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THE TEMPEST
LOW NOx OPERATION UPDATE

by

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LOW NOx OPERATION ON THE TEMPEST GAS TURBINE

ABSTRACT

Demag Deleval Industrial Turbomachinery Ltd generic dual fuel Dry Low Emissions (DLE) combustion system has been in successful operation for several years, but has now capitalised on the Tempest re-rate in 2000, whereby sub 10ppm NOx on gas fuel has been both demonstrated and proven in commercial operation.

This paper describes both the product and commercial validation of the sub 10 ppmvd at 15% O2 levels in a dual fuel DLE configured Tempest gas turbine.

THE AUTHORS:

Brian M. Igoe - Tempest Product Manager

I am an Honours Graduate in Mechanical Engineering from the University of Surrey, 1974. My working career started in the Automobile Industry, but moved in 1983 rotating machinery when I joined Ruston Gas Turbines (now Demag Deleval Industrial Turbomachinery Ltd. A wholly owned Siemens company) as a Principle Development Engineer. I soon moved to Group Leader in charge of gas turbine development activities. In 1997 I moved from a development role to that of an Engineering Project Management, initially on Dry Low Emissions Combustion then in the role of Engineering Manager for the Tempest Product. Early in 1999 this role was expanded to that of Tempest Product Manager which included a more strategic role as well as the engineering activities. I am a Chartered Engineer, achieving this in 1988, and have mentored graduate engineers to achieve the same goal.

Donald J. Cramb – Principal Combustion Engineer

Graduated in 1993 from the University of Strathclyde in Glasgow with BEng (Hons) in Chemical Engineering. Associate Member of the Institute of Chemical Engineers currently working towards chartered engineer status.

Worked for 5 years at Mitsui Babcock Energy Limited, Glasgow in the Mills and Burner Group of the Technology Centre as a project engineer. Responsible for design/testing of Low NOx burners for power station boilers firing coal, oil, gas.
Worked for the past 5 years in the New Products and Technology Group within Combustion Operations at Demag Deleval Industrial Turbomachinery Ltd in Lincoln.

LOW NOX OPERATION ON THE TEMPEST GAS TURBINE

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INTRODUCTION

Since its commercial introduction in 1996 the generic G30 Dry Low Emissions (DLE) combustion system has accumulated more than 2 million hours of operation. This has been achieved using both the gas only and dual fuel versions of the combustion system across the company's range of industrial gas turbines.

As the company's products have evolved, so the performance of the combustion system has evolved with them. The initial targets for the G30 system operating on gas fuel was to achieve NOx emissions guarantee of 25 ppmvd at full load while keeping CO emissions below 25 ppmvd. The vehicle used to develop and demonstrate these capabilities was the range of single shaft Typhoon engines (4.35 MWe – 5.2 MWe).

These targets, along with turndown targets of 25 ppmvd NOx and 50 ppmvd CO down to 65% ISO load, were comfortably achieved on the Typhoon. These were subsequently also demonstrated and commercially achieved on the single shaft and twin shaft Tornado engines (6.75 MWe – 7.5 MWe), the single shaft Tempest engine (7.7 MWe) and more recently the twin shaft Cyclone engine (12.9 MWe). NOx levels of sub 10 ppmvd have been consistently demonstrated on production Cyclone engines and on the 7.9 MWe Tempest engines.

With this capability the company can now offer both the Cyclone and Tempest with sub 10 ppmvd NOx emissions operation. This is aimed at areas where customers are required by local or national legislation to improve NOx emission levels beyond the current 25 ppmvd guarantee limits offered by most manufacturers without exhaust gas clean up system.

This paper describes the programme the company undertook to validate and prove, commercially, the sub 10 ppmvd NOx emissions on the Tempest.

LEAN PREMIX COMBUSTION

The company has successfully used lean premix combustion for the past 8 years as the preferred method of controlling NOx emissions from the company's range of gas turbines.

The combustion system as illustrated in Figure 1 shows the main components in the dual fuel version of the combustor.

