GAS FUEL FLEXIBILITY IN A DRY LOW EMISSIONS COMBUSTION SYSTEM

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ABSTRACT

Stricter emissions legislation over the past 15 years has led to the development of Dry Low Emissions (DLE) combustion systems on gas turbines to minimise the emissions to atmosphere of nitrogen oxides (NOx), carbon monoxide (CO) and unburned hydrocarbons (UHC). These DLE combustion systems have gained considerable experience on premium fuels such as pipeline quality natural gas and No. 2 diesel. However, concern over Greenhouse Gas emissions and rising prices of premium quality gas fuels has led to renewed interest in the use of poorer quality gases for power generation. These gases, ranging from high calorific value wellhead gases through to medium and low calorific value natural gases, can all be used as fuels for gas turbines in power generation or mechanical drive applications. In addition, pyrolysis and gasification technologies, which produce hydrogen-rich combustible gases from biomass and wastes, are being developed for ‘green’ power generation purposes, using gas turbines as the heart of the power plant.

The challenge that has been set manufacturers by the market place is to burn a much wider range of gaseous fuels while still achieving low emissions levels. Demag Delaval Industrial Turbomachinery Ltd.’s ‘G30’ DLE combustion system, fitted on the range of small industrial gas turbines, has now amassed more than 2 million operating hours on premium fuels. This paper introduces the design concept and experience gained by the ‘G30’ system, including its development into an Ultra-Low Emissions (ULE) system on premium fuels, and continues by looking at the potential fuel flexibility of this combustion system design to encompass poor quality and synthetically produced gases.

INTRODUCTION

There is a general recognition that the combustion of fossil fuels for power generation has a negative impact on the environment. Fuel switching from coal and oil to gas has helped reduce Greenhouse Gas (GHG) and sulfur emissions, but there is still a commitment from gas turbine manufacturers and legislative pressures to further reduce the impact of gas turbine operation on the environment. Since the early eighties, much work has been done to reduce the production of
oxides of nitrogen (NOx), due to the role of NOx in ozone depletion and the creation of photochemical smog. Increasingly in recent years, legislators have begun focussing on reducing emissions of carbon monoxide and unburned hydrocarbons (UHCs). The challenge was set to gas turbine manufacturers to produce a combustion system that not only provided low NOx, CO and UHC emissions, but also one that had minimum impact on gas turbine operation and component life. In addition it would be required to operate with low emissions on both gaseous and liquid fuels, and have minimal effect on project economics.

Early methods of NOx control were based on the use of water or steam injection. While these methods successfully reduced NOx to levels of around 42ppmV, and could be used on a wide variety of fuels, they do little to control CO emissions, and the cost of providing water and steam of suitable quality for acceptance in the gas turbine could prove considerable. Legislators were also starting to seek lower NOx emissions, typically below 25ppmV, which could not be achieved using these techniques.

The majority of gas turbine manufacturers looked towards Dry Low Emission (DLE) combustion systems to comply with legislative demands. Several DLE concepts have been investigated for gas turbine operation, most notably lean pre-mixed technology and catalytic combustion. To date, only lean pre-mixed combustion concepts have a proven commercial track record with many millions of operating hours having been attained on gaseous fuels. More recently the ability to burn liquid fuels with low emissions using lean pre-mix technology has also been commercially proven. The next goals must be to expand the range of acceptable fuels as the market seeks to make use of cheaper, locally available or waste gases, which differ considerably in composition and calorific value from pipeline quality natural gas.

**THE ‘G30’ DRY LOW EMISSIONS COMBUSTION SYSTEM**

The philosophy behind lean pre-mixed combustion is simple – the fuel and air are pre-mixed prior to the flame in order to give a homogenous reaction temperature below the temperatures at which NOx production rates are high. However, the realization of a simple reliable combustor,
which still meets all its performance parameters, demands a complete redesign of the gas turbine combustor. Pre-mixed combustion systems are comprised of four main features:

- Fuel/Air injection device
- Stability Device
- Pre-mixing zone
- Flame stabilization zone

The fuel and air injection device needs to distribute the fuel into the air as evenly as possible. Most devices rely on multiple fuel injection points distributed around the incoming combustor air. The stabilization device has to supply a strong low velocity stabilization zone, which is typically achieved through swirling re-circulating flows. The pre-mixing zone provides additional time to ensure as good mixing as possible. The flame stabilization zone is the location where the flame is encouraged to exist, usually designated by area expansion. The aim is to achieve the maximum level of pre-mixing in the shortest possible time before flame stabilization, while avoiding the main combustion issues of pre-ignition or flashback, dynamic pressure fluctuation and flameout during transients. Long-term durable operation is only possible when the correct balance between all these factors is achieved. As the combustor primary zone is running leaner than a diffusion flame device, the margin between full-load operating condition and flame extinction is relatively small. For this reason, almost all pre-mix devices have at least two fuel supplies, one supplying the main pre-mixed fuel, the other supplying a portion of pilot fuel used for creating a diffusion-type flame for stability at off-design conditions.

