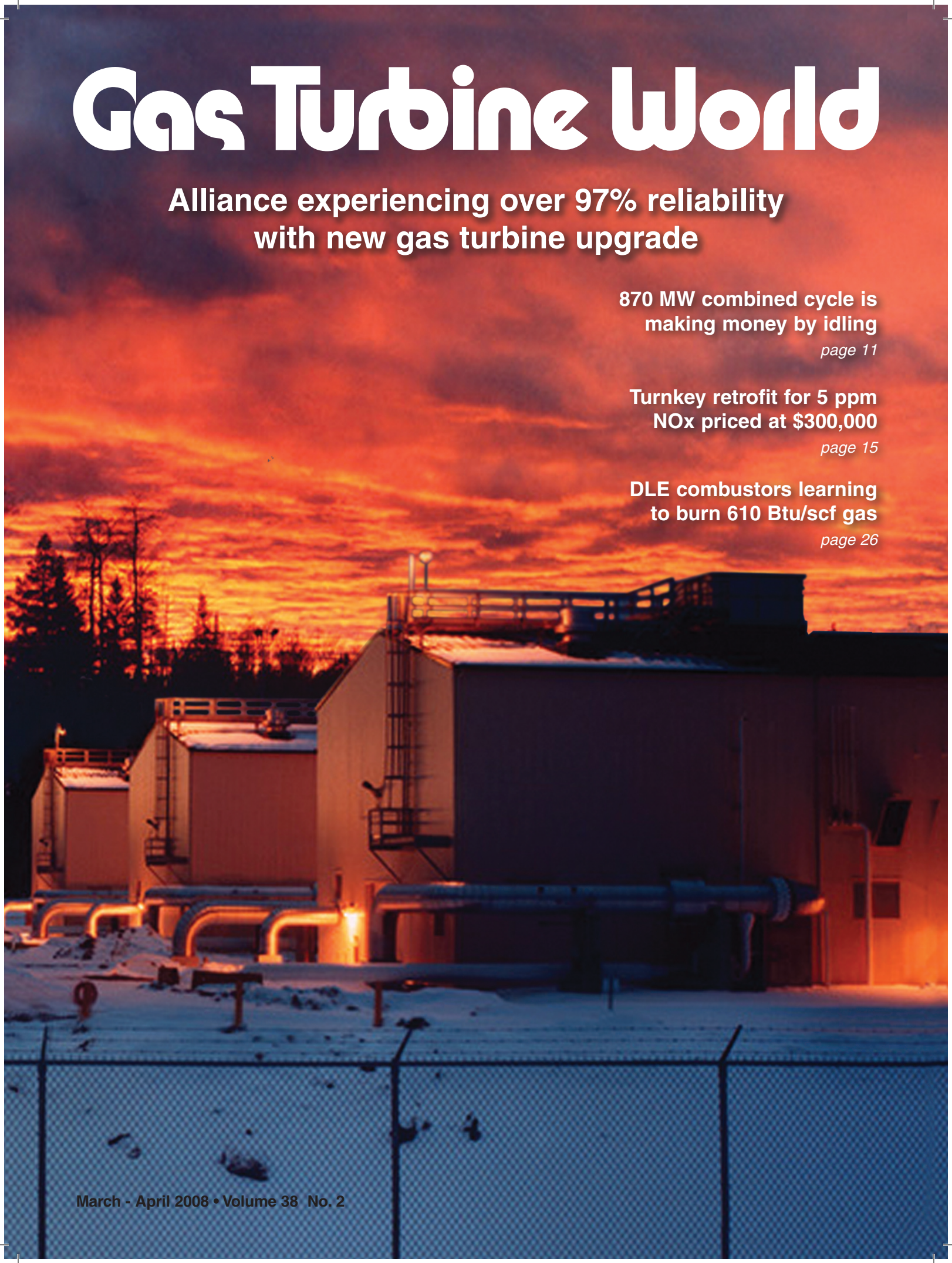
Gas Turbine World

Alliance experiencing over 97% reliability with new gas turbine upgrade



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CLN steam injection limiting NOx emissions below 5 ppm

By Victor de Biasi

Operational tests on a 501 gas turbine confirm less than 5 ppm NOx at a 3 to 1 steam to fuel injection ratio.

International Power Technology has achieved ultra-low emission levels on an Allison 501-KB5 gas turbine with Cheng Low NOx (CLN) nozzle steam injection at conservative steam-to-fuel injection ratios.