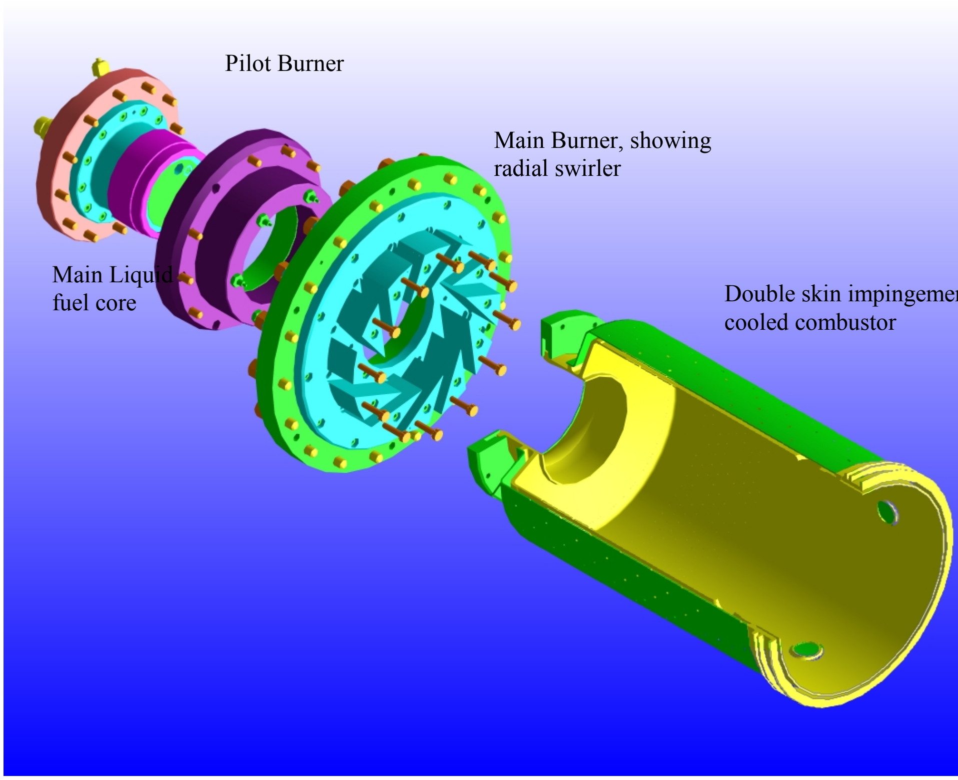

Figure 1: Lean Premix Dual Fuel Combustion system

The main fuel is injected into the radial swirler giving good mixing within the swirler slots and pre-chamber. The high swirl also has the effect of providing a way of stabilising the flame. A lower flame temperature is achieved by mixing a high percentage of the available air with the fuel in the swirler. The combustor is cooled by means of an optimised double skinned impingement cooled liner. A pilot burner is used for light up, pull away and flame stability at conditions that are leaner than the extinction point for a more premixed flame.

The main advantage of the lean premix combustion system is the fact that it is a simple robust economic system that has a proven track record.

Its main disadvantage is that there is a potential flame stability and dynamics issues as the system has to operate in a more premixed state to achieve the Ultra Low Emissions.

TEMPEST SUB 10 PPMVD VALIDATION

The Tempest gas turbine is a single shaft configuration, which was initially introduced with a 7.7 MWe rating. The engine is aimed at the electrical power generation market with the fleet consisting of 70 engines by mid 2003, more than 50 of these configured as DLE. During 1999 a Tempest engine with a number of product enhancements was released. The enhanced performance engine included compressor blades as introduced in the Cyclone, along with improved cooling of the hot turbine blades, and compressor VGV optimisation has given a 1% improvement in overall engine efficiency. This efficiency improvement has allowed the 7.7 MWe engine rating to be achieved at a lower operating temperature and has resulted in a significant change in the emissions characteristic.

Initial testing on the performance improved engine using a dual fuel configuration combustion system showed the NOx levels around 7 ppmvd lower than the original configuration of engine for the same pilot split, Figure 2. This difference was consistently measured on all subsequent performance improved engines.