Even greater technical challenges exist with trying to burn liquid fuels in a controlled manner. Again the design of the multiple fuel injection points, which allow the liquid to vaporize and pre-mix with the air before burning, are of utmost importance.

The DLE system developed by Demag Delaval Industrial Turbomachinery Ltd. (DDIT Ltd., also formerly known as European Gas Turbines and ALSTOM) for its Typhoon, Tornado, Tempest and Cyclone gas turbines is a simple design with no moving parts, based on a lean pre-mixed design. Known as the ‘G30’ system, it was first introduced commercially for natural gas fuels on a Typhoon gas turbine installed in a cogeneration plant in The Netherlands in March 1995. The
first dual fuel DLE units, capable of low emissions operation on both natural gas and diesel fuels, were installed in the UK in June 1998. The gas turbines all use the can – annular combustor concept, with either 6 or 8 combustion cans arranged around the engine and externally accessible.

![Figure 1: The ‘G30’ DLE Family](image)

The ‘G30’ premix burner design consists of twelve radial inlet slots configured to allow a predetermined amount of air into the main head of the combustor can. The air swirler inlet vanes are of the same dimensions and are positioned in order to create a swirling vortex. A considerable amount of analytical design (including CFD) and test evaluation was carried out in order to determine the correct number of swirler vanes, their thickness, the size of the air passage way and to ensure elimination of any recirculatory zones or wakes from the trailing edge of the ‘cheese slice’ shapes. Substantial testing of this design was carried out in order to optimize fuel placement while avoiding undesirable factors like fuel impingement on combustor walls and burner slot faces. The optimization of these parameters led to a design that is inherently safe against flashback, and since the main fuel supply is introduced into these mixing slots with their high velocities, excellent homogenous air fuel mixtures exist at the operating condition. Production of a cone shaped flame which is anchored onto the pilot face therefore produces a simple while robust flame. Anchoring of the flame on the pilot face allows for acceptable levels of combustion noise – low levels of combustion noise when operating on either gas or liquid fuel.
produce an advantageous environment for combustion hardware life and lead to long term durable turbine usage.

The dual fuel DLE burner consists of a two stream gas and two stream liquid fuel system, both systems being operated by independently controlled electrically actuated valves. The pre-mixed main fuel flame is supported during starting and transients with a pilot (gas) or primary (liquid) fuel input, which can be separately configured at full load for various ambient temperatures or local emission requirements. Cross light tubes have been removed from the DLE combustion cans in order to limit emissions, giving rise to the requirement for individual igniters to be mounted in the each pilot body, which emerges onto the pilot face. Purging systems assist in keeping non-operational pilot fuel injector ports free from blockage. The main fuel injector ports, due to their position within the burner swirler, do not require any purging. A single air-assisted primary nozzle is used in each combustor to initiate liquid fuel ignition and to support the main pre-mixed fuel during running.

Since the introduction of the G30 DLE system in 1995, 225 units have now been sold with this combustion system. Over 2.5 million hours operating experience has been gained in a wide variety of Industrial Power Generation and Oil & Gas applications, both onshore and offshore, and the components are meeting their design life. Such confidence has been gained in the durability and operability of the G30 system that the latest DDIT Ltd. gas turbine, the 13MW-class Cyclone gas turbine, is supplied with DLE as standard. The standard emission guarantees,
for the DDIT Ltd. gas turbine range for power generation applications when operating at full load on premium fuels, are given in Table 1 below.

<table>
<thead>
<tr>
<th>Emissions Guarantees(^1)</th>
<th>NOx</th>
<th>CO</th>
<th>UHC</th>
<th>Smoke</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>25</td>
<td>25</td>
<td>10</td>
<td>Bacharach 1</td>
</tr>
<tr>
<td>Liquid Fuel</td>
<td>50(^2)</td>
<td>50</td>
<td>10</td>
<td>Bacharach 2</td>
</tr>
</tbody>
</table>

1. Emissions values stated are at full load in ppmV @ 15% O\(_2\), dry basis
2. Guarantees for the Cyclone and Tornado gas turbines on liquid fuel currently stand at 60ppmV

**Table 1: Standard Emissions Guarantees for sub-15MW Gas Turbines in Power Generation applications**

**ULTRA LOW EMISSIONS COMBUSTION**

While the emissions values given in Table 1 comfortably meet the requirements of most legislation, there are locations in which legislation requires still lower emissions. This has led to the development of Ultra Low Emissions (ULE) technologies, where the aim is to achieve as a minimum single digit NOx emissions, but is more commonly used to describe sub-5 ppmV, or even sub-2 ppmV, NOx emissions.

