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DEVELOPMENT AND ASSESMENT OF AN ADVANCED FLAMELESS OXIDATION BURNER FORVERY LOW NO_X EMISSIONS

(Paper #9)

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ABSTRACT

The operation of turbulent dilute diffusion flames, within an experimental glass furnace is to be studied. The configuration features a small refractory brick furnace with water tubes at the bottom to simulate a thermal load. The burner block comprises of a central hole where preheated air enters and four outer fuel jets to supply natural gas. By separating the air and fuel inlets, the reactants will be diluted by aerodynamic recirculation of inert flue gases prior to burning. This effect will lower peak flame temperatures and thus lead to a lowering of nitrogen oxide emissions. At present the apparatus to conduct this experiment has been assembled and the furnace has been commissioned successfully. Further testing will hope to achieve diluted combustion and quantify its performance.

Key Words: Diluted combustion, entrainment, oxides of nitrogen, recirculation.

1. INTRODUCTION

1.1 Our Objectives

In this project we aim to:

- Design a burner block to allow an existing simulated glass furnace to operate in diluted combustion mode.
- To address safety issues to allow safe operation of the furnace.
- To commission the furnace.
- Quantify the performance of the furnace in diluted combustion mode.
- To review previous work on flameless combustion.

Previously, after studying past research on flameless combustion, and with advice from our supervisors, the burner block has been designed. Following manufacture by the workshop, it was installed in the furnace at the Thebarton Campus. The central jet has been fired and the safety systems are functioning. We are now ready to establish whether our burner design is capable of low NO_X emissions by conducting further experiments.

1.2 The glass furnace

An industrial glass furnace requires temperatures above 1100°C, high enough to melt the quartz and metal oxide mixture. The quartz is located at the bottom of the furnace and is heated via thermal radiation from a flame above. The roof of the furnace is dome shaped so that the heat is reflected onto the quartz to increase thermal efficiency.

To achieve higher thermal efficiency, glass furnaces preheat combustion air in either a recuperative or regenerative system [1]. The recuperative system is indirect and allows preheating combustion air to about 800°C via a heat exchanger that utilises energy from the flue gases.

Pollutants such as carbon monoxide (CO), unburnt hydrocarbons, and oxides of nitrogen (NO_X) must be minimised. In natural gas furnaces the NO_X emissions mainly consist of NO. With conventional burners high levels of air preheating creates very high NO_X emissions, flameless combustion seeks to overcome this problem by allowing high preheat temperatures while maintaining low emissions. With our small-scale glass furnace we can simulate the recuperative system by preheating the air at 600°C.

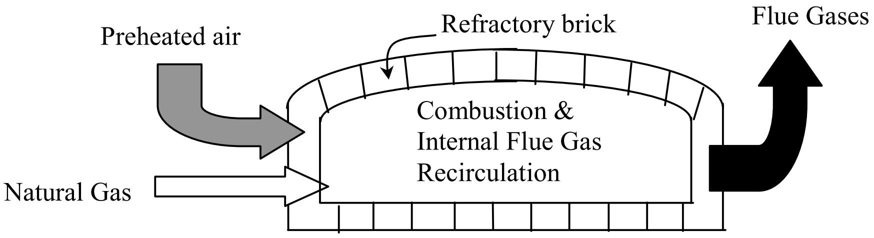

Figure 1 - Simplified schematic of furnace.

1.3 Principals of NO_X formation

NO_X is formed by three mechanisms during combustion. Thermal NO_X is influenced by the peak flame temperature and residence time and occurs via the basic Zeldovich mechanisms [2]. Prompt NO_X is formed via the Fenimore mechanism where hydrocarbon radicals formed in the early stages of combustion react with molecular nitrogen, which form cyano compounds that ultimately lead to NO. Nitrogen compounds present in the fuel rapidly form cyano compounds during combustion that lead to NO in a similar way as the prompt NO_X does [2].

