
8. 140mm-dia. case pipe
9. Joint flange
10. Reverse air passage pipe
11. Recess flange
12. End pipe
13. Reverse air inlet pipe inlet. Inlet P & T tapping

Test Conditions

Tests were carried out at around 400 K inlet temperature simulating domestic central heating unit. The air was preheated by combustion in the main combustion chamber. However, to maintain the inlet temperature at this value is almost impossible since the air preheated temperature cannot be controlled externally. At some point in these tests, the air inlet temperature will exceed 400 K. Natural gas was used as fuel throughout the entire investigation. Temperature of the cooling water was not measured in this experiment.

Domestic central heating boilers operate with a fan air supply at below 0.5 percent (5 mb, 50 mmH_2O) pressure loss compared to 2-5% pressure loss for gas turbine combustion. These pressure losses of 2-5% when converted to burner pressure loss are equivalent to 200-500 mmH_2O.

Tests were conducted using an orifice plate of 59 mm diameter that was inserted at the exit plane of the outlet of the wall injector section (refer to *Fig. 2*). This was to enhance flame stabilisation and to provide better mixing of air and fuel prior to ignition. The orifice plate also helped to prevent fuel from entraining into the corner recirculation zone that will create a local rich zone hence resulting in higher local NO_x emissions which ultimately contributes to high total NO_x emissions.

RESULTS AND DISCUSSION

Figs. 3-6 show the effect of applying water cooling on reducing mean exhaust emissions from gas burner system using a straight blade radial swirler.

Fig. 3 shows the reduction in NO_x emissions when using water cooling. A reduction of 21.5% was achieved at the equivalence ratio of 0.88, while a reduction of about 35.7% was achieved at the equivalence ratio of 0.42 when compared to the tests which water cooling were not applied. These demonstrate that the water-cooling method is quite effective in reducing NO_x emissions in gas burner systems especially near stoichiometric or fuel rich conditions. However, the major drawback is that the flame cannot be sustained when burning lean. This can be seen by looking at the lean flammability limits of 0.42 when compared to the tests where water-cooling was not applied when the lean limit equivalence ratio was 0.33. This is usually the lean flammability limit of this burner and may not have enough fuel in the burner to be burned.

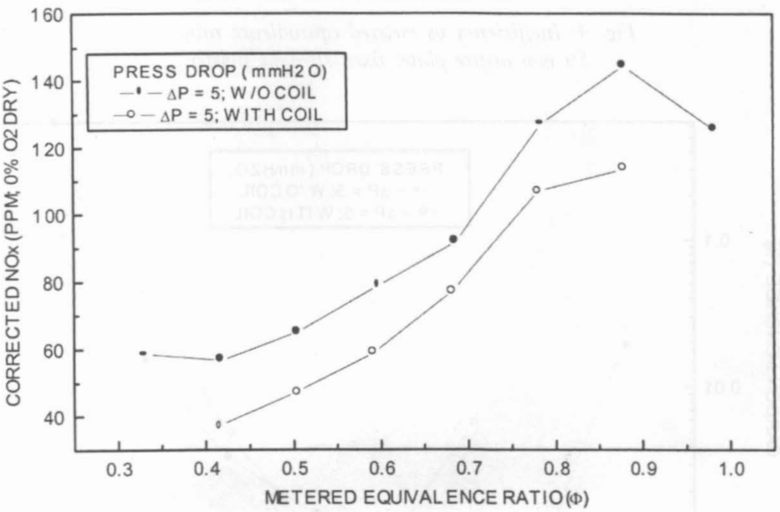

Fig. 3: Corrected NOx vs metered equavalence ratio for 59 mm orifice plate; fixed straight swirler

Fig. 4 shows the combustion inefficiency plotted against equivalence ratio for both test conditions. It could be seen that combustion inefficiency was increased when using water-cooling. Combustion inefficiency increases drastically near lean condition to around 1% from about 0.03% at equivalence ratio of near 0.9. This could be due to flame quenching when using water-cooling where the emission of carbon monoxide increases and causes the combustion inefficiency to rise.

Fig. 5 shows the carbon monoxide emissions plotted against equivalence ratio. It shows the same trend as a combustion inefficiency curve that implies that the combustion efficiency was influenced by carbon monoxide oxidation. However, it could be seen that carbon monoxide emissions increase when

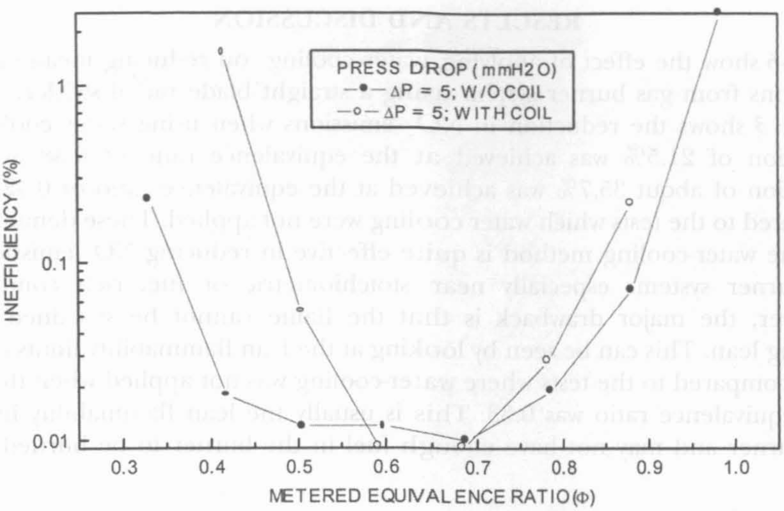

Fig. 4: Inefficiency vs metered equivalence ratio for 59 mm orifice plate; fixed straight swirler