This is a milestone, says IPT president Randy Turley, in confirming the practicality of CLN steam injection to deliver predictable single digit reduction while increasing plant efficiency and power output.

Currently IPT is offering guarantees on equipping 501-KB5 gas turbines for commercial CLN operation. Specifically:

☐ **Emissions**. For commercial retrofit performance IPT is guaranteeing 5 ppm NOx and 80 ppm CO or less at 1895°F turbine inlet firing temperature.

☐ **Budget Price**. Turnkey prices typically range from $235,000 to $295,000 installed, excluding combustion liners and off-engine steam supply.

Sub-5 ppm NOx operation has been achieved by retrofitting a redesigned fuel nozzle compatible with the original 501-KB combustion system but with significantly different flow characteristics from OEM steam-fuel injection nozzles.

Optimized low-NOx nozzle designs involve testing a number of prototypes under varying fuel-steam mass flow, velocity, momentum, radial and axial direction conditions – with the nozzle positioned at different axial locations within the combustion liner.

All of these nozzle design variables contribute to achieving ultra-low NOx while keeping CO low enough for flame stability, says Turley. Since oxygen distribution from front to back varies from one liner to another, different flow patterns (and thus nozzle configurations) are required for different combustion liners.

Keep same liner

In its current retrofit designs, IPT has deliberately left the 501KB combustion liner unchanged so that only standard liners are required for all emissions levels.

The sub-5 ppm NOx achieved in engine tests was with a stock LE3.2 liner design at around a 3.0 to 1 steam-to-fuel ratio.

In general, there is a predictive correlation between the amount of steam injected and emissions reduction. For example, you can reduce NOx to 15 ppm at a 1.75 to 1 steam to fuel ratio and to below 10 ppm by operating at a 2.25 to 1 ratio.

At any steam-to-fuel ratio, Turley points out, CO emissions are safely below the upper limit on combustion stability.

He notes that the CLN technique of mixing steam with fuel to reduce emissions is nothing new in the marketplace. For instance, Rolls-Royce Allison has been using stock low-Btu steam and fuel injection nozzles to accomplish this since the mid 1990s. The difference today is in how and where the steam and fuel are mixed and injected.

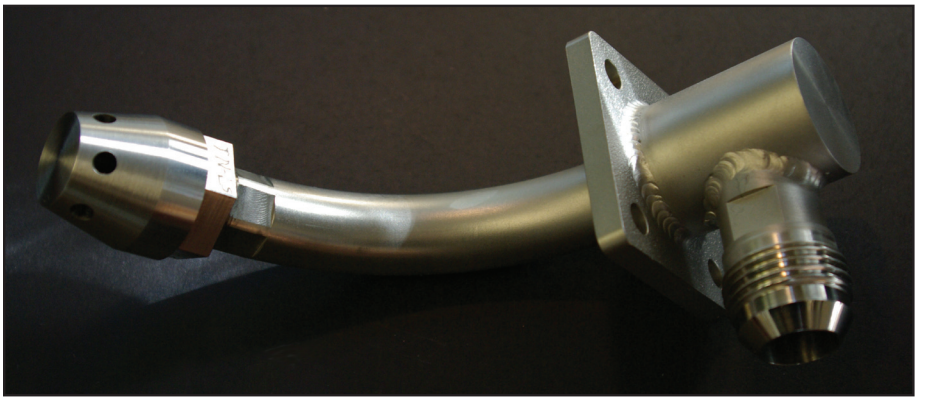
General OEM practice is to adapt standard fuel nozzles for simultaneous steam and fuel injection. This helps in reducing NOx but the design is not optimized for maximum effectiveness or operational flexibility.

The combination of short mixing length (six inches in the fuel nozzle neck) and much lower gaseous fuel temperature (relative to the steam) inhibits homogeneous mixing.

It also leads to steam condensation within the nozzle which can contribute to droplets and high combustor can temperature spreads.