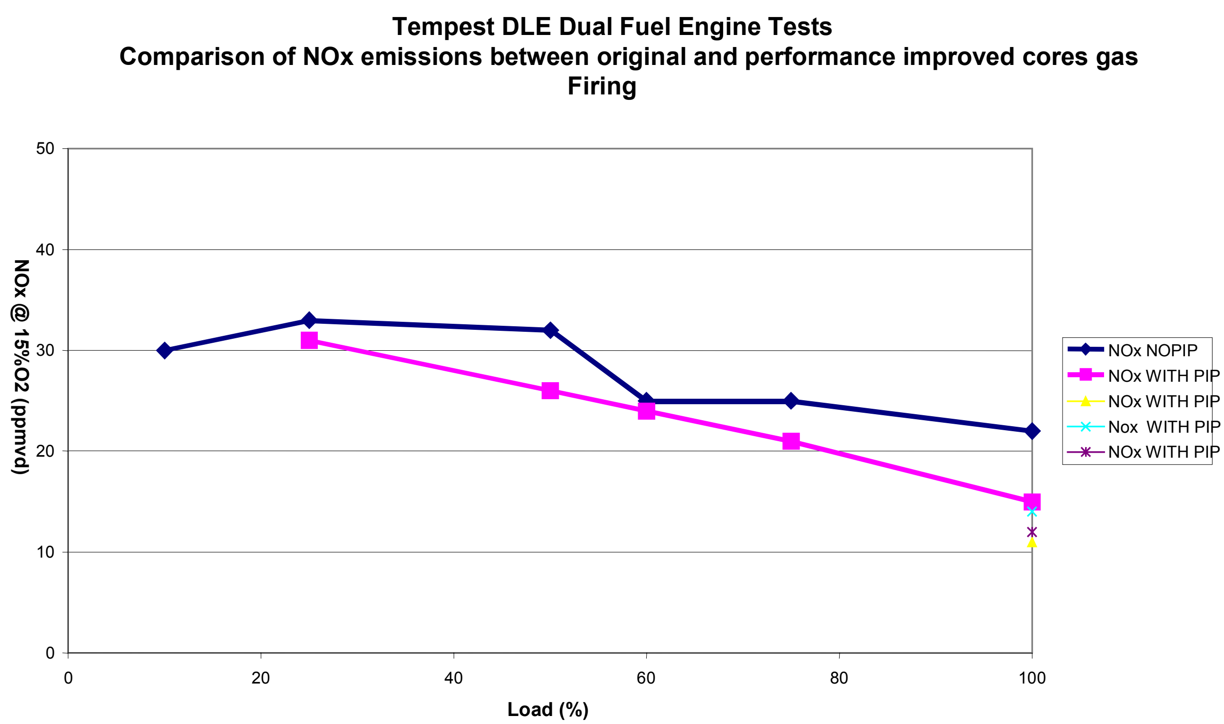

Figure 2: Comparison of NOx emissions performance between the two standards of engine configuration firing gas fuel

The main reason for this drop in NOx levels can be attributed to the lowering of combustor exit temperature by 25 degrees, with the flame temperature still in excess of 1750 K. With the original engine, NOx reduction was limited by the fact that the pilot split could only be reduced to a certain level before the pilot burner tip temperatures became excessive.

With the performance improved engine several cores were tested with a combination of dual fuel and gas only configurations with the pilot split being reduced to levels lower than those typically used on the early engine configuration. With the pilot split reduced to 5% it was possible to achieve NOx levels less than 10 ppmvd on gas fuel, Figure 3. Importantly this was achieved with no impact on combustion dynamics and still retaining CO levels typically 1 ppmvd.

