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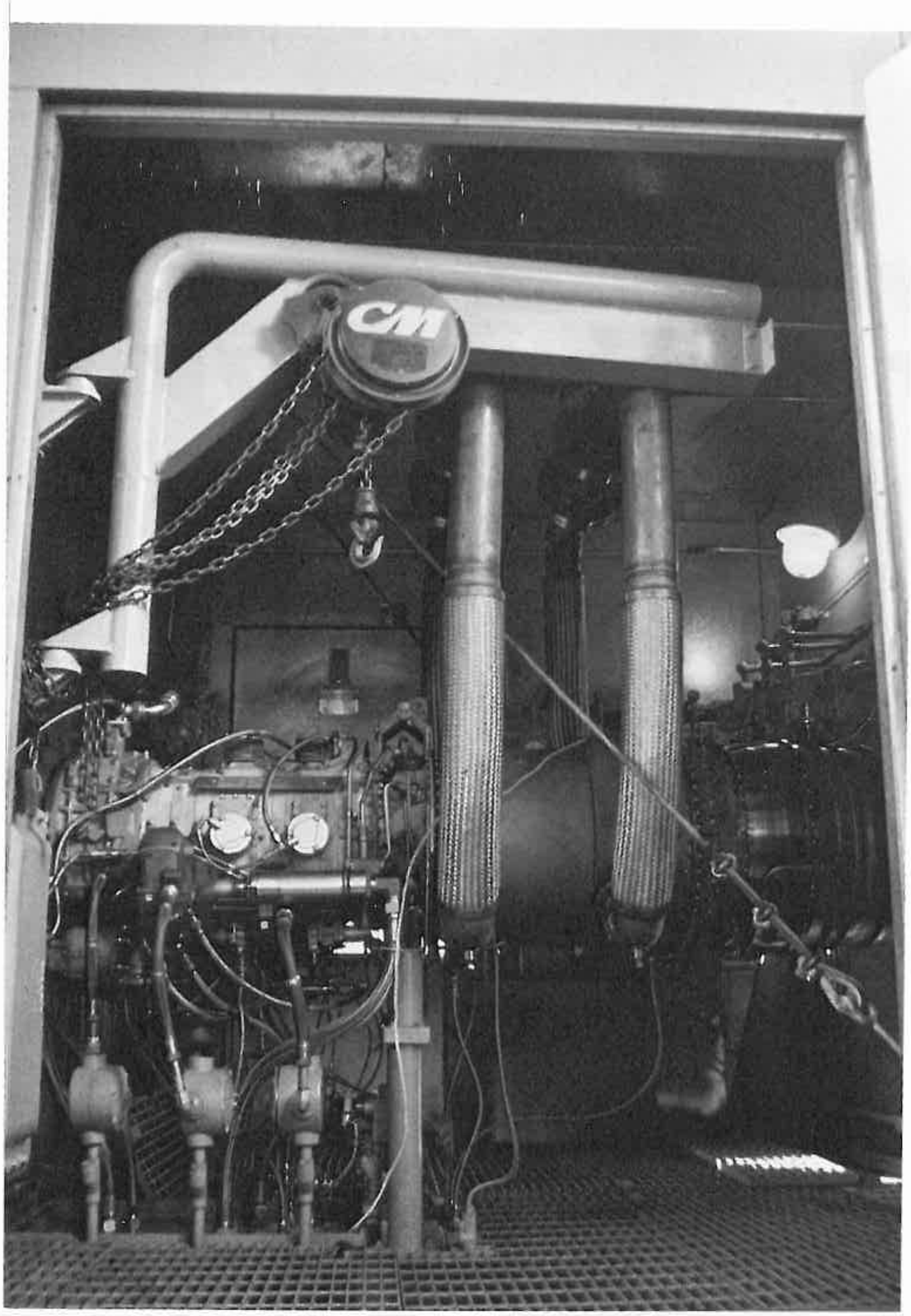
Waste Heat Steams Ahead With Injection Technology



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Owners of Commercial-Industrial-Institutional buildings whose thermal usage is too variable to implement cogeneration are looking to a gas-turbine steam-injection technology, called the Cheng Cycle, to reduce their energy costs.