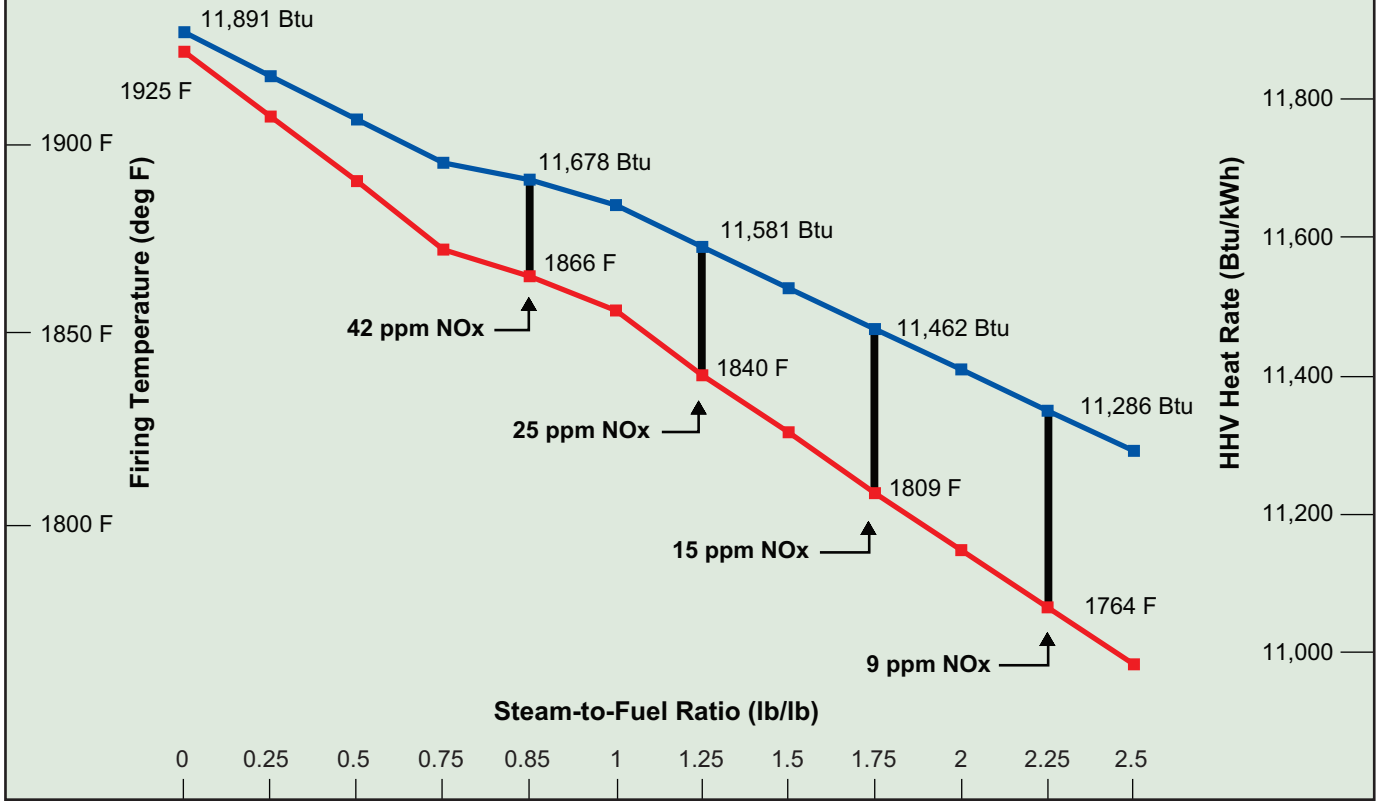
Off-engine mixing

In contrast, with CLN injection the steam and fuel can be mixed off-engine to a very high degree of homogeneity.