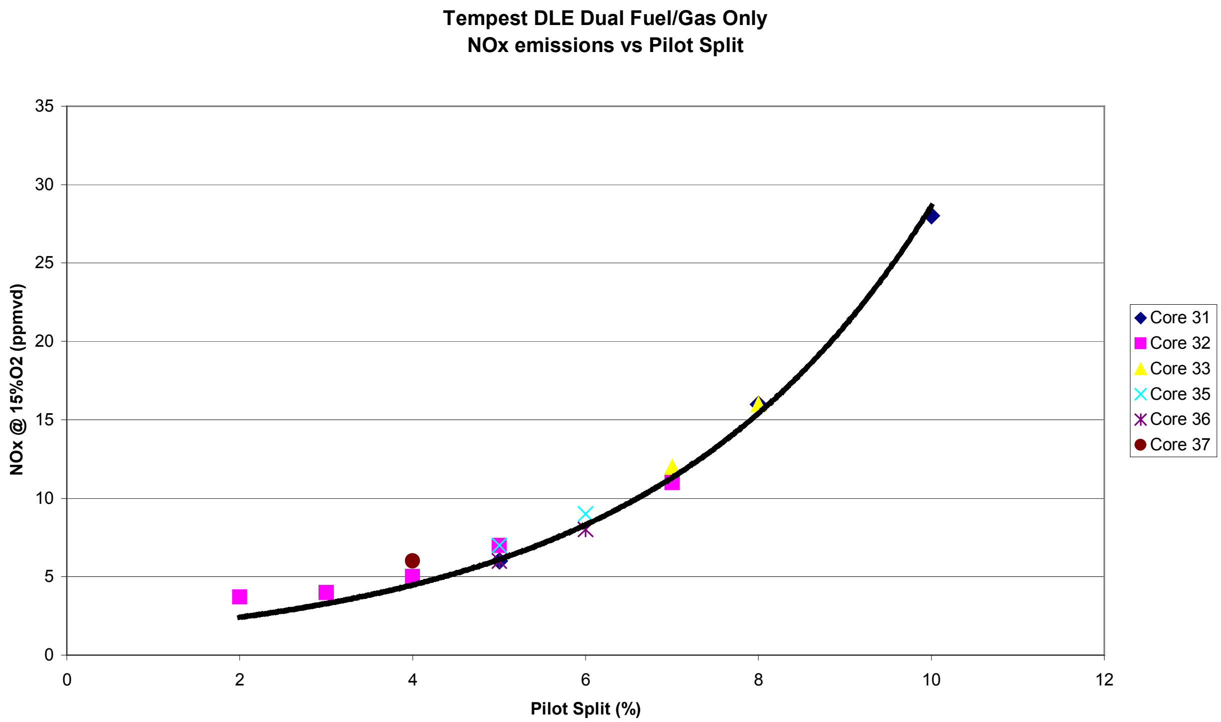

Figure 3:
NOx emissions performance at full load with varying pilot flow

Further reduction of the pilot split to levels around 3% also gave consistently achievable results of less than 5 ppmvd again with no combustion dynamics and CO levels of less than 1 ppmvd.

Over the range of performance improved cores used to map the pilot spit against NOx variation, a boundary point for sub 10 ppmvd NOx, was highlighted. By using the turbine entry temperature (TET) of the original non performance improved 7.7MWe Tempest as a baseline (i.e. TET Ratio = 1) it was not possible to reduce the pilot split low enough to achieve a NOx signature below 10 ppmvd without introducing a low frequency dynamics tone. This occurred at a TET Ratio of around 0.979. When this dynamics tone occurred the NOx levels increased and became very unstable.

Figure 4 shows the line, which was mapped out showing the minimum pilot split achievable at a particular TET Ratio. This line gives the optimum emissions performance of the current combustor configuration. This line is applicable to both the gas only and dual fuel combustor. It should be noted that at this stage the minimum pilot split tested was around 3%. No attempt was made to run with zero pilot.

As can be seen from Figure 4 when operating the performance improved engine at the 7.7MWe rating the TET ratio of 0.983 is very close to the sub 10 ppmvd boundary. As this ratio is a design value, and with several of the cores tested being more efficient than design, this ratio was in fact sometimes slightly lower than the 0.983 for the required power output. Because of this the sub10 ppmvd operation is only offered on the 7.9MWe re-rated engine.

