A cogeneration plant produces two forms of energy using a single source. Today, the term typically describes a system which generates (1) electricity through the use of the gas turbine and (2) steam. Both the output of the gas turbine and the generation of steam depend upon a single source of heat.

Typically, natural gas is burned and the hot combustion gases pass through the turbine which drives a generator to create electricity. The waste gases are directed through a waste heat boiler to create steam. This steam can be utilized to fulfill a thermal demand or, alternatively, pass through a steam turbine creating additional electricity.

The gas turbine operates in accordance with the Brayton Cycle while the steam turbine operates under the physics of the Rankine Cycle.

These advanced technologies for achieving operational flexibility, such as the combined cycle described above, do so with the addition of complex subsystems. Substantial downtime and maintenance costs are often the result of this additional mechanical complexity. The Cheng cycle systems which will be described in this paper involve no more mechanical complexity than conventional simple cycle gas turbine systems. The results are high system availability and low maintenance costs. The systems are designed as integral packages which differ little from one installation to the next. In an arrangement incorporating the Cheng cycle, the steam in the waste heat boiler is superheated and injected into a modified gas turbine to greatly improve the power output and operating efficiency of the unit. The Cheng Cycle achieves a large increase in net power output but, since compressor power requirements (the largest demand on the turbine) are generally insensitive to steam injection level, a large increase in net power output requires a much smaller increase in total power turbine output. Thus an increase of 70% net power output would require only about a 20% increase in total power turbine output. These numbers apply to gas turbines in sizes up to 15,000 horsepower. For larger units, the conventional combined cycle cogeneration unit will offer an increase in power output and heat rate comparable to the Cheng Cycle.

The advent of the cogeneration process has greatly increased the demand for gas turbines. Many of these units are used by electric utility companies as simple-cycle peak load installations. In these units, the utility power producers are providing for peak load and for emergency conditions by building stand-by turbine generating systems.

Typical of these units is the Iowa Electric Light and Power facility dedicated in July 1990. At this unit, outside of Des Moines, two gas turbine stand-by units are available as needed. They can be fired by oil or gas and have "remote start" and "no staff" operating capabilities. They also can provide full service (35 MWe each) within 20 minutes of start. These units will be used when the electric supply to the Des Moines area has been interrupted by storms or other damage to the transmission system.

In a cogeneration plant, by contrast, the waste heat is utilized to convert water to steam. This steam, the thermal component of the energy produced, can then be used in a nearby plant or facility as processed steam. Or, it can be utilized to drive a steam turbine to generate additional electricity in what is termed a "combined cycle" plant.

U.S. commercial electric utility power producers ordered 11 gigawatts (GWe) of new electrical capacity during 1990 and
more than two-thirds of this capacity was gas turbine generation.

About one-half of the total amount of electric power produced by gas turbine technology is generated by facilities that are not part of the electric utility industry. These are typically industrial plants, colleges, food processors, or partnerships set up specifically to provide a source of process steam for a specific need and to generate electricity. Federal regulations mandate that any excess electrical power so generated be purchased by the relevant commercial electric utility company at an "avoided cost" basis. Thus, an assured market is available to the cogenerator for any excess electric power generated. The economics of this technology have proved so promising that non-utility power producers have planned to put 34 gigawatts of new capacity on stream by 1999.

The conventional gas turbine runs efficiently when thermal load is constant. When demand for steam is variable, however, the single-cycle unit becomes very expensive to operate. It must be designed to handle economically the maximum demand for steam. When demand falls below this level, the only option is to bypass the boiler with some of the off-gas thus reducing steam output or to derate the unit and reduce both steam and electrical production. Either option is expensive.

The Cheng Cycle unit, by contrast, is highly efficient, cost effective, and in many ways a less complex facility which can handle a wide range of thermal demand without loss of efficiency. This patented process is offered worldwide by International Power Technology of Redwood City, California, and its licensees.

The unit is designed so that the heat recovery steam generator (HRSG) is large enough to create sufficient steam so that the unit can handle the maximum thermal demand from the system.

When steam demand is high within the cogeneration system, little or no steam will be released to the gas turbine. But, when such demand is low, the efficiency of the gas turbine can be greatly enhanced by utilizing the steam injection feature to the maximum. The heat recovery steam generator can be designed to provide excess capacity for those occasions in which steam and electricity demand are both at a maximum.

Use of these options enables the Cheng Cycle turbine to achieve the 70% increase in net power output and efficiency cited above.

The Cheng Cycle was commercialized in 1982 after years of development. Today, there are a number of plants currently on stream utilizing this technique and operation in Europe, the U.S.A., and Japan.

Because of the importance of maintaining the proper relationship among all the system components, International Power Technology offers a complete unit in which the special gas turbine, manufactured by the Allison Division of General Motors (the conventional Model 501 adapted to steam injection and designated 501KH) is correlated to the HRSG unit to provide up to 6 MWe and 20,430 Kg of steam per hour. The control system is configured to assure entire flexibility and optimum operating efficiencies. In a typical application at San Jose State University, which has been operational since 1984, a single Cheng Cycle unit provides all the needed steam from a peak demand of 13,600 Kg per hour to 0 and all the electricity required to fulfill a need of 5 MWe.

A smaller unit (2.5 MWe) is offered by Industrial Power Technology as well, utilizing a Kawasaki Industrial Gas Turbine unit modified for steam injection.

