MEASUREMENT OF NITROGEN OXIDE EMISSIONS FROM 2MW OIL BURNER FURNACE SYSTEM

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Abstract

This paper presents experimental results obtained from a 2 MW oil burner/furnace system during the warming-up and steady state phase. The experimental work includes temperature profiles and NO-NOx measurements obtained using Chemilimunisence technique and CO measurements obtained using Infrared gas analyser. Measurements were carried out under two operating conditions which were obtained by alterations in power and oil/flow rates. The operating conditions considered during the system operation were at air inlet pressure of 5 mbar (or mixture ratio 1.16), and air inlet pressure of 8 mbar (or mixture ratio 1.63) for 60^o oil jet spray angle. The results were analysed and compared for an operating power range of 0.4 to 1.5 MW and two main mixture ratios.

In this study, NO, NOx, SO_2 , N_2O, CO and CO_2 were measured during the drying-out process, warm-up and steady-state phase. However, most of the discussions are focused on NOx measurements obtained from the furnace, as the levels of SO_2, N_2O and CO were very small generally. The experimental result showed that the majority of NO formed close to the burner via the oxidation of nitrogenous species. The maximum temperatures occurred closer to the burner exit and flame.

Introduction

The environment has been polluted since the beginning of history in many ways. After the discovery of fire, air pollution has become a part of the daily agenda. The combustion of fossil fuels has caused considerable environmental pollution being first identified in the major industrial countries. With the twenty-first century, the problem of environmental pollution and its control presents itself as a demonstrative challenge for the industrialised countries as the rate of technology growth and industrial development continues to increase.

Air pollution occurs with all combustion processes and affects the atmospheric conditions. More than 500 year ago the atmospheric pollution arising from the use of coal has been found especially in the UK and other similar developing countries. The pollutants so emitted cause effects such as the ‘green house effect’, ‘photochemical smogs’, ‘acid rain’ these effects have been exacerbated by the world increase in the use of petroleum based fuels in the last century. Pollutants arising from such combustion systems include: NOx arising from the reaction of nitrogen in combustion air (Thermal NOx); NOx arising from nitrogen chemically bound in certain fuels (fuel NOx); CO, arising from imperfect combustion; CO_2, a major 'green house' gas; SOx, arising from the oxidation of sulphur compounds in the fuel with oxygen. Also of concern can be the emissions of soot and unburned hydrocarbon (UHC) which are the product of imperfect combustion.

Today, it is considered that the combustion of fossil fuels is the major cause of air pollution. In most large industrial centres the threat to public health, the deterioration of the environment, damage to buildings and landscape from air pollution has reached a critical level, and the deterioration of the quality of life has started to counterbalance the benefits in living standards gained by the industrial development.

Usually three approaches are used to control the combustion generated pollution emissions and their effect on the environment. These approaches are; to prevent pollution formation, to destroy the pollutants formed and finally treatment of the exhaust or the substitution of the process producing them. Control of these emissions is of great concern especially NOx that is subject to an ever-increasing restriction due to its role in acid rain, photochemical smog and its effect on the ozone layer [1,2]. This restriction on pollutants emitted into the atmosphere has led to a wide range of research on burner design and of furnace and boiler geometry. Low NOx burners making use of the staged combustion principle are installed in many UK coal-fired and other plants.

In the last decades, many combustion researchers have been interested in the control of NOx emissions. Some methods for reduction of NOx emissions have been tested and investigated. For instance, ammonia injection and staged combustion techniques are the most common solutions applied and installed today in many fossil fuel fired systems [3].

In most cases, the combustion of gas oil has not been fully investigated by research, regarding pollution, since it contributes less to the formation of pollutants, soot, unburned carbon particulates and smoke, compared to coal combustion. Nevertheless, there is a trend toward heavier and more highly cracked fuel oils resulting from attempts to recover as high a proportion of premium distillate fuels from "the heavy end of the barrel" [4]. This worsens the problem of particulate emissions from the combustion of heavy oils and corresponding problems with NOx due to increases in fuel nitrogen content and NOx formation from particulate combustion. Consequently the study of combustion emissions from oil fired systems is of great interest [5,6].

