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Inject steam in a gas turbine —but not just for NO_x control

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Inject steam in a gas turbine —but not just for NO_x control

Steam supplied to a gas turbine from the heat-recovery boiler can also boost efficiency and match load output to demand—with less cycling of turbine-inlet temperature. And the technique is retrofittable to a variety of machines

By **Lee Kosla** and **Jim Hamill,** International Power Technology Inc, and
Jim Strothers, General Motors Corp, Detroit Diesel Allison Div

The majority of cogeneration systems installed today use gas turbines with heat-recovery steam generators (HRSG). In part, this is because a gas turbine operates on a fairly wide range of liquid and gaseous fuels and because its exhaust contains the high-temperature heat necessary to produce adequate levels of steam. Also, the thermal efficiency of this combination is very high—up to 70 to 80%—but only as long as the steam demand of the accompanying process plant is compatible with the required electric-power production.

This is not always the case. When electric power and steam loads are greatly out of step with each other, thermal efficiency can plummet to the 20-30% range. In fact, many cogeneration projects are scuttled because the economics become prohibitive when waste heat or steam is vented or when the turbine is derated on a sustained basis because the steam demand is lower than the design capability of the system.

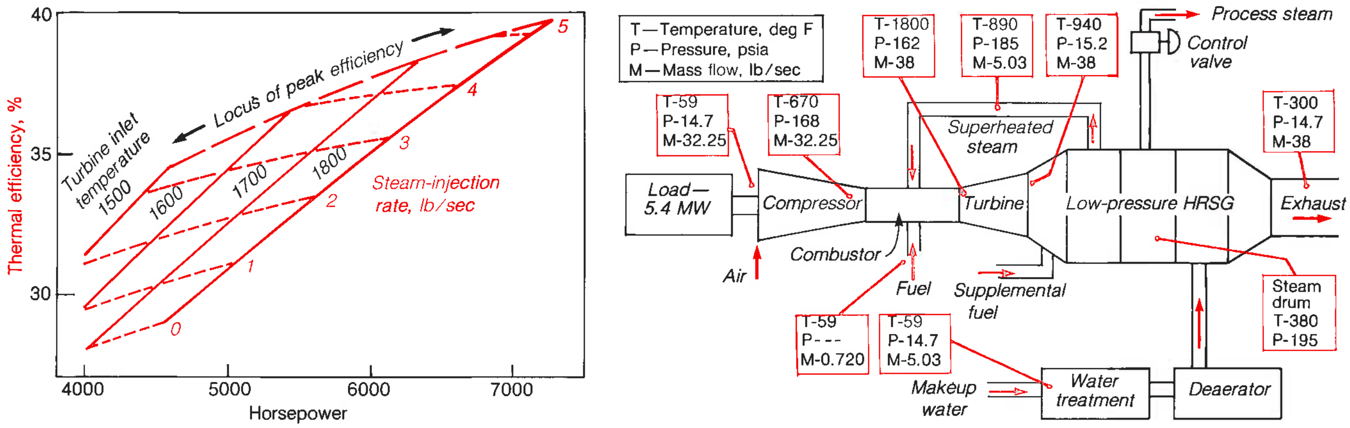
Injecting superheated steam into the gas turbine can solve the problem—the tactic is a bit like teaching an old dog a new trick. Steam injection has been used previously to reduce NO_x emissions from turbine exhaust or to boost the output of the machine when the incoming ambient-air temperature varies considerably. While the technique still holds these advantages, it can be further exploited to improve the load-following requirements of an efficient cogeneration system.

Principles of steam injection

The basic purpose of steam injection is to augment the customary hot expansion gases from the combustor with superheated steam to take advantage of higher overall mass loadings without changing turbine inlet temperature. Fig 1 shows one patented cycle (the dual-fluid cycle as it is called by its inventor), its associated operating parameters, and a typical performance curve. As shown here, it is based on the 501K gas turbine of General Motor Corp's Detroit Diesel Allison Div, but the technique has the potential to be retrofitted to many gas turbines (see box). Major components of the system include the gas turbine, HRSG, auxiliary duct burner, gearbox, electrical generator, and controls.

The HRSG has these three features:

- A superheater upstream of the evaporator is added.
- A duct burner is added between the superheater and the evaporator to provide increased flexibility.
- The ratio of evaporator to superheater surface area is optimized to reach peak efficiency and to meet the different requirements of steam quality dictated by the two separate uses—injection into the turbine and process demand.