2.0 NO_X REDUCTION

2.1 Staged burners

Staged burners create a two-stage combustion in which the flame zone is extended and peak temperatures are reduced, see reference [2] for details. NO_X emissions are up to 70% lower in flameless combustion as compared to staged combustion, figure 1 shows the difference for various process temperatures.

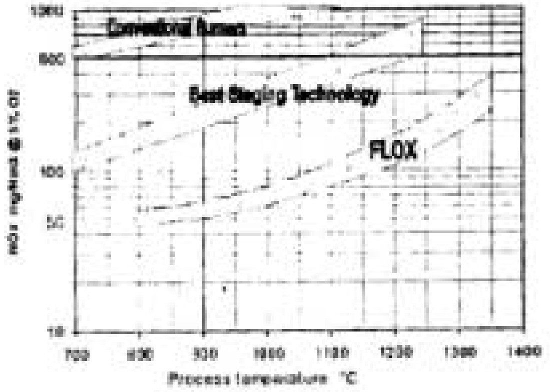

Figure 2- NO_X emissions of Conventional, Staging, and Flameless Oxidation (FLOX) Burners, Milani & Sopanaro [3].

2.2 Flue gas recirculation

To aid in stability of the combustion our burner incorporates aerodynamic internal exhaust gas recirculation. Entrainment of inert flue gases containing N_2, CO_2, H_2O, and excess O_2 will be carried out by the kinetic energy of the jet. The increased heat capacity of the mixture and the lowering of the partial pressure of the oxygen will help lower peak flame temperatures.

Katsuki & Hasegawa [4] showed that combustion with normal ambient air becomes unstable when exhaust gas recycling rate becomes greater than 30%. But if the combustion air is heated much greater amounts of recycling can be sustained. If the combustion air is preheated to the autoignition temperature, then a stable combustion domain appears.

2.3 Diluted combustion

With the reactants and inert flue gases mixture at auto ignition temperatures, and no aerodynamic means of having a stable flame front a volumetric combustion regime occurs [2]. No flame front exists and the combustion is almost transparent, this regime is known as flameless combustion.

The heat distribution across the furnace is much more uniform when the combustion is flameless. Peak flame temperatures are lower and this results in reduced NO_X emissions. This reduction in peak temperatures and the uniform temperature distribution leads to be higher radiant heat flux and an increased thermal increases efficiency.

3. EXPERIMENTAL SETUP

3.1 Burner configuration

The burner block is a composite of stainless steel and refractory brick made to fit a 200×200 mm cavity in the front of the furnace. There are a total of five jets protruding through the brick. The central jet is a conventional burner that protrudes through the conical hollow where the preheated air enters; the flame from this jet will be compared to the combustion formed by the outer jets.

The four outer jets have a single degree of freedom motion. Their motion may be restricted in either the vertical or inclined plane (See figure 3 for details). The fuel streams may be pointed away from the air stream thus allowing self-recirculation of the flue gas. Nishimura et al [5] reports that with his experimental inclined burner a maximum reduction of NO_X emissions and a more uniform temperature variation occurred at an inclination of 30°. The size of our furnace and a late change in design of the jet adjusting mechanism has restricted the motion of our fuel jets to only 7° in each direction (see figure 4 for details).

Figure 3 (a)   Figure 3 (b)

Figure 3 – These images show the burner block, (a) shows the block with the outer jets and part of the manifold in place, (b) shows the mechanism used to incline the jets.

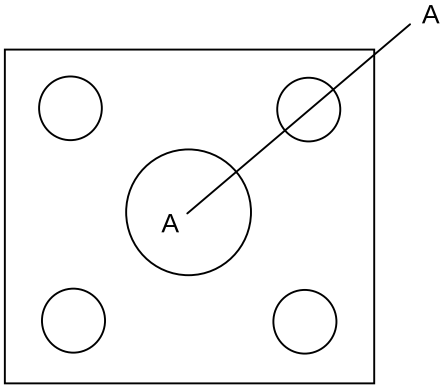

Figure 4 (a)