The Cheng Cycle uses industrial components—a gas-turbine generating set, a waste-heat recovery steam generator and system controls—in a thermodynamically optimized mode. In the process, steam produced from waste heat can be used for space or process heating or to increase the electrical output of a gas turbine. The process was patented in 1974 by Dr. Dah Yu Cheng, of the University of Santa Clara, Santa Clara, Calif.

When a plant's thermal needs fall because of production or temperature changes, unused steam is directed back to the turbine to increase electrical output. As thermal requirements rise, the process is reversed and needed steam is channeled to plant uses.

The system's ability to be changed to work at different sites with minimal redesign in the major equipment package provides users with a flexibility greater than conventional simple-cycle turbine systems. Simple-cycle systems vary steam production by venting unneeded steam into the atmosphere or by reducing the turbine's operating temperature to reduce heat content of the exhaust gas. Both methods waste energy. Systems, such as combined-

Steam-injected gas turbine provides thermal and electrical power at Sunkist Growers plant. Excess power is sold to a local utility company.

Figure 1c). The operating point is determined by process steam demand. Electrical power output is allowed to float.

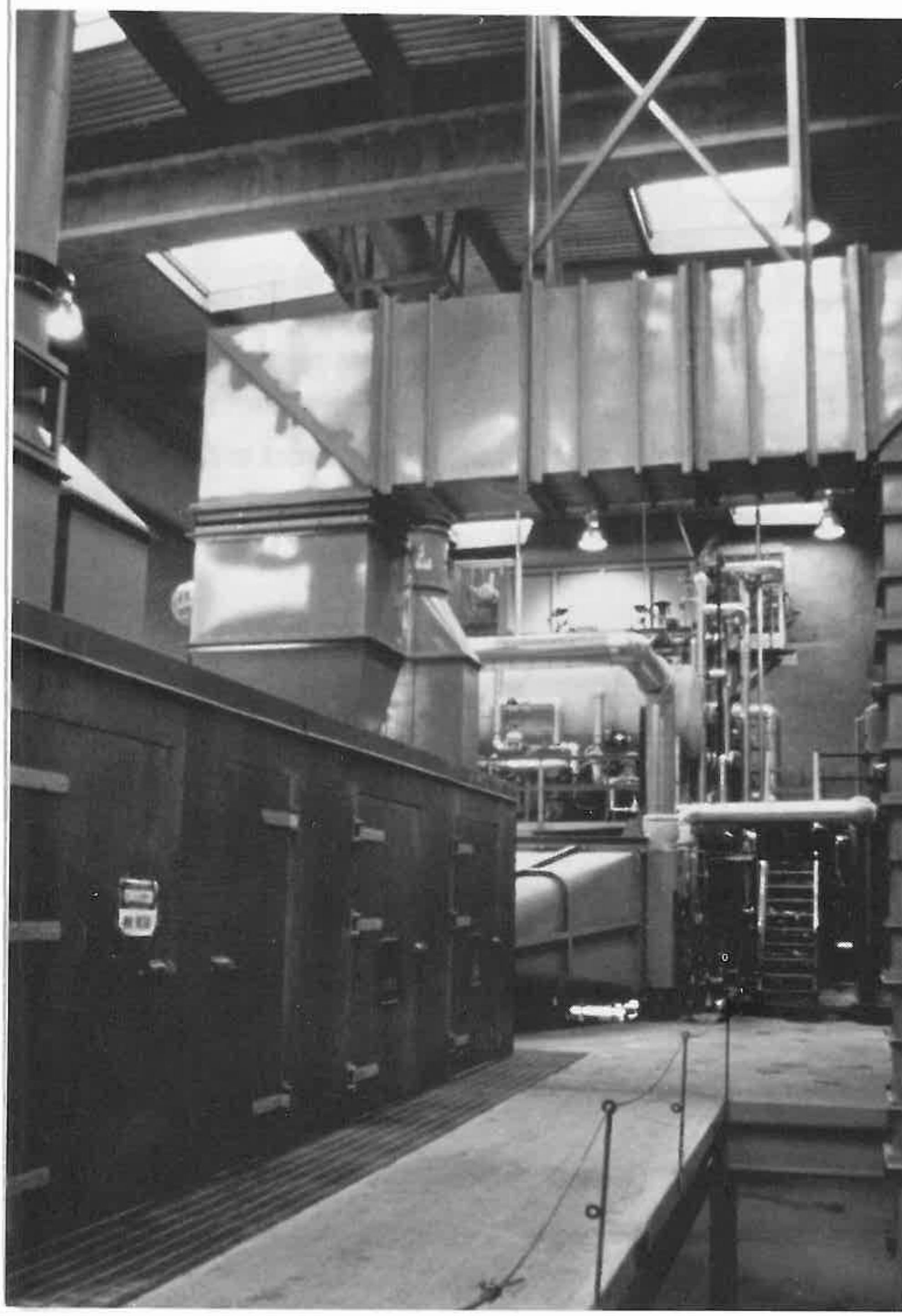
A second mode occurs during periods of high electrical rates. During these periods electrical output should be maximized. The system operates along line 1-4 (see Figure 1c). The third mode occurs during an outage or low-electricity buyback rates. In this mode, thermal and electrical output are matched to the requirements of the site. The operating point in this mode could be anywhere in the operation (Regions A, B or C in Figure 1c).