Experimental set-up

The combustion rig used for the experimental study was a stainless steel cylindrical ceramic lined tunnel furnace (Figure 1). The experimental facility comprised of a Nu-Way 2 MW burner, which fires horizontally into a cylindrical furnace chamber of 0.8 m internal diameter, 4.2 m in length and 0.22 m in refractory wall thickness. The rig was fitted with gas sampling ports along its length, enabling access to the combustion chamber for in-flame sampling. The stainless steel walls were insulated with two different insulating materials, the inner part lined low cement refractory (thickness 101 mm), and the outer part covered with insulation refractory (thickness 101 mm) and micro-therm blanket (thickness 25.4 mm). The burner (front) end of the furnace comprised a cast refractory cone to minimise re-circulation of combustion products, so that the initial post flame region was essentially in plug flow. The furnace outlet (back) was connected to a gas extraction system fitted with a butterfly valve to balance the induced draught extraction fan with the forced draught burner fan, in order to maintain the atmospheric pressure balanced in the combustion chamber.

The furnace consisted of five sections on rollers, which could be de-coupled. Thus the section with the quartz window can be positioned anywhere to allow Laser access measurements along the furnace axis. This section afforded optical access for laser diagnostic measurements such as LDA or Phase Doppler Anemometry (PDA) for velocity and particle sizing. All the other sections of the rig have ports allowing access for gas species and temperature measurements. All the sections of the furnace, each with 600 mm in length, were bolted together and fitted with sampling ports at regular intervals along the length of the furnace. A schematic of the measurement section of the combustion rig is shown Figure 1.

The oil burner was a typical industrial fully automatic, NU-Way pressure-jet oil burner. A Delevan spray nozzle with a 60^{o} spray angle was used on the burner.

Experimental measurements were taken at 40 sampling points (8 radial x 5 axial) in the cylindrical refractory line furnace at five ports which were positioned downstream from the burner nozzle at 300mm, 900mm, 1500mm, 2100mm and 2700mm axial distances. Gas concentration and temperature measurements were taken from all furnace ports and at the rear port in the exhaust section. Two different gas analysers were used to measure the flue gas concentration in the combustion zone and in the exhaust section. The first: a new Horiba gas analyser was purchased for this work for on line NO-NOx (NO + NO_2) measurement. The gas analyser uses the Chemilimunisecent technique for the measurements. Emissions were measured using this Chemilimunisence technique at different power rates from 0.825 MW to 1 MW. The second: a Testo-term infra-red gas, on line analyser was, used to determine several species, O_2, CO, SO_x, NO, flue gas and ambient temperature and lambda (λ) (air fuel ratio) in the exhaust section after water cooling.

Measurement were done under two different operating conditions at air inlet pressure of 5 mbar (or mixture ratio 1.16), and air inlet pressure of 8 mbar (or mixture ratio 1.63) at the same thermal power of 0.825 MW. Oil flow rate was calculated by timing the rate of volume decrease in a small measuring tank. The burner airflow rate was measured by traversing a Pitot tube across the air supply duct.

Results and Discussions

The furnace combustion processes were characterised by two main phases: the warm-up phase during which temperatures gradually rose, and the steady-state phase during which the combustion stability had been reached several hours after ignition. The steady state phase was more important than the first phase. The steady state phase was characterised by the stable temperatures throughout the combustion chamber after a period of operation at constant fuel supply, air/fuel ratio and power input. Most of the gas concentration measurements were carried out in the phase with steady temperature conditions. The measurements under the steady state phase were important because this is the normal operation condition 90% of the time. The measured results provide important information for the characterisation of the combustion system.

In this study, NO, NOx, SO_2 , N_2O, CO and CO_2 were measured during the drying-out process, warm-up and steady-state phase. However, most of the discussions are focused on NOx measurements obtained from the furnace, as the levels of SO_2, N_2O and CO were very small generally.