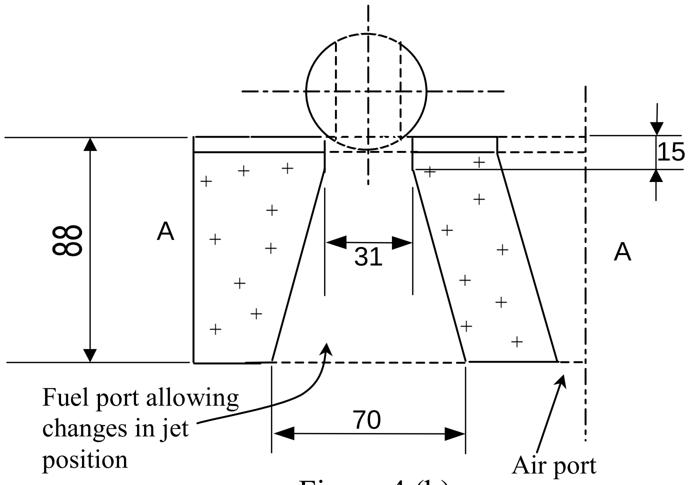

Figure 4 (b)

Figure 4 - (a) shows a basic diagram of the block with a line showing where the cross section shown in (b) originates.

To ensure equal amounts of fuel are delivered to each jet, a three-way valve with two T-pieces connected in series is being used. This three-way valve has made it impossible to directly switch between the conventional and the outer jets without the flame going out.

3.2 Combustion air

The combustion air is from a compressor system and its flow is regulated by means of a manual regulating valve and measured using an orifice plate flow meter and U-tube manometer. The air is preheated to 600° before entering the furnace and enters through the air heater manifold bolted to the burner block.

3.3 Temperature sensing

There are various different locations where temperatures are measured. R type thermocouples, measuring temperatures up to 1400°C and K type thermocouples, which measure temperatures up to 900°C, are used. The R-types are installed to measure all crown and wall temperatures and the K-types are installed to measure exhaust, air preheat and cooling tube temperatures. The exhaust temperature is used as the reference temperature.

To transfer this data to a ‘Microsoft Excel’ file, a ‘Data Scan’ digital scanning unit with a couple of sixteen-channel modules is used. Each thermocouple has its own channel and this data is transferred to the computer via an RS 232 interface.

3.4 Emissions analysis

The concentrations of O_2, NO, NO and CO_2 will be measured using a gas analyser once it has been calibrated. Currently a portable oxygen analyser has become available that can measure the percentage of oxygen gas present in the exhaust gases.

4. COMMISIONING

4.1 Initial test

The first firing of the central jet was conducted on the 5th September 2001, it was evident that all safety systems are fully operational. The UV flame detector ensures that reactants flow only when combustion is occurring. There was no means of analysing the emissions but it was possible to see how the furnace responded to heat input. The following settings provided a successful ignition.

AIR TEMPERATURE	15°C
AIR FLOWRATE	3.6 L/s
GAS FLOWRATE	0.3 L/s
WATER FLOWRATE	0.03 L/s

Table 1 – This shows the ignition conditions used on the firing day

Assuming that the methane combustion has a lower heating value of 50010 kJ/kg and using the conditions displayed in the table we can calculate how much heat is transferred to the thermal load.

Mass Flow Rate (Gas) = $\dot{m}$ = $0.0003\text{m}^3/\text{s} * 0.7167\text{kg/m}^3 = 0.000215\text{kg/s}$
Heating value of gas = LHV × $\dot{m}$ = $50010 \times 0.000215 = \underline{11\text{ kW}}$
Mass Flow Rate (Water) = $\dot{m}$ = $0.00003\text{m}^3/\text{s} * 1000\text{kg/m}^3 = 0.03\text{kg/s}$
Change in water temperature = $\Delta T = T_{out} - T_{in} = 298 - 293 = 5$ K
Heating Value (water) = $C_p = 33.56$ kJ/kgmol.K
$\therefore$ Enthalpy Change = $\Delta h = (0.03)*(5)*(33.56) = \underline{5\text{ kW}}$

Around 45% of the heat is transferred to the base of the furnace. This value agrees with measurements taken in a previous year [] where low gas flowrate was used. By using our flowrate data it is known that approximately 8% by volume of the reactants entering the furnace were fuel molecules. Using table 5.1 in Borman and Ragland [2] we find that at 8% fuel to air ratio a mixture of methane and air is flammable.