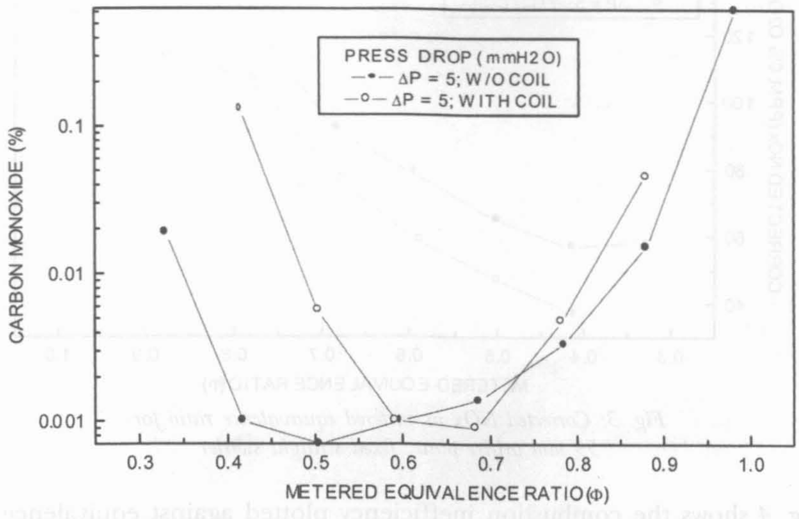

Fig. 5: Carbon monoxide vs metered equivalence ratio for 59 mm orifice plate; fixed straight swirler

water cooling is applied. There was some reduction in carbon monoxide emissions between equivalence ratios of 0.6 to 0.73. The carbon monoxide curves show the same curvature for both conditions. There is a significant increase in the lean region that is due to insufficient residence time for carbon monoxide burnout at the low flame temperatures of these lean mixtures. The significant increase in carbon monoxide emissions on the rich side is due to high equilibrium carbon monoxide at these rich equivalence ratios.

Unburned hydrocarbon emissions of less than 10 ppm can be achieved for both conditions over a wide range of operating equivalence ratios and this is shown in *Fig. 6.* However, water cooling actually increases unburned hydrocarbon emissions rather than reduce them, except over a small range of equivalence ratios of 0.53 to 0.65. This may be due to several reasons. One of them is the chilling effect of water cooling and the other may be inadequate burning rates at lean conditions.

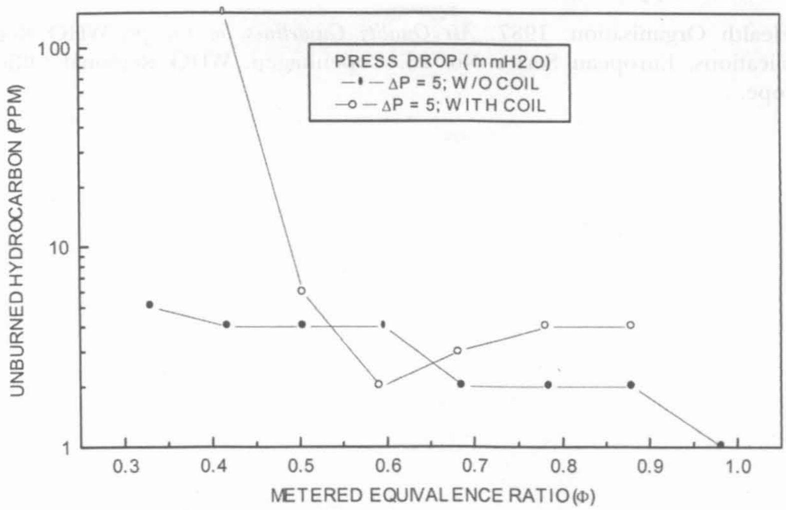

Fig. 6: Unburned hydrocarbon vs metered equivalence ratio for 59 mm orifice plate; fixed straight swirler

CONCLUSIONS

It could be concluded that there was a significant amount of NO_x emission reduction when applying water cooling. A reduction of 21.5% was achieved at equivalence ratio of 0.88. However, this was achieved at the expense of an increase in other emissions such as carbon monoxide and unburned hydrocarbon by 200 and 100%, respectively. These increases in carbon monoxide and unburned hydrocarbon are even larger for lean burn since at this condition, the chilling effect is greater due to lower temperature caused by water cooling and also by burning less fuel, thus producing lower temperatures.

REFERENCES

CORREA, S.M. 1991. A review of NO_x formation under gas-turbine combustion conditions. *Combust. Sci. and Tech.* **87:** 329-362.

FOX, T.G. and B.C. SCHLEIN. 1992. Full annular rig development of the FT8 gas turbine combustor. *Journal of Engineering for Gas Turbine and Power* **114:** 27-32.

HARRISON, R.M. 1990. *Important Air Pollutants and Their Chemical Analysis. Pollution: Causes, Effects and Control.* pp. 156-175. London: Royal Society of Chemistry.

SAROFIM, A.F. and C. FLAGAN. 1974. NO_x control for stationary combustion sources, *Prog. Energy Combustion Science* **2**: 1-25.

SHAW, H. 1974. The effects of water, pressure, and equivalence ratio on nitric oxide production in gas turbines. *Transactions of the ASME, Journal of Engineering for Gas Turbines and Power* July: 240-246.

VAN DER MEIJ, C.E. *et al.* 1994. On the effects of fuel leakage on CO production from household burners as revealed by LIF and CARS. *Twenty Fifth Symposium (International) on Combustion,* pp. 243-250. The Combustion Institute.

World Health Organisation. 1987. *Air Quality Guidelines for Europe.* WHO Regional Publications, European Series No. 23. Copenhagen: WHO Regional Office for Europe.