

One of the critical factors in gas turbine design today is emissions reduction. In mature markets such as the USA, permits to install new gas turbines include increasingly restrictive emissions requirements across a wide range of ambient temperatures and loads.

To meet these requirements, GE Energy has developed a new combustor for the latest version of its heavy duty GE 10-2 gas turbine, a 12 MW class, double shaft machine used predominantly for mechanical drive applications but also available for power generation. To meet diverse application requirements, the turbine is designed for high operability as well as low emissions.

The new K-1 low emissions combustor ensures the latter, being capable of guaranteeing the following emissions levels at loads ranging from 50% to baseload and at ambient temperatures of -20 °F - 100 °F:

- 15 ppmvd (15% O₂) for NO_x emissions.
- 25 ppmvd (15% O₂) for CO.
- 15 ppm for UHC.

Computational fluid dynamics (CFD) tools were used extensively for studying and designing the overall flame structure of the new combustor, specifically for investigating

the flame front and the stabilisation capabilities of the new pilot system, as well as for predicting emissions levels. Calculated emissions were compared with measurements obtained by rig and engine tests, producing useful design information and validation.

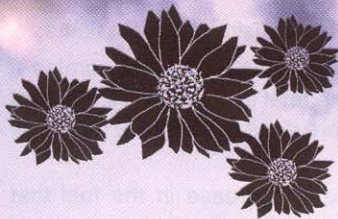
Description of the new combustor

While the new K-1 combustor is geometrically derived from the previous GE 10 model, its flame stabilisation concept has been revised significantly.

As before, the compressor discharge air is introduced into the premixing channel via a variable geometry intake. This device is composed of two cylindrical coaxial parts, each provided with slots. By rotating around the main combustor axis, these parts make the slots overlap by a variable amount, therefore modulating the airflow and providing the turbine with excellent operability and turndown capability.

The main fuel premixes with air and the resulting mixture is introduced into the combustion chamber, generating a flame that is stabilised by a proper amount of pilot fuel.

In the old K 1 combustor (Figure 1), this fuel is injected at the throat and surrounds the main flame over an entire circumference, so that the main flame is stabilised by a



Meeting the emissions challenge

Antonio Andreini and Bruno Facchini, University of Florence, Italy, and Antonio Asti and Gianni Ceccherini, GE Energy, USA, explain how the company's new combustor for its GE 10-2 gas turbine faces up to emissions restrictions.

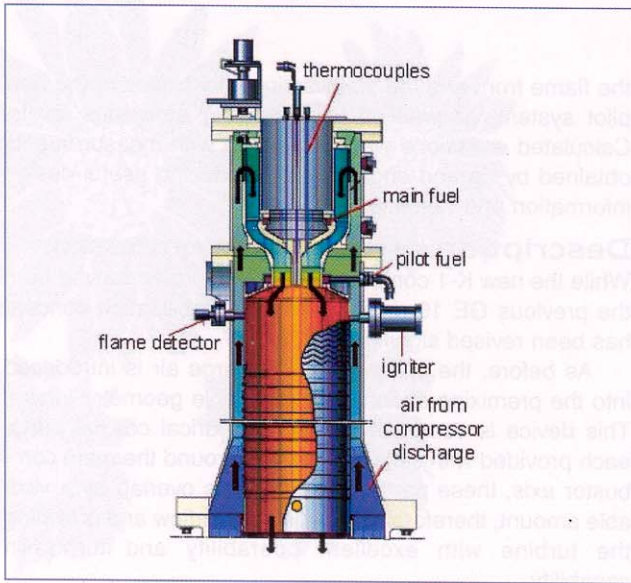


Figure 1. Schematic view of the old K-1 combustor.

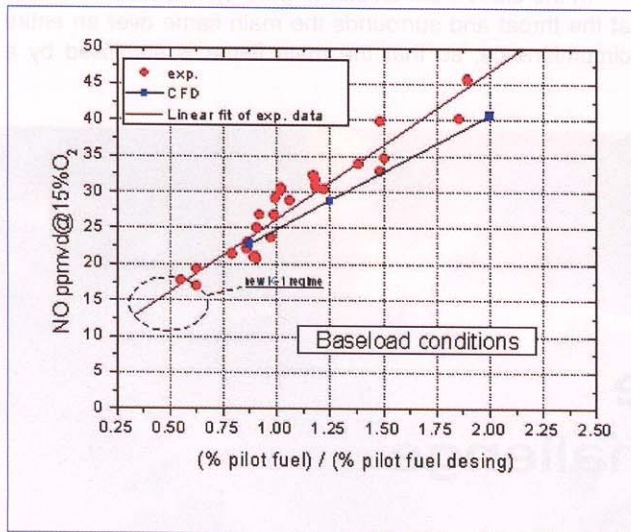


Figure 2. NO emissions of standard K-1 combustor as a function of pilot fuel percentage, normalised with nominal pilot fuel percentage.