1. Performance curves for a gas-turbine cogeneration cycle equipped with steam injection (left) show substantial gains in thermal efficiencies. Operating parameters at full rated output (right) show major changes in cycle design

Applications to other machines

Although the steam-injection technology described here is based on Detroit Diesel Allison's 501K machine without aerodynamic modifications, it has the potential to be retrofitted to other gas turbines. In most cases, however, some changes will be necessary.

An earlier evaluation performed by International Power Technology Inc (IPT) found that the turbines most suitable are the larger generating sets—in the 30-100-MW range—because they require the least amount of mechanical changes. IPT feels that the technology is more suited for retrofit in General Electric Co's Frame 7 and Frame 9 packages than in Westinghouse Electric Corp's equivalent series of machines. A Frame 7 retrofitted with steam injection would have a heat rate below that of the average utility thermal plant. This potential for retrofit offers utilities the opportunity to convert their standby peaking systems into base-loaded units with additional power capacity, lower heat rates, and increased flexibility as cogenerators. In fact, it may be one way for utilities to own part of an industrial cogeneration system.

Retrofit design efficiencies would vary according to the simple cycle efficiency of the base machine.

Where there are site-specific constraints, other options are available. For example, in regions where water is scarce, a closed-cycle design can be made available by installing a low-temperature membrane-distillation package and a cooling tower. Or if heavy fuels are to be used, some of the steam can be used for fuel pretreatment.

This scheme has a number of advantages over a more conventional gas-turbine-based cogeneration system.

Flexibility. When steam is not required by the process, the injection feature lets you maintain the gas-turbine power output instead of having to decrease it to follow the decreasing steam demand. In fact, the power and efficiency of the gas turbine improve with the lower-process-steam requirements. Depending on your plant's steam-demand curves, this mode of operation can have a significant economic impact. Likewise, when steam from the waste-heat boiler is not supplied to the gas turbine—such as during a maintenance outage—the turbine still operates at its standard performance level. Also, keep in mind that the cycle retains all the advantages of NO_x control.

Consider the weekly steam and electric-power load profile shown in Fig 2. Here, both loads are relatively low over the weekend and spike up with production during the week. This profile is typical of many batch manufacturing processes and facility heating and cooling units. Keep in mind that although this specific trend is weekly, it could be compressed or expanded for a daily or yearly output, depending on the nature of the process.

If a conventional cogeneration system was designed to fulfill the maximum steam demand, it would produce reasonably constant electric power at some weekly average level. When electric-power demand exceeds or falls below the system's output, the shortfall is sold to the local utility or purchased from it under a Public Utilities Regulatory Policies Act (Purpa)-based contract. In the case of the steam load, the excess thermal energy must be vented.

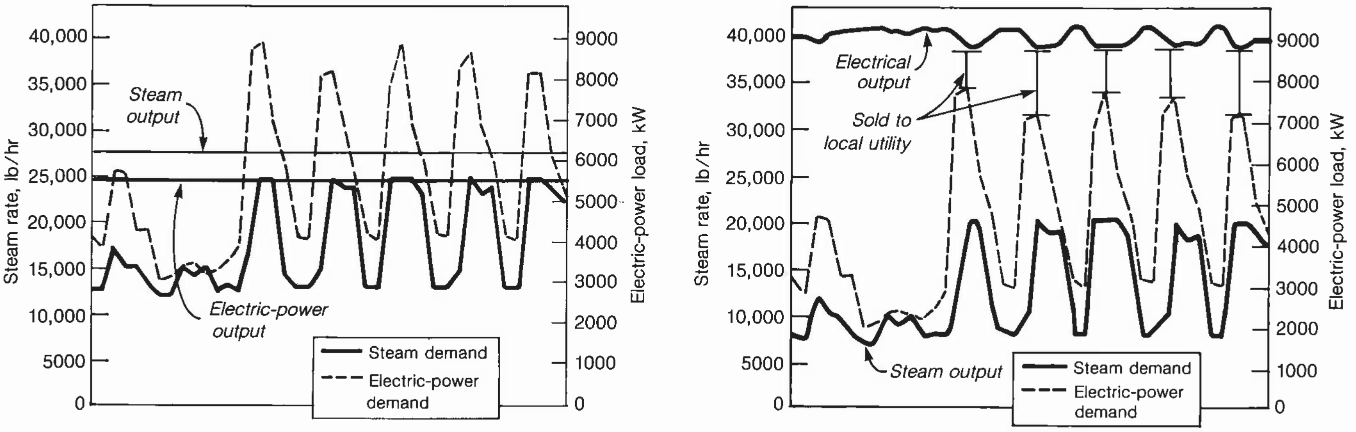
In Fig 2, a steam-injection supply cycle is superimposed on the weekly demand. Here, the HRSG is sized to follow the process-steam demand while the turbines are kept fully loaded. Because electric-power production is always greater than internal demand, it can be sold at attractive buyback rates to the utility.