4.2 Thermal effects

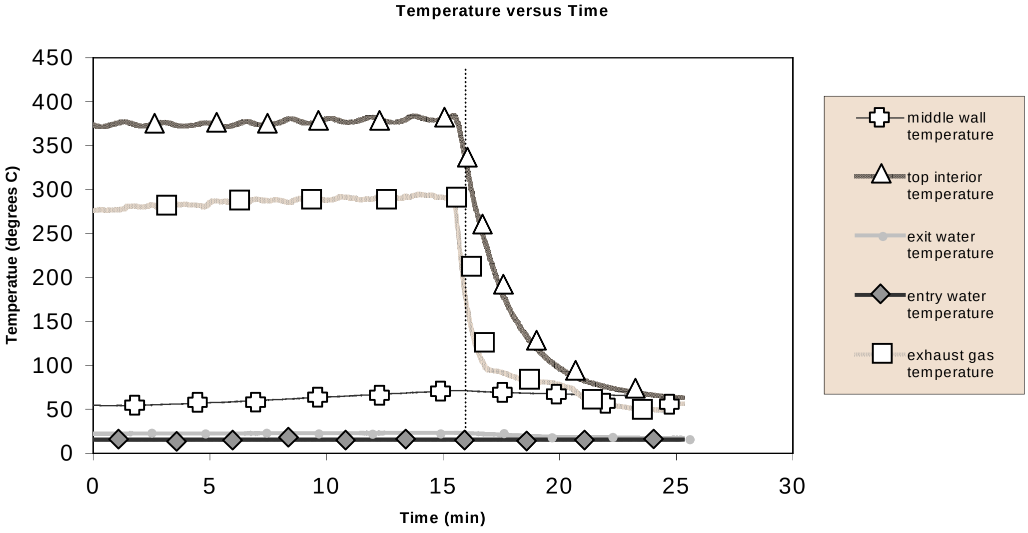

Figure 4 – Diagram showing temperature variations in the system, the dotted line indicates the time at which the kiln was shutdown.

Figure 4 shows the temperature in various areas of the furnace. The highest temperatures are located within the interior, where the combustion gases and thermal radiation heat the thermocouple. The wall temperature rises slowly as the bricks absorb the radiated heat, but after shutdown the bricks continue to remain hot; this attribute will help us maintain high temperatures within the furnace. Using the conventional jet the furnace can be heated until the reference temperature has stabilised, the furnace may be shutdown, and then restarted with the four outer jets with the bricks as an initial source of heat.

In 1997, while the furnace was operating at 61 kW, the exhaust thermocouple was reading 701°C [6], we hope that our configuration the will heat the furnace to 850°C required for flameless combustion.

5. CONCLUSION

The design of the new burner is complete, the safety systems are fully operational and the furnace has been commissioned. Further testing needs to be done to see if the reactants can reach autoignition temperature with preheat temperatures below 600°C. Otherwise it may be necessary to upgrade the air preheater. We look forward to trying to achieve flameless combustion, analysing the furnace emissions, and conducting a detailed assessment of its thermal efficiency.

6. ACKNOWLEDGMENTS

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Particular thanks must be extended to Graham Kelly at the Thebarton Campus of Adelaide University who made it possible for us to make our first test on our burner. He made sure all components were put together satisfactorily and that a safe operating procedure was followed.

Ron Jager, Malcolm Bethume, Anthony Sherry and the rest of the workshop staff who contributed towards building our burner must be thanked also.

7. REFERENCES

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