Current commercially available technologies to reduce NOx emissions to these levels are based on post-combustion clean-up technologies. While this enables ultra-low NOx emissions to be achieved, it adds to both the capital and operating costs of the plant. These additional costs can be very significant for Distributed Generation or Cogeneration applications.

Considerable work has been carried out on catalytic combustion technologies. This route would seem to offer a number of advantages over post-combustion clean-up, but before this technology can be employed on a widescale, several issues need to be addressed. These include the ability of the catalyst to operate at the high Turbine Inlet Temperatures required for higher power rating, high efficiency gas turbines and the ability to work on a wide range of fuels – an important
consideration in today’s deregulated energy markets where natural gas prices fluctuate and fuel
availability dictates that back-up fuels need to be used at certain times.

DDIT Ltd. has decided to concentrate on building on the DLE experience already gained to
achieve ultra-low emissions. The concept being pursued is to achieve ultra-low emissions without
degradating turbine performance or component life, while having minimal impact on unit capital
and operating costs. However, as the system has to operate in a more pre-mixed state to achieve
ULE levels, there are potential flame stability and combustor dynamics issues.

Work carried out to date on improving the operating characteristics of the G30 combustion
system has already led to Tempest and Cyclone gas turbines consistently achieving single digit
NOx emissions with no detriment to performance, not only on test beds but also under
commercial operating conditions. A dual fuel DLE Tempest unit installed in a Cogeneration
application in the UK was installed with Continuous Emissions Monitoring system and provided
data over a twelve month period. During this time, NOx emissions on natural gas fuel remained
consistently less than 10 ppmV while liquid fuel NOx emissions were comfortably within the
guarantee level of 50 ppmV. These measurements were further confirmed by measurements taken
by an independent consultant during full package works tests of a Tempest unit at the Houston
packaging facility. During factory tests, Cyclone units have been consistently achieving levels
below 10ppmV NOx on gas fuel.

As a consequence of these results, DDIT Ltd. offers NOx guarantees of 10ppmV on the Tempest
and Cyclone gas turbines for specific applications, typically in North America. It is the intention
to build on this initial achievement in reaching ULE levels, with work ongoing to both expand
the applicable load range and to lower the NOx emission levels on natural gas fuel to 5 ppmV,
enabling the company to offer a more commercially acceptable dual fuel combustion system with
ULE performance.
EXPANDING THE FUEL RANGE

For small industrial gas turbines, pipeline quality gases are typically defined as those which fall within a Temperature Corrected Wobbe Index (TCWI) range between 37 and 49MJ/Nm³. As environmental concerns grow over the emissions of carbon dioxide to atmosphere, legislation is starting to be put in place to limit flaring of waste gases, such as associated gases on oilfields and landfill gas. Instead of flaring, many companies are looking to use these waste gases as a fuel source for power generation or cogeneration applications, expanding the fuel TCWI range which a gas turbine is required to burn. Once this occurs, a new set of regulations comes into play regarding atmospheric emissions from the power plant itself, often with strict emission limits in place for NOx, CO and UHCs.

Work has been undertaken to expand the range of fuels that can be burned in the G30 DLE system. A gas mixing plant has been installed at the Combustion Development facility in Lincoln to enable tests on simulated gas mixtures to be carried out on the High Pressure Test Rig (HPAF) facility, which simulates actual engine operating conditions for a single G30 combustor.
Mixtures of methane and inert gases with Temperature Corrected Wobbe Indices between 15MJ/Nm³ and 37MJ/Nm³, referred to as Medium Calorific Value (MCV) gases, have been successfully tested in slightly modified G30 combustion systems, with exhaust emissions equivalent to, or in some cases better than, the emissions profile achieved on pipeline quality natural gas. Tests have indicated that the widened fuel range will not have an adverse affect on combustor dynamics or component life. This new capability is now being offered on the Typhoon and Cyclone gas turbines, and is particularly attractive for applications involving, for example, depleted gas wells where increasing levels of CO₂ may be present in the gas.

Some work has been done using the HPAF on the G30 system for the Typhoon gas turbine looking at High Calorific Value (HCV) fuel gases (those greater than 49MJ/Nm³). Only small modifications were made to the G30 combustion system and it proved possible to operate on gas fuels with a TCWI up to 66MJ/Nm³ (gaseous propane).