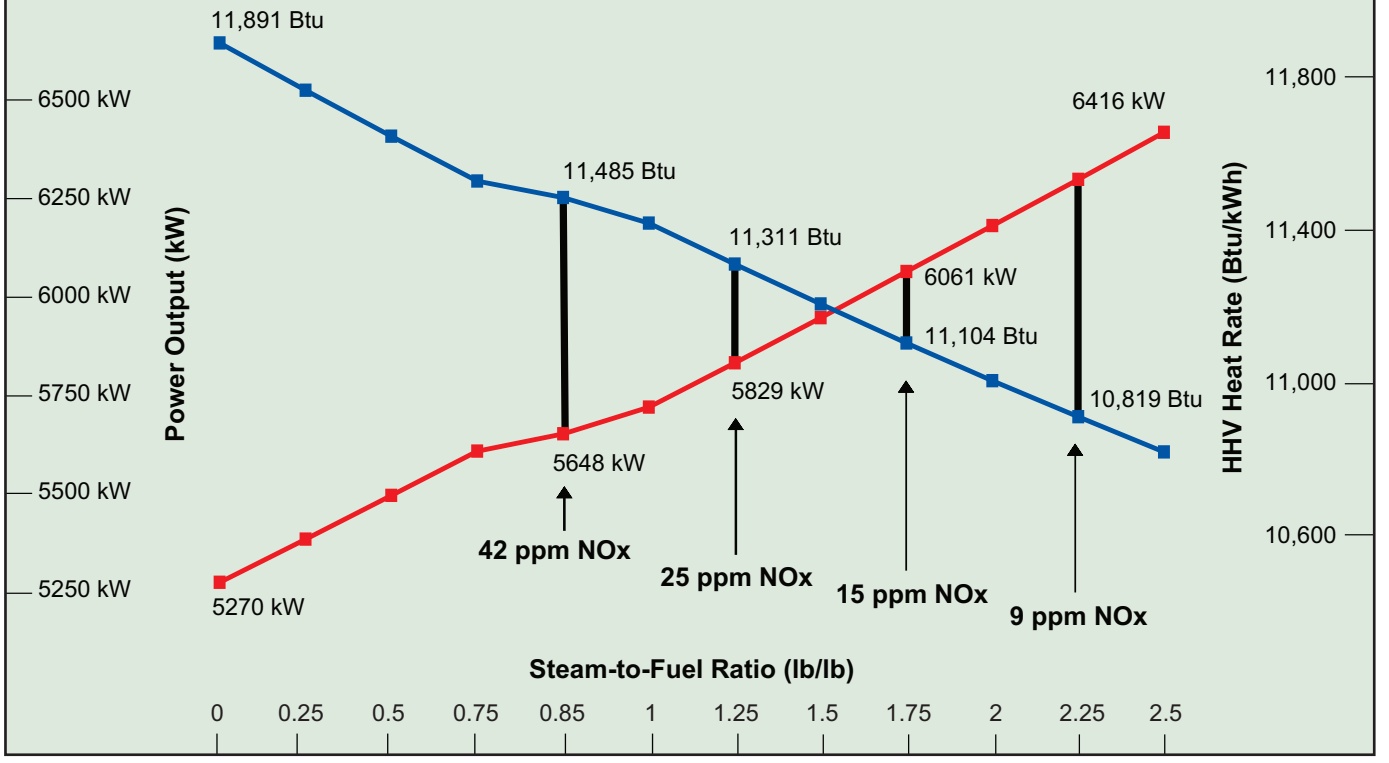


Low NOx nozzle. Design features a large diameter fuel-steam inlet port (for minimum backpressure) and removable tip for low-cost nozzle maintenance. Nozzle diameter, holes and flow angle are custom designed to match combustion liner.

Constant output. Variation in firing temperature and heat rate with increasing steam ratio as shown here by plots of turbine inlet temperature and HHV heat rate (all values are approximate) for Allison 501-KB7S tests at constant 5270 kW output over a range of CLN steam-to-fuel injection ratios.



Constant temperature. Variations in heat rate and power output with increasing steam ratio as shown here by plots of generator output and HHV heat rate (all values approximate) for Allison 501-KB7S tests at constant 1925°F turbine inlet temperature over a range of CLN steam-to-fuel injection ratios.



And the fuel gas can be heated prior to mixing so as to prevent any possibility of condensation.

The combined effects of these design changes are what make it possible to achieve much lower NOx, says Turley, and to control CO even at very high steam injection rates (4 to 1) and maintain better flame patterns.

The lower limits of NOx are determined by fuel nozzle design and the amount of CO produced by the axial location of the nozzle within the combustion liner.

Standard or custom designed fuel nozzles can be used for CLN operation, depending on requirements, provided they are properly located.

For gas turbine installations equipped to operate at 15 ppm NOx, for example, OEM hardware can be used for all on-engine mounted components of the system.

But getting down to between 5 and 15 ppm NOx requires specially designed fuel nozzles tailored to combustion liner configuration and flow characteristics.

In either case, IPT claims that retrofitting custom designed fuel nozzles will produce much better BOT flame patterns at the inlet to the first stage of the turbine.

