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Cheng Low-NOx Turbine Booster Is Picking Up Steam


CLN test nozzles

Innovative fuel-and-steam technology augments power, conserves fuel, and slashes emissions.

BY DAVID ENGLE

More power to you, the saying goes; and this is the story about a novel way of getting it affordably from turbine generators; more power with a lower heat-rate and dramatically reduced emissions—without pricey catalytic technologies; and all costing under $100 per kW.

Better still, this outlay can in some cases be readily recouped on emissions-credit markets in nonattainment air districts. So it's an instant payback, and pure gravy on the back end.

It may sound too good, but proponents are persuasively showing that it is happening, and the underlying physical principles are sound. Developed recently by Dah Yu Cheng, Ph.D., of Cheng Power Systems (Mountain View, CA) and patented in 2002 as "Cheng Low-NOx" (CLN), the eponymous turbine technology retrofit injects steam into the fuel mix, producing all of the above dramatic performance gains. Emerging on the market recently after several years in R&D, the system is currently being demonstrated commercially on a 6-MW Allison Rolls-Royce 501-KB5S turbine at the Stanford Research Institute (SRI) in Menlo Park, CA. This has been running almost continuously since early-2005, and is being closely monitored for performance and emissions.

Overseeing the prototype application is Randy Turley, CEO of International Power Technology Inc. (IPT), who reports: "Our most significant achievement with this technology to date is that we have achieved single-digit NOx and CO [8.5 ppm and 6.5 ppm respectively] simultaneously, in a diffusion flame, by using steam only."

In other words, it's nearly meeting the toughest emissions standards anywhere, yet without additional gear.

Turley and Cheng are now hoping to challenge competing lean premix and quasi-experimental exhaust-gas recirculation (EGR) systems for leadership as the technology-of-choice for the next-generation of low-emissions turbine genset applications.

Performance Breakthrough

Power-augmentation via steam injection into turbine air has been around for decades, of course; its big drawback has been its impairment of oxygen supply, resulting in incomplete combustion. Thus, an earlier generation of steam-injection was largely supplanted in the 1990s by expensive DLE systems and selective catalytic reduction (SCR) and ammonia injection systems.

Cheng thus set out to improve on steam injection methodology, and ultimately discovered that advantages could be gained by adding steam to the fuel rather than to the air. The resulting mix beneficially alters the combustion flame and ignition characteristics in several ways. Turley explains: "By diluting the fuel instead of the air, the diluents do not oppose the flux of the combustion products." Also, "diluting the fuel and increasing the fuel/steam jet momentum causes the flame front to move closer to the fuel jet," he adds.

As a result, the temperature gradient in the flame increases, breaking down the fuel faster. Moreover, "the diffusion rates and the concentration gradients of the combustibles increase," thereby speeding-up the combustion rate. These changes in flame kinetics produce, he says, "a smaller flame for the same heat release, with a more uniform temperature distribution, lower peak temperature, and shorter residence times for N species, all of which inhibit NOx formation."

For example, using steam-fuel mixing with standard OEM nozzles, Turley found that simple steam-fuel mixing can attain a sizable reduction in NOx formation—down to about 13 ppm. Pushing this envelope still further, Cheng and IPT then developed custom-modified fuel nozzles with precise hole-spacing to accomplish things like dispersing the oxygen more thoroughly and preventing flames from merging. The swirling mix of fuel and steam remains homogenized at the molecular level; it distributes evenly over the combustion liner. Burning accelerates and continues to more thorough completion. High steam pressure also accelerates the burning yet reduces flame size while displacing some nitrogen.

The result is a drastically curtailed formation of NOx, volatile organic chemicals (VOCs) and CO, down to the neighborhood—as the Stanford turbine is continuously proving—of single-digit ppm levels. This result, says Cheng, is a straight-out reduction "of 95%"— achieved by steam alone and without further control systems.

Turley adds: "The emissions results achieved to date are low enough to be applied in 100% of the world on a retrofit basis and 90% of the world on a new installation basis."