SYNTHETIC GASES

Legislation in many countries is now encouraging the generation of electricity from renewable sources. While well-proven, in today’s liberalized energy markets wind and hydro power are deemed unpredictable and because of this may be penalized by the electricity trading mechanisms in place. Therefore there is growing interest in using biomass, either in the form of ‘clean’ biomass such as energy crops or forestry residues, or derived from Municipal Solid Waste (MSW). While conventional biomass combustion and waste incineration technologies are well-established, the financial benefits being introduced for producers of renewable electricity are causing developers to look for more efficient means of electricity generation. For this reason there is growing interest in using gasification and pyrolysis technologies to produce a fuel gas for small Combined Cycle Gas Turbine schemes. This potential new market, with the wide variation in Calorific Value (anything between 3.5 and 35 MJ/Nm³) and composition of the synthetic gases produced (with hydrogen and carbon monoxide being the main combustible constituents), has created a considerable challenge for gas turbine manufacturers and combustion engineers in particular. Although there are many different types of gasifier, two particular gasification
technology groups – pyrolysis and steam reforming systems – can produce a syngas with a calorific value over 15MJ/Nm³ which would be classed as MCV fuels.

At present it is unclear for ‘clean’ biomass sources used to fuel Biomass Integrated Gasification Combined Cycle (BIGCC) schemes whether emissions limits will be based on emissions from conventional combustion technology plant or on natural gas-fuelled gas turbines. However, for MSW and other waste-derived fuels, the European Waste Incineration Directive (WID) makes it clear that a BIGCC scheme will be classed as an incinerator and will have to meet the same emission limits as an incineration plant. While ‘wet’ emission control technologies would enable compliance with NOx limits, CO emission limits for incineration plant are quite low and could not be achieved by a gas turbine using water or steam injection.

To try to ensure compliance with legislation such as the WID without needing to resort to post-combustion clean-up technology, tests have been carried out on the G30 combustion system to investigate the effects of using MCV containing significant quantities of hydrogen and carbon monoxide on a DLE combustion system. Despite the higher flame speed of hydrogen and hydrogen/carbon monoxide mixtures compared to methane, the G30 combustor has proven extremely flexible in its ability to operate on a wide range of fuels with very little modification required, even for those syngases containing quantities of around 15% hydrogen and 20% carbon monoxide by volume. This mixture is typical of some pyrolysis kilns already proven on MSW-derived feedstocks, and rig tests carried out on a Typhoon combustor indicate that exhaust emissions from the gas turbine will be within the limits stipulated by the WID. The Typhoon gas turbine will become commercially available for suitable MCV syngas mixtures in 2004, while this capability on the Cyclone gas turbine will follow in 2005.

The laminar flame speed of hydrogen and methane mixtures varies proportional to the square of the hydrogen content and is further increased by the presence of carbon monoxide. This considerably increases the risk of flashback. Combustion development work is continuing to design a G30 DLE combustion system capable of operating on gases with higher hydrogen and/or carbon monoxide concentrations.
POTENTIAL FUTURE DEVELOPMENTS

With new emissions legislation being introduced worldwide, and manufacturers being requested to operate gas turbines on a greater variety of gaseous fuels, Demag Delaval Industrial Turbomachinery Ltd. are investing heavily in Combustion Technology Development programmes. Programmes are in place to improve existing, operational designs while also developing new advanced solutions based on the G30 concept. Among the programmes in place are ones to improve turndown capability while maintaining exhaust emission guarantees at full-load levels, and to develop ULE combustion technology which consistently achieves sub-5 ppmV NOx emissions. Some work has also started looking at the possibility of using a G30 variant to operate on Low Calorific Value fuels, such as blast furnace gas or those gases produced from biomass or coal by air-blown gasification processes. The ultimate aim is to be able to burn a wide variety of gaseous fuels in a DLE-based combustor (as indicated by the yellow bars in Figure 4 below) including those currently acceptable only in a conventional diffusion flame combustor (the red bars in Figure 4 below).

Figure 4: Targeted DLE gas fuel capability chart
CONCLUSIONS

The operational experience already gained by the G30 DLE combustion system has shown it to be a robust, reliable system generating low emissions on both pipeline quality natural gas and premium liquid fuels.

The tests already carried out have demonstrated that the G30 concept appears to be extremely flexible with regard to fuel calorific value and composition, with the ability to achieve emission levels similar to, or better than, natural gas over this wide range of gaseous fuels. The modifications required to achieve this increased fuel range would appear to have negligible impact on performance and durability, while having minimum impact on capital and maintenance costs.

The G30 combustion system has provided a firm foundation on which to build, with further work planned to expand still further the range of acceptable gaseous fuels and improve the operability of gas turbines equipped with such a combustion system. Successful completion of the development and testing of this combustion technology will enable Demag Delaval Industrial Turbomachinery Ltd. to offer a DLE combustion solution for a very wide range of naturally occurring and synthetically produced gas fuels, while helping to assist in the development of the market for clean, efficient power generation using waste gases and biomass or MSW-derived fuels.

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