The operating mode is chosen automatically by the control computer, based on real-time load and price information. Automated controls minimize costs and ensure optimal operations.

Using the Cheng Cycle, turbine life and mean time between overhauls are increased. As long as the system operates in Region A, turbine operating temperature remains constant. The Cheng Cycle system will not derate or decrease its thermal load. Eliminating thermal cycling can significantly add to turbine life.

Using steam injection, a 21% increase in power turbine output increases the net power by up to 70%. Most of the power turbine output goes to driving the compressor, while 30% is used for work.

Water quality requirements for the system are set by the boiler rather than the gas turbine. The Series 7's pressure of 200 psi offers no carryover of impurities from the drum to the superheater. Guidelines for low-pressure boilers are adequate for design of the system, but the designer may want to assess the trade-offs between blowdown and water treatment costs.



L-shaped air duct above gas-turbine housing provides filtered air for a Cheng Cycle system at San Jose State University in San Jose, Calif. Turbine exhaust is vented through a triangular-shaped transition duct into a waste-heat boiler, where steam is produced for injection into a gas turbine.

Simple, conventional cycles

Two conventional systems used to keep costs down are simple- and combined-cycle cogeneration. A simple-cycle system's gas turbine exhausts hot gas into a waste-heat steam generator (see Figure 2).

If the thermal load drops below the rated design point for significant periods of time, the simple-cycle system will not run efficiently. If that happens, two options are available: 1) bypass the exhaust around the boiler and reduce the steam output, or 2) derate the gas turbine and reduce the thermal steam and electrical output (see Figure 1a).

Bypassing the exhaust creates wasted energy, and derating the system means lowering the output of a large capital investment. In either case, returns on investments for a project are reduced. The simple-cycle system best applies to constant load situations.

One solution to the problem of fluctuating thermal loads is a combined-cycle system. One variation consists of a gas turbine exhausting hot gas into a steam generator. The generator sends steam to an extraction-condensing steam turbine (see Figure 3).

This provides an economic alternative to bypassing the exhaust or derating the turbine. Steam not needed for process is expanded throughout the turbine and condensed, producing more electricity (see Figure 1b).

In most cases, the combined-cycle system boosts economic return enough to justify the investment. But

FIGURE 1

COGENERATION CYCLES

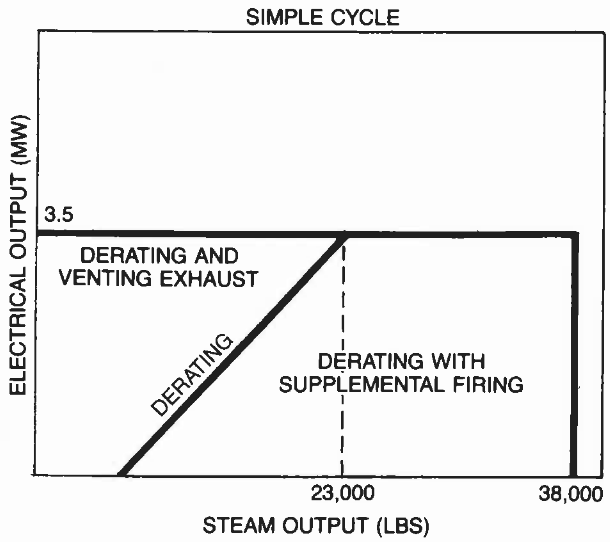


FIGURE 1(A)

Operating regimes, the range of steam-electrical output in which equipment can safely be operated, are shown for the simple cycle (a), combined cycle (b), and Cheng Cycle (c) cogeneration systems.