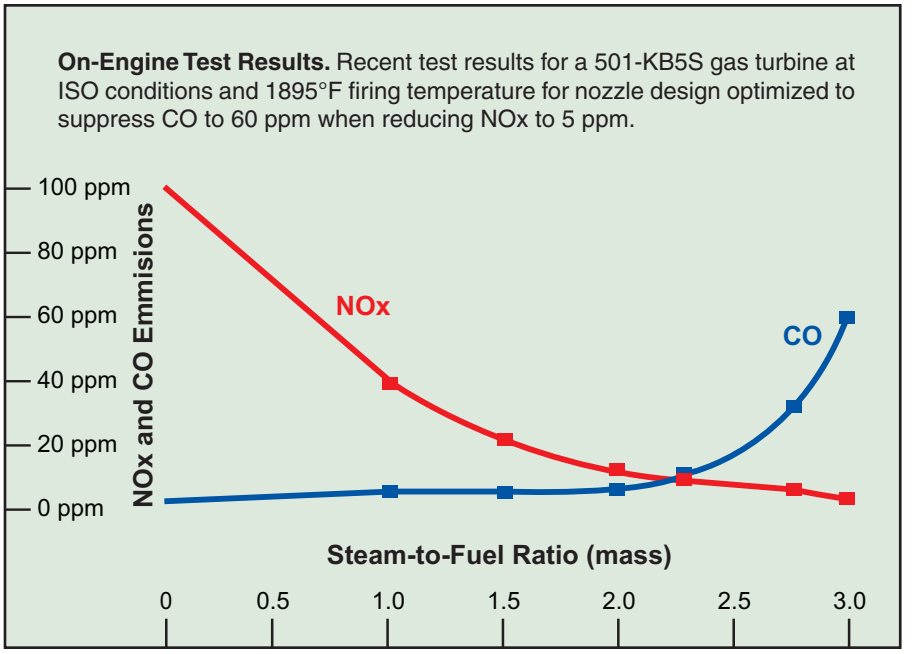
Nozzle options

For 501-KB5s equipped with LE3.2 combustion liners, IPT offers a "standard package" for emissions reduction using OEM low-Btu fuel nozzles.

The standard package with a 1.75 to 1 steam-to-fuel injection ratio can limit emissions to 15 ppm NOx and 25 ppm CO for operation at up to 1895°F turbine inlet temperature.

Company also offers "customized packages" with special nozzles capable of operating with steam-to-fuel injection ratios of between 1.75 and 3.0 to 1 for limiting emissions to between 5 and 15 ppm NOx and 80 ppm CO at 1895°F firing temperature.

Off-engine steam requirements call for a minimum 250 psig saturated steam supply – with lower steam pressures acceptable for higher NOx limits – and minimum 275 psig natural gas fuel pressure at the turbine inlet. No fuel treatment is required for pipeline natural gas.



On-Engine Test Results. Recent test results for a 501-KB5S gas turbine at ISO conditions and 1895°F firing temperature for nozzle design optimized to suppress CO to 60 ppm when reducing NOx to 5 ppm.

Turley notes that Rolls-Royce Allison requires a steam injection quality of 50 ppb total dissolved solids or less for 501-KB5 gas turbines. This is done by installing external steam separators in the injection steam lines between the outlet of the boiler and injection steam control valve.

Steam quality and purity are functions of the degree and effectiveness of moisture separation devices, he points out, and not related to feedwater quality which impacts on boiler operation.

IPT says its steam injection designs can be applied to boiler systems with high fluctuations in feedwater quality. For operational purposes, however, silica levels must be minimized for boiler pressures in excess of 500 psi because silica will volatize above these pressures.

Where CLN fits

Likely candidates for retrofit to CLN steam injection include DLE gas turbines suffering high maintenance costs and operating problems such as high heat rates at part-load, carbon blasting and premature failure of combustion liners.

Similarly, say application engineers, water injected gas turbines (for emissions control and power augmentation) are subject to higher heat rates overall and shortened combustion liner lifetimes compared with steam injection.

CLN also helps reduce greenhouse gases as a result of converting to steam injection, they explain, in direct proportion to reductions in heat rate.

Worldwide, the trend to enact increasingly stringent emissions regulations make CLN steam injection an attractive low-cost alternative to SCR and DLE combustion – whether for limiting site NOx to meet air quality limits or to sell offsets on the open market.

Clean up or else

San Joaquin Valley in California is a case in point. Effective as of September 2007, air pollution control district Rule 4703 requires all gas turbines under 10 MW to comply with a 5 ppm NOx limit or shut down.

With a 5 ppm guarantee point for the KB5 achieved, Turley says that other gas turbine models operating locally (such as small Solar Turbine units) are candidates for CLN steam injection that will allow them to remain in service.

It does require interested collaboration on the part of owner-operators, however, to provide a host site for IPT project engineers to develop and confirm the performance of appropriate fuel nozzle designs tailored to the gas turbine model. ■