He's also on the cusp of meeting California's very high 2007 best available control technology (BACT) standard, assuming a cogeneration credit. This will mean compliance with BACT emissions standards in 100% of the world. Turley sums up: "Single digit NOx and CO emissions can now be achieved in the conventional diffusion flame structure"—a breakthrough "never accomplished before." This, he says, "puts the CLN in a very exclusive single-digit NOx and CO club" along with engines that use lean premix fueling—but which come at a higher initial cost, with higher heat-rate "and reduced lifetime on hot-section hardware."

Again, even lower emissions are readily doable, he adds. Output levels using CLN are simply a function of steam-to-fuel ratio and proper fuel nozzle design. The Stanford demo is achieving single-digit ppm by mixing steam with fuel at a 2.8-to-1 ratio. But NOx and CO (and CO_2, "greenhouse gas") could be trimmed to a minuscule one- or two-ppm by achieving higher steam-to-fuel ratios Turley notes: "The challenge at the Stanford demo is to achieve steam-to- fuel ratios of up to 4-to-1 at normal turbine firing temperatures"; accomplishing this "is a function of having enough steam and fuel pressure and a properly designed fuel nozzle."

Powering Up, Fueling Down

Besides dousing turbine emissions to near-trace levels, Cheng's steam-fuel carburetion also jacks-up the turbine power by as much as 30% to 50%, depending on steam quantity applied. For gas turbines, this boost naturally translates into more power and reduced heat-rate, with commensurate fuel savings. Suddenly, more onsite power projects become more cost-effective.

Moreover, this bonus output comes essentially as a freebie, by virtue of its being cogenerated from the turbine's exhaust heat. This assumes, of course—as is very often the case—that not all of the exhaust heat is needed for other plant purposes. Thus, the exhaust heat is readily available for recycling into the CLN system. "The beauty is," says Turley, "with gas turbines, as you add more mass, the efficiency goes up. Adding steam to a 501-KH5 gas turbine at 6 lbs.-per-second raises the turbine's efficiency from its baseline of about 28% up to over 40%"—obviously a significant jump.

Engine heat-rate—which is defined as the amount of Btus of fuel needed to generate a kWh of electricity—is all-important in power project economics. The lower the heat-rate the better, in terms of relative cost-effectiveness. Steam-injection dramatically lowers heat-rate. Again, the additional steam comes, in some cases, not from burning more Btus but from the turbine's exhaust heat, which is effectively recycled. It's truly turbine optimization. "The business case continues to be favorable in most cases," Turley says, "in applications where fuel is needed to produce the steam," because "the combination of decreased overhaul costs, increased power production and decreased heat-rate outweigh the cost to produce the steam."

Heat-rate reduction will naturally vary with each engine, but, to give one example: According to calculations furnished by engine-maker Rolls-Royce/Allison, the KB7S turbine, using an LE2 combustion liner and running without steam on a simple cycle, achieves a heat-rate of 10,848 Btu/kWh—LHV; adding only one pound of CLN steam per pound of fuel reduces the heat-rate by about 4%.

Retrofit Candidate?

Steam-fuel injection can be applied to turbines of virtually any size or manufacture, says Cheng, providing the compressor is adequate. Among the suitable models he has already formally explored are the Rolls-Royce/Allison 501K(x) aero-derivative gas turbines; Kawasaki M1A-13 lines; Ruston (Siemens); GE Frame 6B, 7EA, 7B, 5P; and the Westinghouse 501-D5 turbine. Specific performance data is available on a number of configurations, he says.

As for fuel options, although the concept was designed with natural gas in mind, it will also probably work with "extremely low Btu gas," Cheng believes. His firm recently began looking into a landfill gas application in New Mexico. A naphtha-fueled 27.5-MW, steam-augmented LM 2500 turbine for the Kaua'i Island (HI) utility co-op is also in operation. At the latter site, "Steam injection is greatly extending hot parts' life and facilitating load-following," he notes.