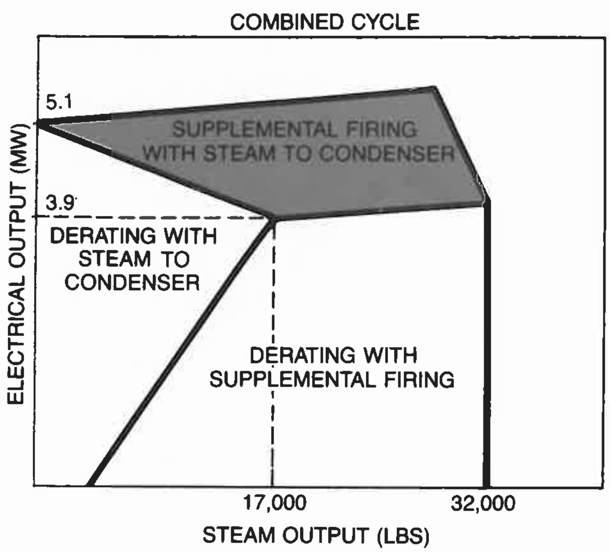


FIGURE 1(B)

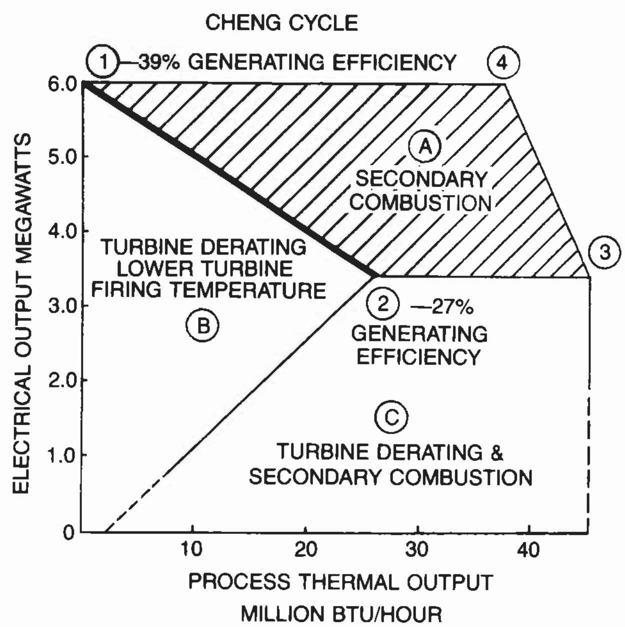


FIGURE 1(C)

Steam-injected gas turbine cycle provides operating flexibility, simplified equipment configuration and reduced energy costs

cycle systems, also waste energy.

Steam injection systems, however, cost up to 18% more than conventional gas turbine systems. But the difference, on the average, can be made up in 18 to 36 months by increasing electricity output with steam that would otherwise be wasted.

Steam injection technology is not new. Experiments have been performed on it since 1905. But until Cheng's discovery in 1974, experiments have been limited to NO× control, or simple-power augmentation.

Cheng gained insight into the nature of steam-to-air ratios, steam-to-fuel ratios and other cycle parameters in optimizing the efficiency of the steam-injected gas turbine cycle.