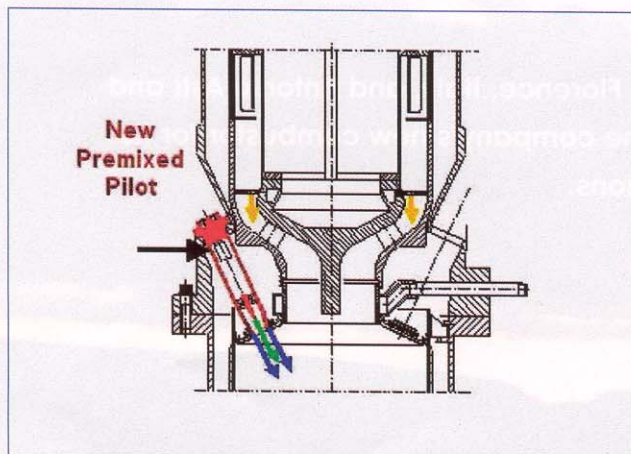


Figure 3. Sketch of the new pilot burners installed on the new K-1 combustor: yellow is main premixed fuel; green is secondary premix fuel; and blue is subpilot fuel.

	T _{amb} (K)	Load	PCD (bar)
Cold	244k	Baseload	17.00
Iso	288k	Baseload	15.75
Hot	311k	Baseload	14.00

diffusive and high temperature pilot flame, where approximately 90% of the total NO_x is generated.

To quantify such dependence of emissions on pilot fuel, Figure 2 displays the trend of NO_x exhaust concentration vs. pilot fuel percentage (red points, experimental data) as measured in the old GE 10 combustor. To reduce emissions from the existing 25 ppmvd at 15% O₂ to the new standard of 15 ppmvd at 15% O₂, it would be necessary to decrease pilot fuel percentage below 0.5 of design pilot fuel percentage, entering an operating region with a high risk of pressure dynamics and lean blowout. This means that the existing combustor would not have been able to achieve that goal, so a different strategy is required.

In fact, the new combustor was conceived with the objective of having a totally different stabilisation for the main flame, changing from a diffusive flame to a premixed pilot flame. This is the key to achieve a relevant reduction of NO_x levels.

Based on both experience and CFD calculations, a new configuration was developed consisting of four premixed burners located on the cap, every 90 degrees. In this geometry, the four premixed flames, converging on the main one, provide the desired stabilising effect. The four new burners, or premixed pilots, are not fully premixed, as they in turn need stabilisation; a small amount of fuel is injected for this purpose (referred to as subpilot fuel).

Figure 3 shows the overall split of the fuel, which includes:

- Main premixed fuel.
- Secondary premixed fuel, stabilising the main flame.
- Subpilot fuel, stabilising the pilot flame. It generates a lean diffusive flame. Of the total fuel injection it is a very small amount and therefore does not limit the decrease of emissions.

The overall goal is a clean decrease in the fuel that burns in a diffusive way. The resulting flame, composed of many different subflames, is very complex. In addition, each of the four premixed pilots has a swirler inside, producing a complex flowfield.

The combination of the main premixed flame, the premixed pilot flame and the subpilot flame presents a very demanding case for a CFD calculation. The role of CFD at this point is critical: it helps to check the overall flame configuration (by means of user defined combustion models) and to predict emissions levels at different combinations between load and ambient temperature.

Extensive testing

The new K-1 combustor was extensively tested both on a rig and on the new GE 10-2 gas turbine. Rig tests focused on decreasing the NO_x/CO emissions by as much as possible over the wide load and ambient temperature ranges, while engine tests were dedicated to achieving the most robust turbine operation possible.

Of the vast amount of data obtained by the entire set of tests, specific operating points were selected to test the accuracy of the NO_x user defined models. The selected operating conditions are shown in Table 1.

An interesting aspect of performing NO_x calculations for these points is the ability of the model to identify both an absolute value and a trend in values, which is challenging because the machine adjusts its own fuel across the