Turley adds that, although the combustion process is a bit more exacting, fuel tolerances are not extraordinary. "The [steam-injected] turbine is self-adjusting, essentially," he says. "It will either pull in more volume or less volume of the gas to meet its heat release requirements. Standard pipeline gas is OK." Moderate Btu fluctuations present no problems; gas moisture is controlled with the standard heating package.

Bonus Energy With Little Work

Apart from the dramatic emissions improvements, gas turbine steam-injection can solve assorted onsite power problems, as the following case illustrates. (This was actually the first commercial CLN application, coming even before Turley's demo at Stanford.) As Cheng recounts, CLN was applied to a GE Frame 6B-powered CHP plant at the Chevron refinery at El Segundo, CA. The site had been equipped some years ago with three GE frame 6Bs in a CHP application; over time, though, the turbines were derating, losing about 8 MW of power each, on average, on hot days (i.e., delivering only 34 MW each rather than the contractual 42 MW). The turbines' exhaust heat was already being used for the refinery, so an additional full-fledged heat-recovery steam generator was dicey. And obtaining new permits to install a supplemental turbine with concomitant SCRs would have been costly and difficult.

However, on two of the three units, CLN steam injection and Cheng Boost—using nozzle steam-to-fuel ratio of only 1½ to 1—presented an easy fix to both the 16 MW power makeup and emissions cap. By taking only the minimal amount of steam needed, the injection phase could be carefully balanced to augment 16 more MW without exceeding NOx limits or robbing any process steam. In the bargain, this client was also able to defer, by four years, the cost of an SCR equipment upgrade on the two 6Bs. Eventually, complete heat-recovery steam generators were also added.

The ending was happy but marred: As this was the first customized CLN application that produced expected NOx and CO emissions results, an engineering subcontractor failed to perform as contracted, which resulted in a protracted commercial dispute. Technically, the installation has performed to all expectations, and Chevron is reportedly considering the CLN retrofit of the third unit.

Lessons Learned, Applied

The Stanford demo by IPT benefited from insights gained in earlier trials and from Cheng's ongoing R&D. Performance so far has been flawless. Turley reports that steam and power output have run almost continuously for about 10 months as of early 2006. Built-in continuous emissions analyzers and a Horiba analyzer monitor the numbers—again, 8.5 ppm NOx and 6.5 ppm CO at a 2.75 steam-to-fuel ratio.

Additional confirmation came recently from the Bay Area Air Quality Management District engineering division. BAAQMD's Bob Nishimura handles permitting for regional power plants, and he notes that, in this region, "There are engines out there that could probably use this system" as a retrofit; the impact on emissions reduction would probably amount to one ton, and perhaps up to several tons, per engine, he estimates. Moreover, the reduction achieved for the Stanford engine—dropping from 25 ppm to 5 ppm NOx—is on the order of 20 tons per year of NOx. This works out to one ton per year for every one ppm NOx reduction, for this size engine. The expectation with CLN is that, on a retrofit basis on the same size engine as at Stanford, the reduction will be from 35 ppm to 15 ppm—or about 20 tons of emissions saved per year.

Turley's immediate objective for the next phase of the demonstration is to reach 5 ppm and 10-ppm output, NOx and CO, respectively. When this happens, the SRI turbine will be meeting California's BACT rules—yet, again, without the costly SCR and lean pre-mix apparatus now needed. This ambitious target "has already been demonstrated on the atmospheric test-rig for the Allison 501, the RR Avon, and various GE models including the LM2500, 7EA, 6B, 5P and 7B," he says. All are achieving astounding results of below 2 ppm NOx and 2 ppm CO, "and the Stanford project is heading in the same direction," he says. "If we can achieve the same emissions levels [there] that we achieved on the test rig, it will be an achievement we never dreamed of."

Combined-Cycle Efficiency

The news is all good news, then, regarding power output, heat-rate, and emissions. But what about the economics?