Detailed results obtained at the steady state operating conditions (at 8 mbar) are shown in Figures 2a to 2d for several ports as a function of radial distance from the wall, as a function of the axial downstream distance from the burner. Also comparisons with temperature level are depicted in Figures 2a to 2d. The two air/fuel ratios (1.16 and 1.63) give highest levels of NOx close to the axis and for the air fuel ratio of 1.16 next to the burner exit at port 1, Figures 4. The highest NO concentration was measured at the radial distance of 100 mm from the central axis at port 1 for the air inlet pressure of 8 mbar. The highest NO level for 5 mbar was 72.5 ppm while it was about 60 ppm for 8 mbar.

Furthermore, the highest NO level of 72.5 ppm was obtained for the air inlet pressure of 5 mbar (mixture ratio 1.16) considering measurements at the exhaust section (Figures 4). The greatest variation was of the order of 10 ppm across the furnace radius in this condition and was probably caused by the configuration of the exhaust system. The exhaust duct entry point was fixed on the side of the stack wall. Therefore, the gases passing through this section are strongly affected by the exhaust duct.

Conclusion

It can be concluded that for air inlet pressures of 8 mbar and 5 mbar, the NOx concentration levels are considered relatively low and within the EEC limits [7]. The limit for burner/furnace size is 400 mg/m3 (or 219 ppm). This level is much higher than the maximum level of 72.5 ppm for the case of the maximum power consumption (1.076 MW). Under the operating conditions the furnace was therefore environmentally friendly.

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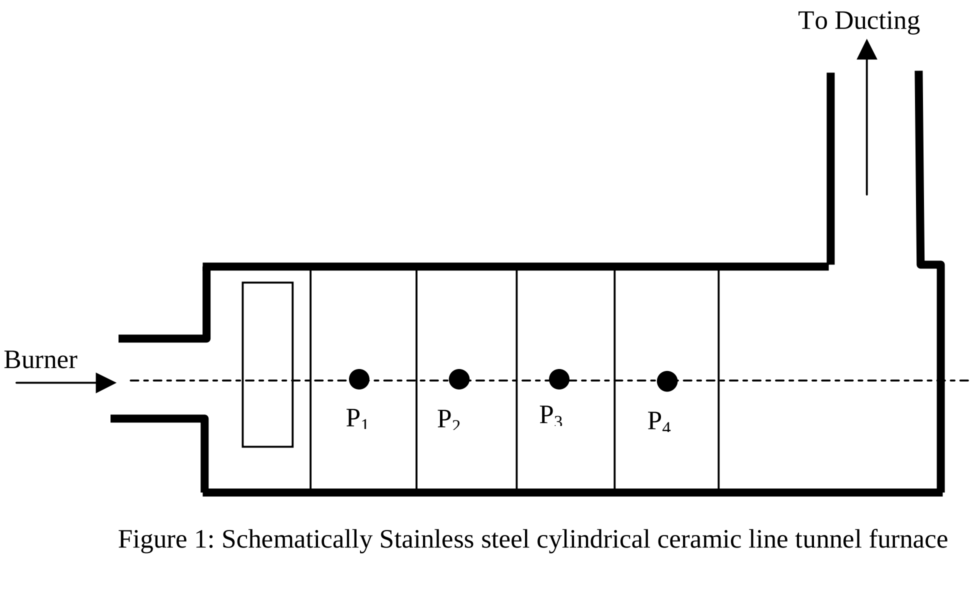

Figure 1: Schematically Stainless steel cylindrical ceramic line tunnel furnace

Figure 2a: NO and Temperature profile, steady state, 825kW, 8 mbar air inlet pressure, port 1.

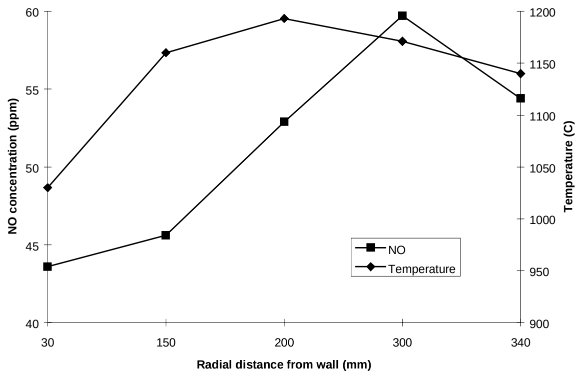

Figure 2b : NO and Temperature profile, steady state, 825kW, 8 mbar air inlet pressure, port 2.