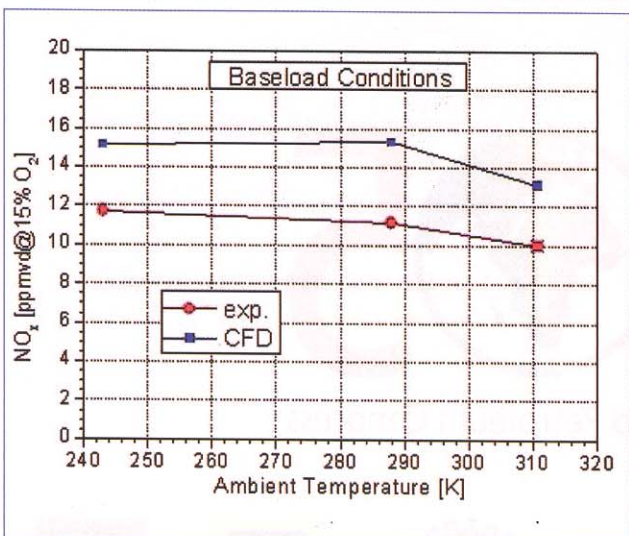
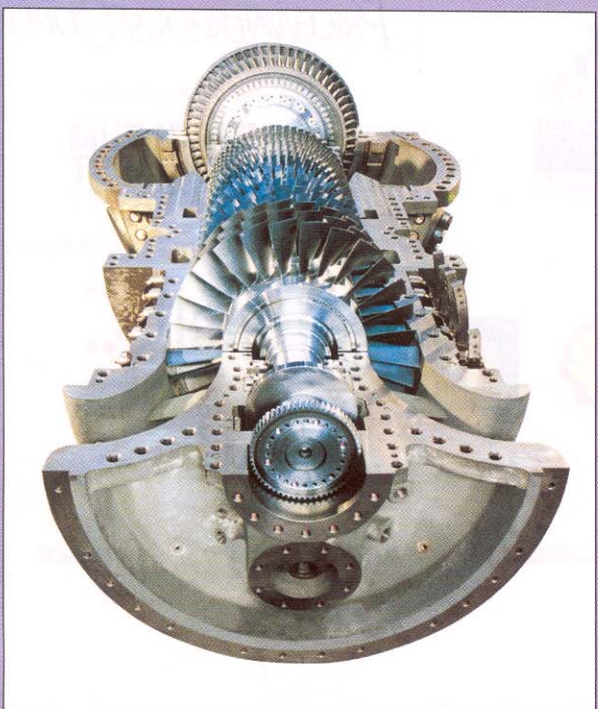
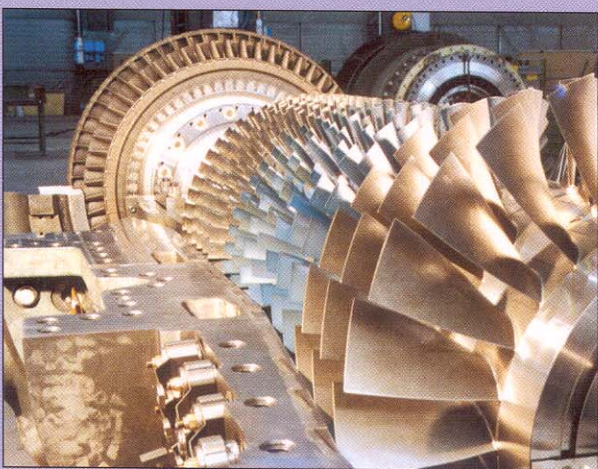


Figure 4. Comparison between measured and performed NO emissions in the three operating points studied.



Figures 5 and 6. The GE 10-2 gas turbine rotor.

load/temperature range and therefore changes its levels of emissions. For all of these operating points, CO emissions were negligible.

The three different operating points corresponding to three different ambient temperatures were simulated, always at baseload conditions. Mass flows and compositions at main and pilot inlets differed slightly in each point, but the structure of the reactive flow field did not show significant variations.

As previously stated, the reduction of NO_x emissions can be achieved through a reduction of the percentage of pilot fuel burning in a non-premixed manner, thus abating peak temperatures. In the new K-1 combustor, pilot fuel mass flow is globally increased compared with the old version (approximately two times the design value), but only a small fraction burns in a non-premixed mode (the subpilot fuel), letting the combustor work in the operating range indicated in Figure 2. This Figure also shows the results of a CFD validation test performed with the KPP (Kolmogorov, Petroskii, Piskunov) combustion model and the NO_x emission model used in this work.

Meanwhile, Figure 4 shows a comparison between measured exhaust emissions and calculated data. The overestimation of exhaust emissions is primarily due to overestimating the flame temperature of the pilot burners' non-premixed flames, due to the assumptions of the turbulent combustion model. Nevertheless, CFD calculations are able to reproduce the trend of NO emissions with respect to ambient temperature.

It is interesting to note the apparently inverse trend of NO concentration with respect to the ambient temperature. As the firing temperature at baseload is kept constant, a decrease in the compressor discharge temperature results in an increase of heat release and therefore in an overall increase of equivalence ratio across the combustion chamber. This obviously leads to an increase in emissions.

These test results were compared with an additional calculation of the reactive flow field, performed at ISO ambient conditions. In this second CFD analysis, a detailed laminar flamelet model based on a level set approach was used. The comparison showed a reasonable agreement between the two models, supporting the validity of the entire CFD study.

Ready for commercial use

In addition to the full scale operability tests conducted on the GE 10-2 engine in Florence, Italy, the new K-1 combustor system hardware and software were extensively tested at GE Energy laboratories in Greenville, South Carolina, USA. With tests completed, the new technology was introduced at the GE Energy Oil and Gas annual meeting held in Florence from 31st January to 1st February 2005. The theme of that meeting, attended by more than 800 oil and gas industry leaders from around the world, was 'New Technology Frontiers'.

For all new GE 10-2 gas turbines, this new 15 ppm combustion system is now available, and for current GE 10-2 users, existing 25 ppm machines can easily be upgraded. The new technology will be also adapted for the GE 10-1 (single-shaft) gas turbine for power generation applications. This means both new and current users can benefit from the new K-1 emissions technology, enabling small and medium pipelines or other mechanical drive applications, particularly in densely populated urban areas, to meet increasingly tight emissions regulations worldwide. ■