Cheng suggests that, by simple logic alone, steam injection "will always make money" on any appropriate turbine, because there's no significant payback curve to be faced in justifying the hardware. "Adding a boiler," he says, "is a lot cheaper" than replacing or supplementing a gas turbine genset. And a boiler—combined with some steam piping, control valves, some mixing hardware, and CLN steam nozzles—are essentially all that's needed to produce steam-fuel injection. "Your incremental kilowatt will be cheaper," he says, "than with a simple-cycle gas turbine." The same comparative advantage holds even truer with a combined-cycle system, he adds. In a sense, steam injection can be thought of as achieving "combined-cycle efficiency," he says, "but at simple-cycle cost."

For one example of the outlay: The cost to retrofit a Rolls-Royce/Allison 501-KB5 or KB7 gas turbine is between $250,000 and $300,000, Turley says, and other engines or larger sizes will probably conform to similar per-kW relative costs.

Turley notes, too, that besides offering relatively affordable up-front costs, other benefits of the CLN steam include: (again) lower heat-rate; increased power and peak-shaving capability; much lower maintenance costs; a smaller footprint than SCR and ammonia system; and lengthened hardware life because of improved heat-stress dynamics.

Reaping Emissions Credits

Better still, any significant reduction in permitted emissions is potentially self-funding and readily recouped, in some markets. At the very top of the list of good retrofit candidates are those that might benefit from potentially sizeable emissions offset credits. For example, if a turbine is currently permitted for, say, 35 ppm NOx, and can reduce this to 15 ppm (as is readily doable with CLN), the NOx offsets can be sold on the open market for as much as $110,000 per ton (the current price for the California South Coast Air Quality Management District). Local valuations vary, of course, depending on the locale, current permit level, and local demand for emissions offsets.

To illustrate how the offset-credit values might work using a case and equipment identical to the SRI demo site, but located in the South Coast AQMD: Assume that the turbine is currently permitted for 25 ppm NOx, and that adding CLN succeeds in reducing this to about 8 ppm—a difference of 17 ppm. Thus, if the owner should decide seek to a new permit at the 15 ppm level (leaving some permitting headroom), the improvement in performance would theoretically mean that the owner could reap a valuable emissions-offset credit. For a turbine of this size, a reduction of just one ppm equates to saving about a ton of NOx emissions annually. In the South Coast this is worth about $110,000; so, multiply by 10 ppm and the resulting full credit value is $1.1 million.

This will pay for a lot of retrofitting.

Moreover, the current $110,000 per-ppm value actually represents a decline from recently higher levels. Although demand is momentarily depressed, values may easily rise again someday. The $1.1 million credit might then be held onto like a speculative commodity, then sold in a bull market for even more.

Emissions-credit prices in the San Joaquin Valley and San Diego are currently fairly strong, according to data available from Evolution Markets. In the latter, 10 ppm of NOx reduction, notes Turley, "is now worth about $1,000,000." Thus, a typical CLN steam retrofit on a 6-MW CHP turbine using OEM combustion liners and fuel nozzles would reduce NOx and CO sufficiently to earn offset credits worth up to $1,650,000. Such a dramatic reduction of ppm, he adds, "is based on readily achievable steam-to-fuel ratios."

In some instances, even better yet, a CLN steam system will enable the elimination of costly SCR/ammonia systems. This may equate to tens or hundreds of thousands of dollars in cost-avoidance. On top of this there's (say) a 20% savings in fuel because of the lowered heat-rate—again, an economizing worth thousands of dollars.

All in all, says Turley, retrofit economics in such conditions "make it a slam dunk." Payback is instantaneous. And future operations will see dramatic savings.

Re-permitting is generally easy because the applicant is merely requesting a lower limit: There's no need for a new source review. "Typically, all that is needed is an authority to construct and a permit modification" Turley says. If there's an interconnection agreement limiting power output, it can be satisfied by simply reducing turbine firing temperature.

Bottom line: The retrofit capital is very quickly recovered.

