Testing time for FlameSheet™

James Varley reports from DLR (German Aerospace Centre), Cologne, where PSM’s FlameSheet™ combustor technology recently completed a test campaign at full scale on a high pressure rig.

Recent FlameSheet™ test campaigns at DLR have focused on design concepts for liquid fuels, further improvements in turndown and proving of flameholding prevention capabilities (particularly when using “exotic” fuels that may be prone to flashback and autoignition).

PSM, now part of Ansaldo Energia, says the DLR facilities offer test conditions “equivalent to those used by the OEMs”. The test rig used for the FlameSheet™ combustor tests provides full F class baseload operating conditions, with air flow up to 27 kg/s, pressure up to 24 bar, inlet air temperature up to 920K, exhaust temperature up to 1650K, with access to a wide range of fuels.

Overall rig control, including supply of a wide range of fuels (both gas and liquid), as well as air, at the required conditions – with the ability to rapidly change fuel composition – is the responsibility of DLR, while extensive instrumentation and dozens of screens enable PSM to control test boundary conditions, hardware integrity, emissions and combustion dynamics.

Side by side performance tests on the DLR rig have enabled the FlameSheet™ combustor to be benchmarked against incumbent OEM burner technologies, including 7F DLN2.6 and W501F DLN.

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Turbine technology

Among the key benefits envisaged for the FlameSheet™ gas turbine combustor are improved fuel flexibility, lower emissions and increased turndown capabilities, including a reduced low load “HRSG protection mode”, with low load firing curve, to “optimise emissions and HRSG durability”.

FlameSheet™ is designed as a replacement for combustors in a wide range of gas turbine types (including GE (6F, 7E, 7F, 9E, 9F), Siemens/Mitsubishi (501F, 501G, 701F, 701G) and Siemens (501B/D).

Headend components (to the left of the illustration below), including the main and pilot injector, are common across various gas turbine platforms, aiding retrofitability. Different transition pieces are used to match each engine type.

The FlameSheet™ combustors at Longview have surpassed well over two years of continuous operation, with the fleet leader clocking up more than 17000 hours. No degradation in turndown or emissions has been recorded, with the hardware expected to achieve the targeted 32000 hour interval.

Examples of DLR rig test results for CO emissions, showing how FlameSheet™ improves turndown performance compared with OEM combustors. Left hand graph is 7F FlameSheet™, right hand graph is 501F FlameSheet™. Typically, the challenge in operating at low turn down levels for extended periods is excessive CO production due to low combustor reaction zone temperatures. The FlameSheet™ “combustor within a combustor” concept helps get around this problem.

The rig tests have demonstrated that FlameSheet™ combustors are able to achieve less than 9 ppm NOx over the entire load range (down to 5 ppm and less with PSM’s AutoTune system), as well as CO below 9 ppm, but with greatly improved turndown capabilities, down to 30% load on standard firing curve in the case of a 7F for example, while still maintaining emissions compliance (largely thanks to the “combustor within a combustor” concept of FlameSheet™).

Using a range of exotic fuels made available at DLR, the inherent fuel flexibility of the FlameSheet™ combustor – with no diluents or steam injection required – has also been amply demonstrated (see table below), including dual fuel capability.

With its robust mixing characteristics the FlameSheet™ combustor is able to tolerate a large (30%) variation in MWI (Modified Wobbe Index, a normalised measure of fuel flexibility). DLR rig tests have confirmed, for example, that low NOx levels are maintained over a wide range of MWI levels.

High premixer exit velocities mean that FlameSheet™ is able to avoid flashback and cope well with highly reactive fuels such as H2, with levels as high as 65% investigated at the DLR rig in F class conditions.

With FlameSheet™ installed on two commercially operating 7F engines, at

<table>
<thead>
<tr>
<th>Comparison of “allowable” fuel constituents (premix operation)</th>
<th>501F DLN</th>
<th>7F DLN 2.6</th>
<th>7F DLN 2.6+</th>
<th>FlameSheet™</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH4 (min)</td>
<td>90%</td>
<td>85%</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>H2 (max)</td>
<td>0%</td>
<td>5%</td>
<td>20%</td>
<td>40%</td>
</tr>
<tr>
<td>C2 (max)</td>
<td>5%</td>
<td>15%</td>
<td>25%</td>
<td>40%</td>
</tr>
<tr>
<td>C3 (max)</td>
<td>2.5%</td>
<td>15%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>C4 – C6 (max)</td>
<td>0.5%</td>
<td>5%</td>
<td>10%</td>
<td></td>
</tr>
</tbody>
</table>

Benefits of FlameSheet™

FlameSheet™ head-end components (left) are common across different gas turbine types

- Pilot Cartridge
- Pilot Injector
- Ignition Case
- Diffuser
- Main Injector

Constituent 501F     7F DLN 2.6 | 7F DLN 2.6+ | FlameSheet™
CH4 (min) 90% 85% 40%     |  |  |  |
H2 (max) 0% 5% 20% 40%     |  |  |  |
C2 (max) 5% 15% 25% 40%    |  |  |  |
C3 (max) 2.5% 15% 20%      |  |  |  |
C4 – C6 (max) 0.5% 5% 10%  |  |  |  |


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Turbine technology

Eastman Chemical’s Longview CHP plant in Texas (see Modern Power Systems, August 2016, p14), it has been possible to correlate rig and engine test results. Lowest achievable NOx levels at baseload recorded on the Longview machines and on the DLR rig matched closely. The FlameSheet™ equipped engines achieved below 5 ppm for all operating points from baseload down to 25% of load, with 20% increased turndown at reduced engine exhaust temperatures.

Illustrating the benefits of rig testing, the DLR installation has been able to demonstrate FlameSheet™’s promising NOx capabilities in “overfire” conditions, ie when turbine inlet temperatures are increased beyond 7FA baseload levels. This has shown, for example, that when FlameSheet™ is overfired by 140°C beyond 7FA baseload turbine inlet temperatures, NOx is maintained at around 12 ppm (at 15% O2), which bodes well for potential applications of FlameSheet™ in H and J class turbines.

Additional confirmation of FlameSheet™ performance in an operating machine has come from Ansaldo Energia’s validation trials of the new GT36 gas turbine in its Birr test power plant in Switzerland.

FlameSheet™ is used in the first of two burner stages employed in the sequential combustion system of the GT36 (see Modern Power Systems, August 2016, pp 12-14).

Example of DLR rig test results for NOx emissions, FlameSheet™ vs OEM combustor (SW501F). FlameSheet™ achieves significantly lower NOx at loads between 100% and about 25%

Right: Basic air and fuel/air-mixture flow scheme for the FlameSheet™ system, which can be seen as basically two combustors in one:

**Pilot stage.** Pilot air passes through the radially outermost circuit to the head end of the combustor where it enters a radial inflow swirler. Fuel is mixed into the air stream through a row of vanes. The fuel/air mixture then enters the pilot stage combustor and the flame is swirl stabilised behind a bluff body on the centreline of the combustor.

**Main stage.** The main stage air flows through a main fuel injector and the fuel-air mixture is then turned 180 degrees and flows into the main stage combustor. As the flow enters the combustor it separates off the combustion liner and forms a strong recirculation region (aerodynamically trapped vortex), which stabilises the flame.
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