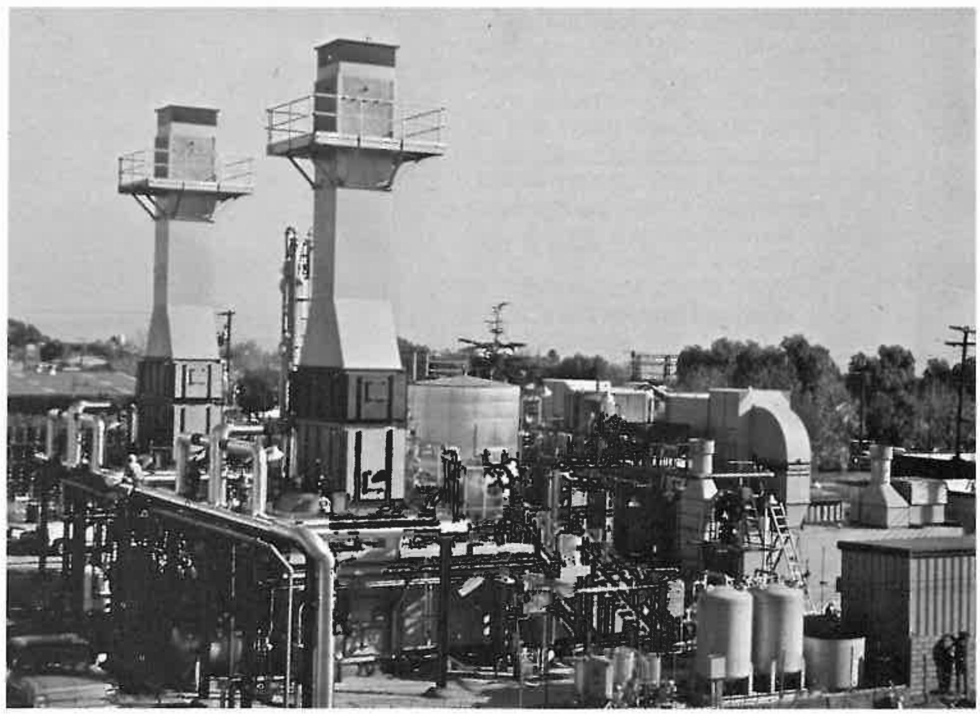
The first commercial application of the concept is a system that can produce up to 6 Mw of power and 45,000 lb of steam per hour. Prime mover is a modified Allison 501 gas turbine.

This system's waste-heat recovery steam generator (HRSG) is very similar to a conventional waste-heat boiler with two exceptions—the addition of a superheater upstream of the evaporator and the controlled ratio of surface areas between the superheater and evaporator.

The cycle's control system, which coordinates the equipment through distributed-digital-control hardware, operates on two levels—supervisory and functional. The supervisory level controls the system on a real-time basis and is programmed for optimization of energy. Performance characteristics and current energy prices are considered also.

A functional level controls the physical parameters (fuel flow, steam flow, etc.). This level implements the operating strategy chosen by the supervisory level and ensures that process requirements are met.

The operating regime, the range of steam-electrical output in which equipment can be operated, is shown in Figure 1c. The line from point one to point two indicates power and thermal output for operation at constant-rated turbine inlet temperature and various levels of steam injection.



Sunkist Growers' cogeneration plant in Ontario, Calif., operates around the clock on twin systems.

At point two, no steam is injected. Power and thermal output are equal to a simple-cycle cogeneration plant. At point one, all available thermal energy is used to produce injection steam, so power and generating efficiency are maximized. (The turbine operating temperature does not change along line 1-2. But the amount of steam injection does.)

Region A in Figure 1c shows supplemental firing in the HRSG. This allows the system to produce any combination of electrical and thermal outputs within the region. As before, the turbine operates at constant temperature throughout the regime.

In most applications, the system will operate almost exclusively in Region A. But when load requirements or economics dictate, it can operate in Regions B and C. Region B represents steam injection with lower turbine inlet temperature. It can be visualized as a series of lines parallel to line 1-2, each representing progressively lower turbine firing temperatures. Region C represents lower turbine inlet temperatures with supplemental firing but without steam injection.

The user can have three modes of operation, which depend on load and energy requirements. The most typical mode operates along line 1-2-3 (see the combined-cycle systems are more mechanically complex than simple-cycle systems and have higher investment and operating costs.