The CLN Alternative

In January 2005 the Kyoto Protocols ratcheted-down emissions limits for CO_2 in Europe and other participating nations; Turley and IPT now anticipate rapidly expanding market opportunities, and they're already making headway. In November 2005 in Scotland, working in conjunction with Cheng's Scandinavian partner, Cheng tested CLN on a fully pressurized Rolls-Royce Avon gas turbine. Engineers are now performing the tests on the GE-LM2500. The same month, CLN was tested and approved by a Norwegian tech qualifications review; the door is now open there.

In October 2005 IPT sold a retrofit to the first Allison KB7D "DLE"-equipped (dry low-NOx emissions) engines powering a paper mill in Germany. This particular application, Turley notes, demonstrates still another potentially important niche. As it turns out, Rolls-Royce/Allison DLE emission control systems have been found to be problematic—suffering cracks in combustion liners, and carbon residue accumulation—when running at temperature at full load and under part-load conditions. The underlying problem may be that DLE technology itself is flawed. In any case, CLN steam-fuel retrofit now appears to be the best means for achieving lower emissions while reducing turbine overhaul costs; all Rolls-Royce/Allison DLE-equipped engine owners are now potential retrofit customers. Turley observes: "This is a perfect marketplace for us to prove our technology, because we know the Rolls-Royce/Allison 501-K (x) platform..." As Low-NOx retrofits prove their worth and durability, there'll be a natural progression to ever-widening acceptance; the "exotic" aspect of steam-fuel injection will fade, and the technology will become commonplace.

As the original developer, Cheng, too, anticipates an expanding role for steam in providing cleaner, more efficient energy. He believes, for example, that the nation's summertime peaking-power crunch would be readily solved by the country adopting an energy policy supportive of steam-injection as appropriate upgrades. Simply erecting power stations alone won't solve the nation's power-delivery problems, he notes: transmission cables are already strained. Steam-injection is truly the most viable fix: "There's no siting and zoning" issues to face, he notes; "no environmental assessments"; no power lines to add, no additional fuel to expend or emissions to control.

In the bargain, the US would be able to satisfy the Kyoto Protocols on greenhouse gases (CO_2). All of this, thanks to steam. He sums up: "There's really no better alternative... Whether it's SCR or dry low NOx, there just is nothing else that is going to do it."

Company Profiles: Cheng Power Systems and IPT

In 1974 Dah Yu Cheng co-founded International Power Technology (IPT) of San Jose, CA, to develop gas turbine steam injection. A decade later—in partnership with Allison Gas Turbines of Indianapolis, IN—IPT co-developed and began marketing what Allison called the 501-KH Cheng Cycle steam-injected turbine. Over 130 Cheng Cycle systems have been sold throughout the world.

Beginning in the mid-1990s catalytic and ammonia-based emissions controls, and combined-cycle systems, came to the forefront. Cheng responded in 1996 by launching Cheng Power Systems to do more new research. CPS has since developed an array of steam-based technologies to enhance turbine efficiency, augment power, and reduce emissions. CPS now holds more than 140 patents, licensing its technologies internationally.

IPT has evolved into a full-service power engineering firm, doing project development, design, management, operations, maintenance, and controls.

To date, more than 20 projects have been commissioned, six of them using Cheng-cycle steam systems. Turley became IPT's president and CEO in 1999. In 2003 IPT became the exclusive licensee for CLN and other Cheng technologies on Rolls-Royce turbines worldwide. DE

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Founded in 1974, International Power Technology, (IPT) has been involved in the development, startup, and ongoing operations, maintenance, and management for over twenty projects worldwide, including five Cheng Cycle gas turbine projects in California that were developed by IPT.

In 1983 IPT co-developed the Allison 501-KH "Cheng Cycle" gas turbine with Allison Gas Turbines of Indianapolis, Indiana. Additionally, IPT is internationally recognized for the development of over 45 U.S. and international Cheng Cycle patents.

With headquarters in San Jose, California, IPT is a well established professional services organization offering a broad range of project development, distributed generation, and operations, maintenance and management services.

IPT is the worldwide licensee for the CLN technology for the Allison 501-K(x) and Kawasaki M1A-13 line of gas turbines.