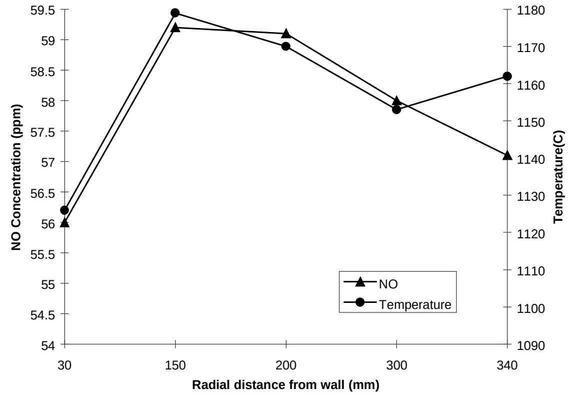

Figure 2c: NO and Temperature profile, steady state, 825kW, 8 mbar air inlet pressure, port 3.

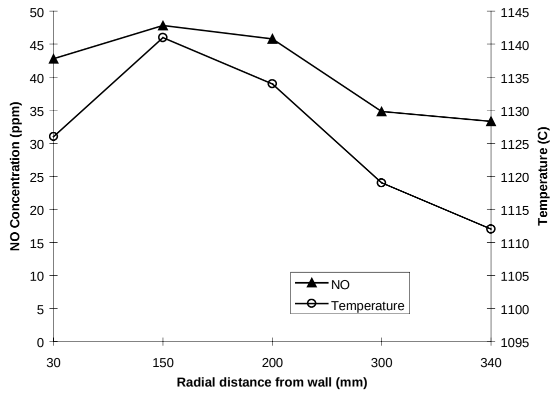

Figure 2d: NO and Temperature profile, steady state, 825kW, 8 mbar air inlet pressure, port 4.

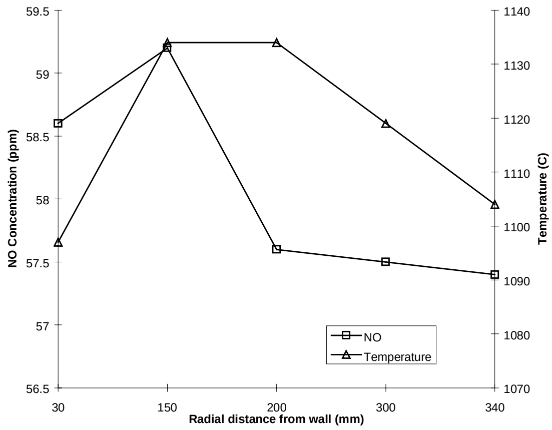

Figure 3:NO concentration, steady state, port 1, 5mbar and 8 mbar.

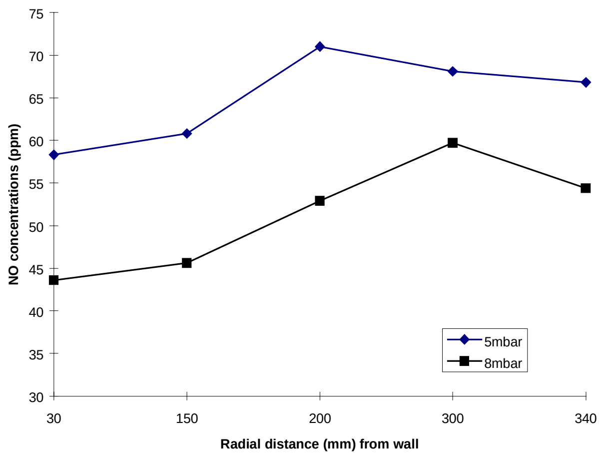

Figure 4: NO profile at rear port, steady state, 825kW, 5mbar air inlet pressure.