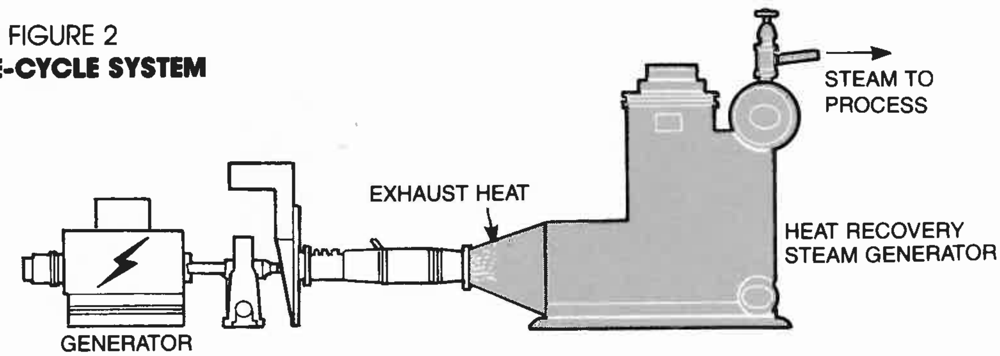
Compared to other cycles, the Cheng Cycle and the simple cycle are mechanically simple (see Figure 4). Comparing those two, the Cheng Cycle has greater operating flexibility than the simple cycle (see Figure 1c). Compared to the combined-cycle system, the Cheng Cycle is not as complex and has greater flexibility and performace for thermal and electrical output.

To date, two users have implemented the technology—San Jose State University, San Jose, Calif., and Sunkist Growers Inc., Ontario, Calif.

San Jose State selected a $7-million, 6-Mw system because it meets the university's steam and electrical loads while producing power during offpeak periods—on weekends and during the summer. A boiler plant acts as a backup during maintenance.

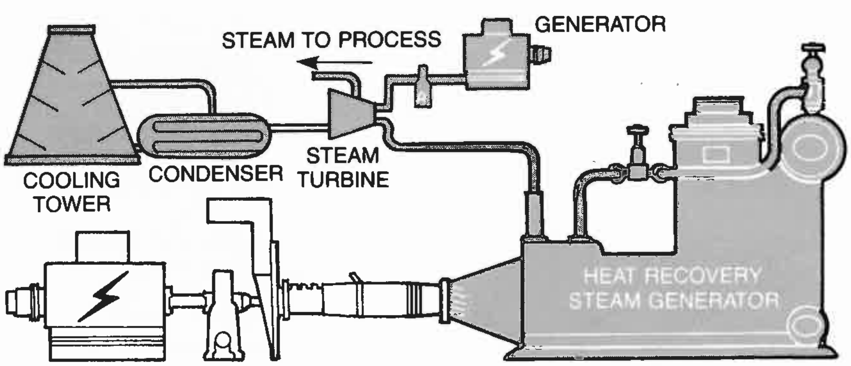
Sunkist selected the technology because they have a steam load that fluctuates with the citrus-growing season. Twin systems, at $13 million, operate around the clock, providing electrical and thermal power to Sunkist's plant. Excess power produced by both groups is sold to local utility companies. Both facilites were third-party financed. □

FIGURE 2
SIMPLE-CYCLE SYSTEM



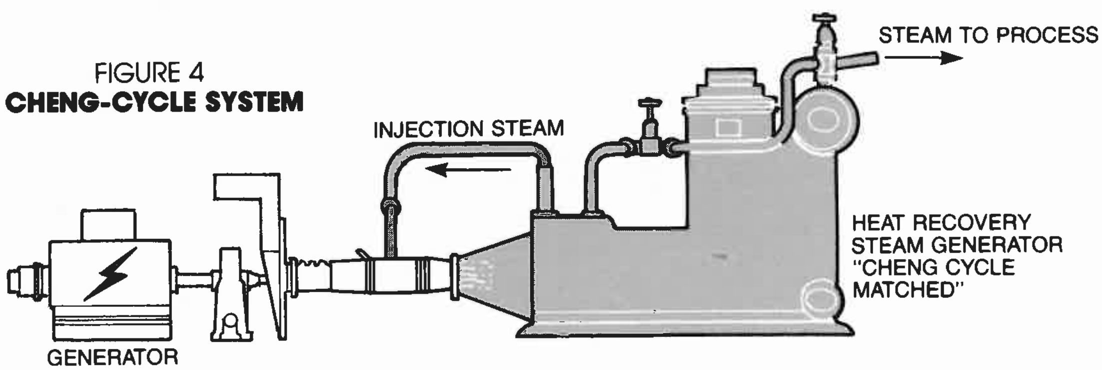
Simple-cycle system's gas turbine exhausts hot gas into a waste-heat steam generator.

FIGURE 3
COMBINED-CYCLE SYSTEM



Combined-cycle system's gas turbine exhausts air into a steam generator, which sends it to an extraction-condensing steam turbine.

FIGURE 4
CHENG-CYCLE SYSTEM



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