Fig 3 summarizes this operational flexibility. One line represents the dual load-following characteristics of a conventional plant. The other line is the operating curve of the same gas-turbine system equipped with steam injection.

Reliability. In a conventional plant, the turbine-inlet temperature is constantly cycled to follow steam loads; otherwise, thermal energy must be vented to atmosphere. In a system equipped with steam injection, the inlet temperature can be held constant because the mass flow of the expansion gases varies instead of the inlet temperature. In most cases, the entire range of process-steam flows can be accommodated at constant firing temperature. Thermal cycling of hot gas-path components directly affects the long-term reliability of the machine.

Supplementary firing. Both conventional cogeneration cycles and steam-injection cycles benefit from the addition of an auxiliary burner in the exhaust duct. If multiple units are installed and one is down for maintenance, the single HRSG with the auxiliary burner can, in many cases, carry the full process load.

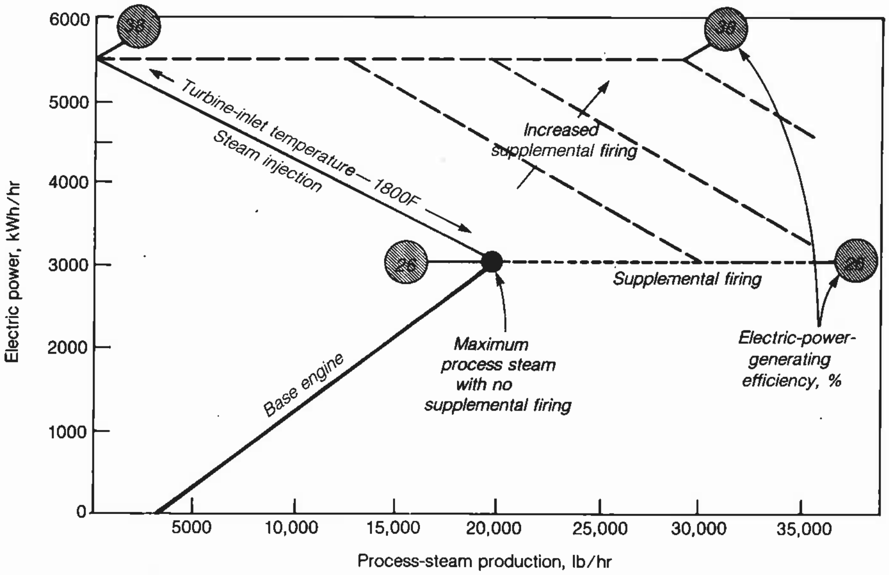
But the duct burner is even more efficient in the steam-injection cycle. As configured here, it is about 96% efficient in converting fuel energy to steam based on lower heating value; a stand-alone process boiler is typically 60-80%. The gain is due to the higher moisture con-



2. Output and demand curves are better matched with steam injection (right) than with base engine/HRSG (left). This advantage helps steam-injection technology compete against combined-cycle plants tent of the turbine exhaust—about 15% by weight at full injection. The specific heat of water is nominally twice that of air. Thus, heat-transfer efficiency in the tubes is greater. Another advantage is that low-Btu gas and biomass can be used in duct burning applications.

A steam-injection cycle as described here will always perform with higher efficiency than the base engine. For example, to qualify as a cogenerator, based on the Federal Energy Regulatory Commission (FERC) guidelines of about 5700 lb/hr of steam to process—the steam-injection cycle is about 35%. Compare this to the 26% maximum efficiency available from the base engine without heat recovery.

The electric-power-generating efficiency of the steam-injection cogeneration cycle will invariably be higher than the average efficiency of the utility. Assuming that the avoided cost for electric-power purchase is based largely on the cost of fuel, then a cogeneration plant that meets its steam requirements with higher efficiency than the utility will always have the greatest immunity from fluctuations in the avoided cost.



3. Supplemental firing, though requiring more fuel, expands the operating regime

Commercial status

The city of Santa Clara, Calif, has submitted a letter of intent for two of the gas-turbine cogeneration sets described here to provide it with baseload electric power, and heating and air conditioning of local buildings. Steam will be sold to a nearby paper mill. Startup is expected in early 1984.

In addition, the state of California has selected this cogeneration system for the state university campus at San Jose. The project is one of several state-sponsored cogeneration projects—the majority of them so far have selected combined-cycle installations. This brings up an interesting point: At least some evaluaters believe that simple-cycle gas turbines with steam injection can compete against combined-cycle technology.

Edited by Jason Makansi