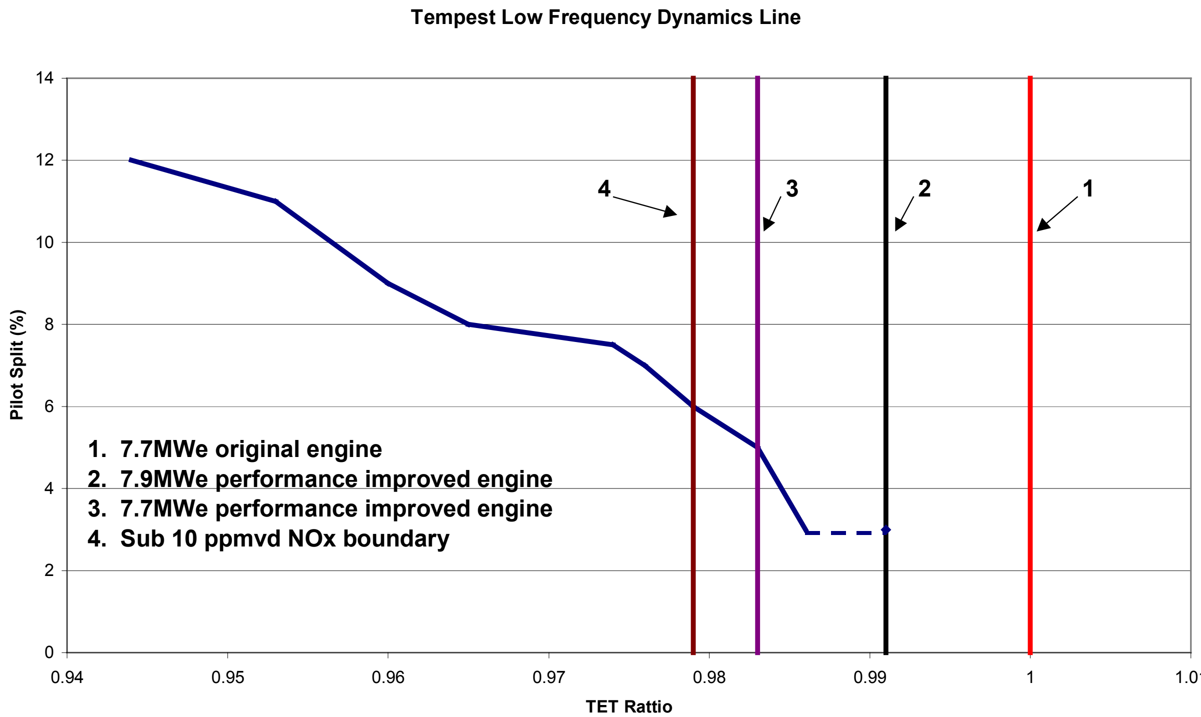

Figure 4: Sub 10ppmvd boundary point on current combustor configuration

SITE EXPERIENCE

Figure 5 illustrates emissions data recorded at the lead Tempest dual fuel DLE site following a series of on site tests to optimise the pilot split schedule and the engine performance. The engine has operated since the middle of June 2001 with NOx levels consistently below 10 ppmvd level accompanied by CO levels of less than 2 ppmvd and no combustion dynamics.

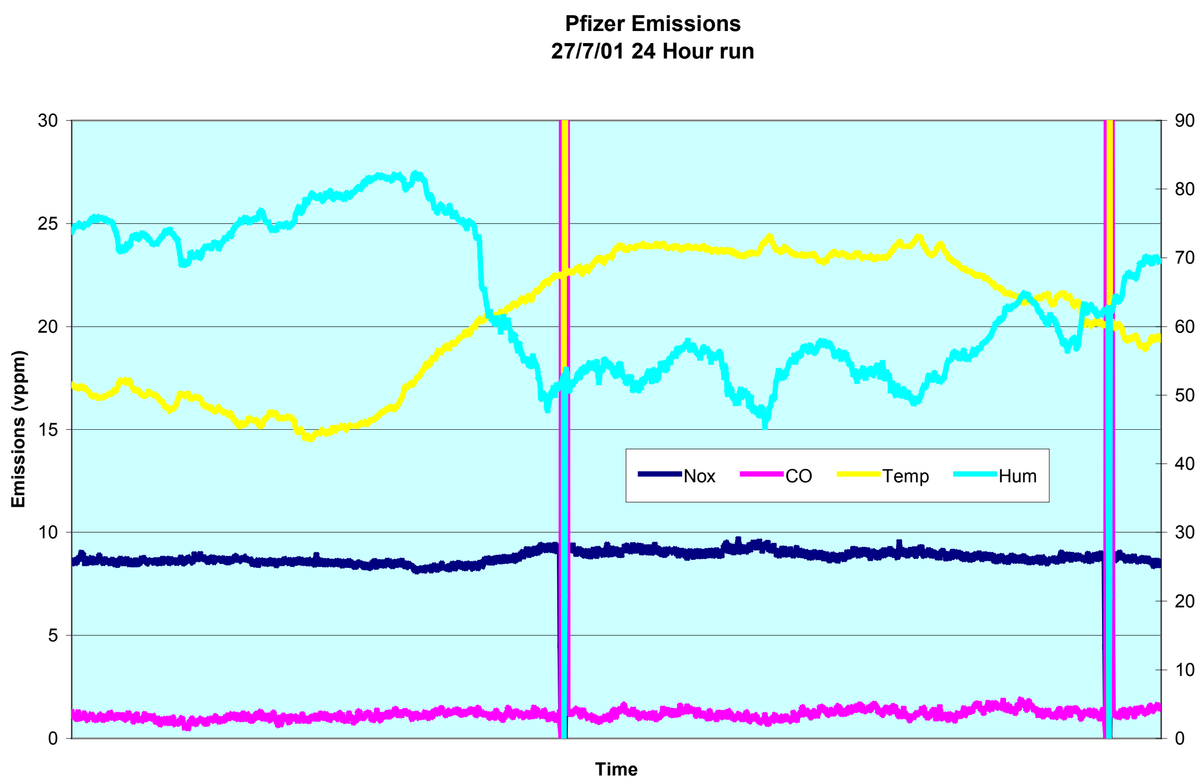

Figure 5: Lead Dual Fuel DLE engine emissions data over 24 hour period

A continuous emissions monitoring unit was installed on this site and provided data over about a 12 month period. In that time the NOx signature remained consistent at less than 10ppm NOx, as can be see in the chart, Figures 6A & 6B. This application was for a dual fuel configuration and periods of distillate operation were completed, typically during times when the gas fuel supply was interrupted. The level of exhaust emissions were very good achieving 20-24ppm NOx during full load operation (against a guarantee of 50ppmvd corrected to 15% O2) and below 2ppmvd CO emissions, figure 6C.

More recently, exhaust emissions measurements on a Tempest were undertaken by a US emissions company, ENSR,at the company's Industrial Gas Turbine packaging facility in Houston. This confirmed a sub 10ppm signature for the turbine when operating on gas fuel.

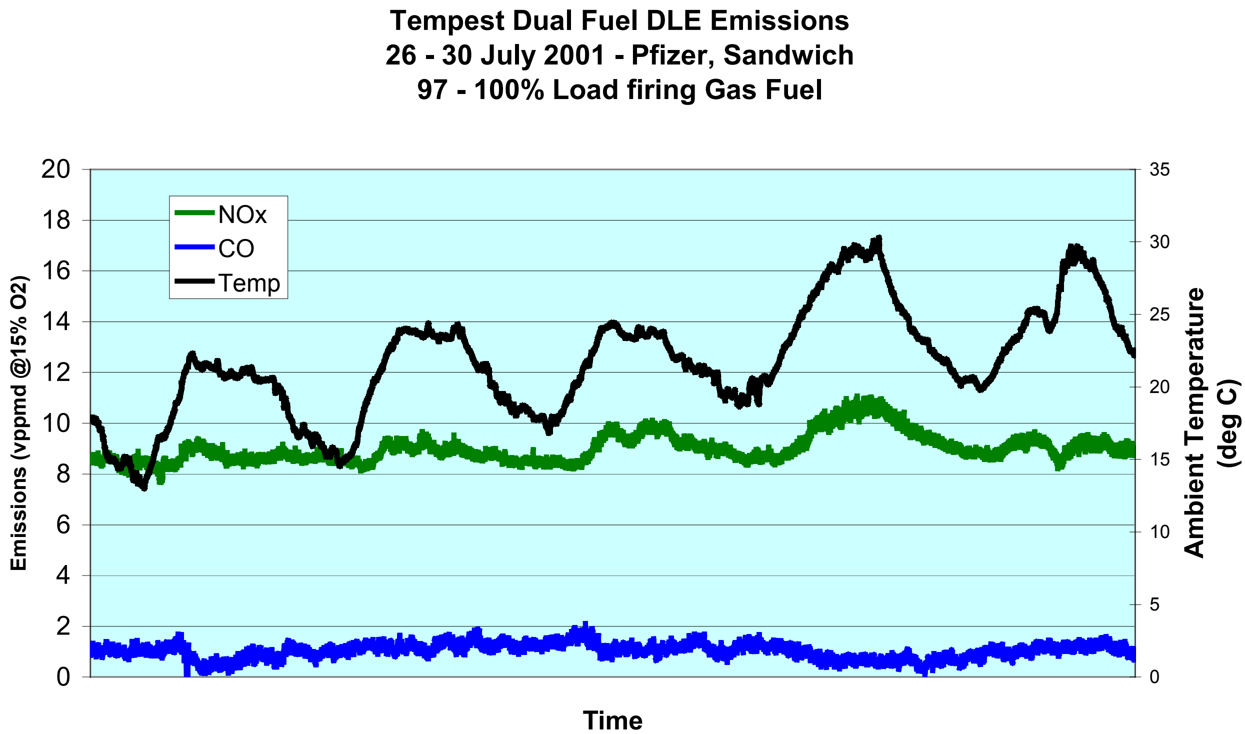

Figure 6A: Emissions Data July 2001

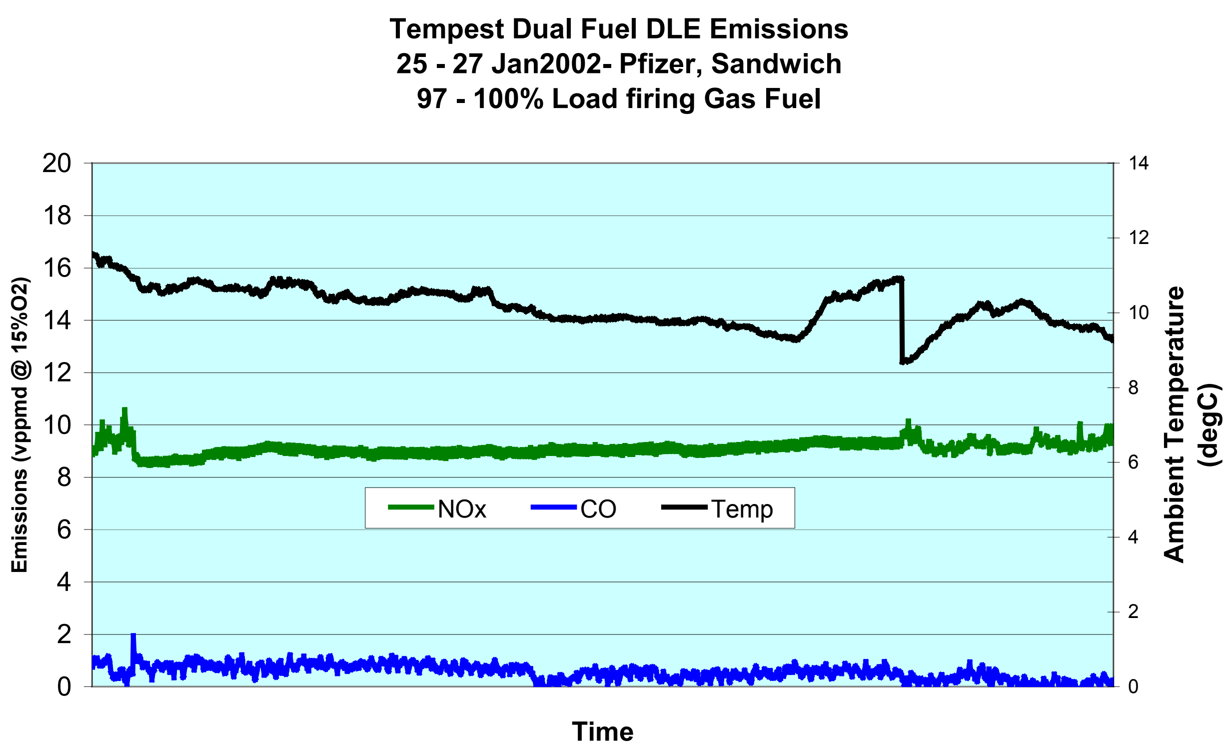

Figure 6B: Emissions Data Jan 2002

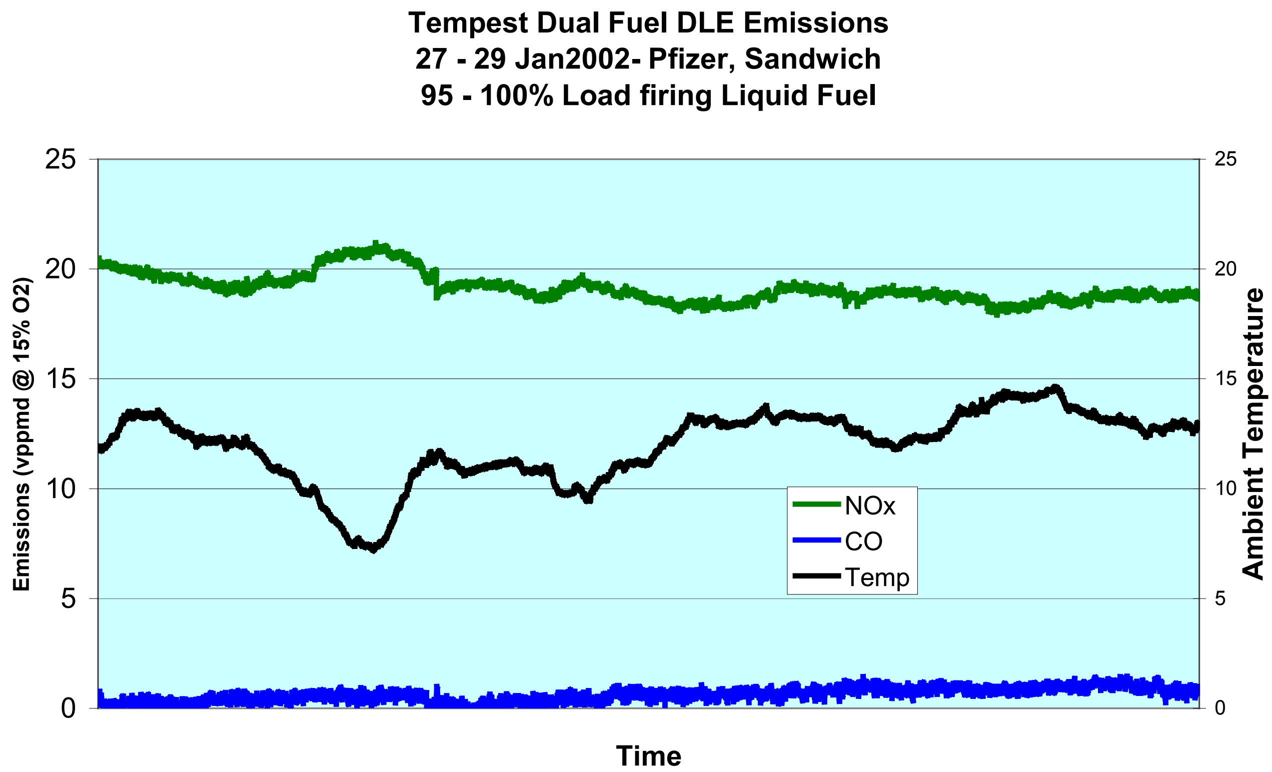

Figure 6C: Distillate Fuel Emissions Jan 2002

CYCLONE EXPERIENCE

Whilst this paper concentrates on the Tempest gas turbine, it is worth pointing out that the Cyclone turbine has a similar emissions profile.

The data shown in Figure 7 has been collected from production pass of tests for customer engines leaving Lincoln. As can be seen depending on the pilot fuel setting the Cyclone consistently produces between 3 and 10 ppmvd NOx. The first commercial sites have now been validated by independent emissions measurements at operating between 6 and 8 ppmvd NOx.

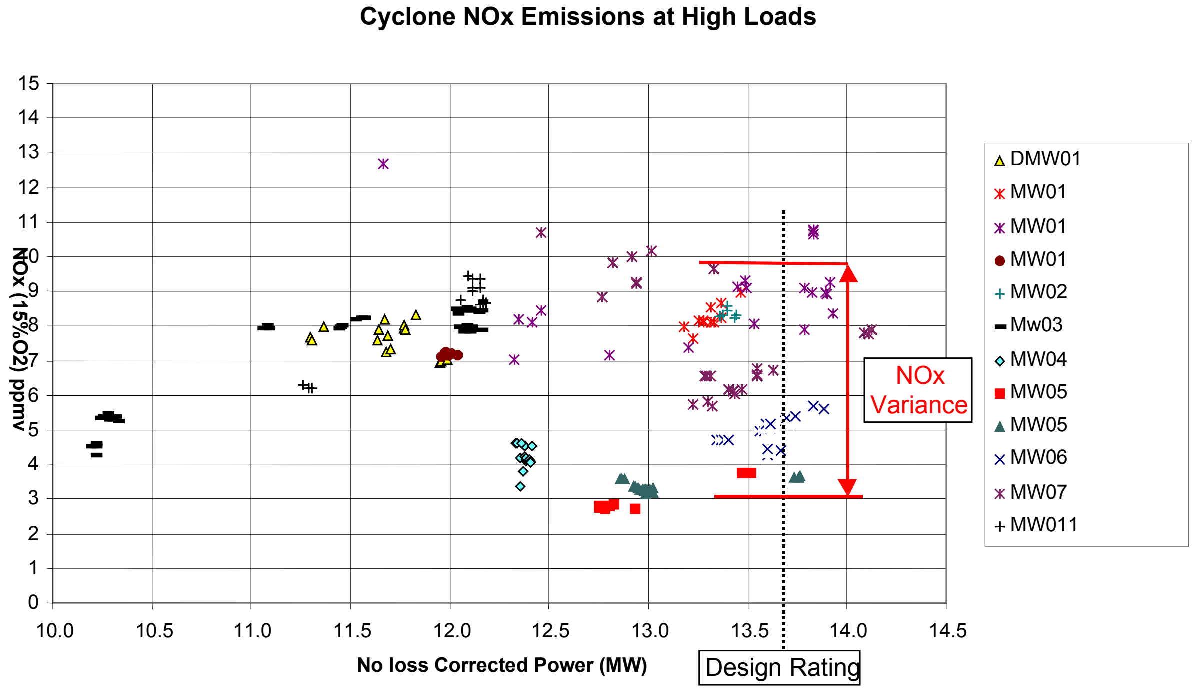

Figure 7: NOx as a function of Power for Cyclone production cores

FUTURE DEVELOPMENTS

The next stage in the development of the Tempest's premix combustion system is to investigate the relationship between the flame temperature and the low frequency dynamics which define the sub 10 ppmvd boundary point.

High pressure combustion rig testing is planned with the view to making modifications to the combustor aerodynamics. This should enable both an improvement in <10 ppmvd turndown and allowing further reduction in pilot fuel schedule, even to zero pilot, in order to find the maximum NOx reduction possible with this combustion configuration.

SUMMARY

This work presented in this paper has shown that simple and a robust dual fuel lean premix combustion systems has been developed producing sub 10 ppmvd NOx. This has been backed up not only by rig and development engine testing, but also by full production engine demonstration in a commercial environment and by independent verification. In addition low NOx and CO emissions were achieved when operating on distillate fuel for a dual fuel configuration.

NOx emissions levels of 3 ppm at base load conditions have been demonstrated using standard production cores.

Future combustion programmes will expand on this to achieve sub 5 ppm NOx capability.

These results are significant in terms of offering a flexible combustion system at a reasonable cost but giving ultra low emissions performance.