One of the critical elements of the system is the HRSG. This is really a waste heat boiler with a superheater and an evaporator with a burner in between.

Careful control of the ratio of the surface area in the superheater with that in the evaporator is critical to efficient operation of the unit. The boiler used in the International Power Technology unit is of standard design, and engineering calculations needed to optimize the performance of the HRSG over differing gas flows, inlet gas temperatures, gas analyses, steam pressures and feed water temperatures must be made by the supplier of the unit. Such performance calculations are described by Mr. V. Ganapathy, heat transfer specialist of Abco Industries, Inc. of Abilene, Texas, in a memorable article which appeared in Hydrocarbon Processing, March 1990. Abco has designed, fabricated, and supplied the HRSG unit in many of the International Power Technology cogeneration plants.

One of the conditions which the supplier of the boiler package must assure is that of absolutely clean steam leaving the superheater and moving into the turbine. Any metallic-oxide particles which would impact on the blades of the gas turbine would damage the unit, and a quantity of such contaminates would quickly destroy it.

The inside of the tube is subject to oxidation, erosion, and exfoliation. Abrasive attack, over a period of time, can occur as well. The problem with any of these forms of degradation is not so much damage to the tubing, although that is important, but the fact that corrosion product will move downstream with the steam into the turbine.

The outside surface of the tubes is also subject to corrosive attack, depending upon the nature of the high-temperature heating gases employed. Oxidation, sulfidation, attack by molten salts, such as sulfates, nitrates, or even vanadates, can be present and corrosive depending upon the fuel used and the nature of the heating gases.
To assure the long-term cleanliness of the steam, Abco specified that the ALON™ aluminum pack cementation process be applied to the alloy fin tubes in the superheater and the inlet pipes leading from the superheater to the gas turbine.

The surface produced by the ALON™ process eliminates scaling and reduces corrosion on metallic surfaces exposed to high-temperature oxidation, sulfidation, and/or carburization. The process is a high-temperature vapor diffusion process during which aluminum is deeply alloyed into the surface of a steel, alloy, or stainless substrate.

This is not a coating operation. Rather, a true metallurgical alloy is formed which remains an integral part of the base material.

Prior to processing, the pieces are first cleaned to remove any mill scale, weld slag or spatter, oil or grease. The cleaned components are then placed into a steel retort, which can measure up to 3' x 6' x 50'. A powder mixture consisting of aluminum, alumina, and an activator is used to fill the inside of the tubes and to completely surround each individual tube inside the retort. When the retort is completely filled with tubing and processing powder, the top of the retort is hermetically sealed.

The process itself begins when the loaded retort is placed within the furnace. The temperature is raised to over 1750°F and maintained at that level for a period of approximately 24 hours. At this temperature, the aluminum component in the powder mix vaporizes and is diffused at the ionic level into the surface of the steel. Following the heating cycle, the retort is cooled, the tubes removed, and metallurgical tests taken to assure compliance with specifications. The tubes are then re-straightened and shipped to the client.

Diffusion process times and temperatures vary depending upon the nature of the substrate. Stainless steel or high nickel superalloys require higher process temperatures and longer cycles. Ferritic alloy materials containing more than 2-1/4% Cr are slow cooled to a temperature of 1100°F at a predetermined cooling rate before being allowed to cool further to room temperature.

On the surface, the aluminum-rich diffusion is virtually impervious to high-temperature oxidation, sulfidation, and/or carburization. Since the process adds nothing to the mechanical strength of the steel, it is necessary to observe requirements for mechanical properties if ASME or other Code specifications are going to be followed during construction of the unit utilizing the ALON™ processed components.

In addition to being oxidation-resistant, the ALON™ surface is very hard (approximately Rc 53) and will remain free of scale.
The choice of the ALON\textsuperscript{TM} process was made by Abco in order to assure that the superheater tubes and inlet piping would remain clean, that they would not scale or exfoliate, and to reduce potential occurrence of breakdown while in service. Otherwise, metallics would be introduced into the superheated steam to the detriment of the steam turbine downstream. The possibility of such an occurrence is greatly enhanced by the engineered flexibility which is the hallmark of the Cheng unit. Cycling the boiler on and off as steam/thermal demand varies will tend to promote scaling and exfoliation. A metallic tube surface stable under these conditions was an absolute design criterion.

A series of scale traps was used in the superheater unit and, after a brief initial show of some powder found to be a residuum of the alumina used in the ALON\textsuperscript{TM} process, the unit ran clean and scale-free. After the initial installation, Alon modified the post process cleaning requirements to ensure removal of alumina powder.

There are two additional advantages to the Cheng cycle technology.

1) NO\textsubscript{x} suppression. NO\textsubscript{x} emissions are reduced from 100/130 to 10/20 ppmv (dry @ 15\% O\textsubscript{2}). This is due to the fact that the water buffers the peak flame temperature, and the large volume of steam present reduces O\textsubscript{2} partial pressure.

2) Constant firing temperature. Under most operating conditions, the Cheng Cycle regime will fire at constant temperature. Decrease in steam demand does not result in a system derate. This adds significantly to the life of the turbine and extends time between overhauls.

Today, thanks to a variety of carefully developed fabrication, assembly, and operating techniques and to a series of state-of-the-art components engineered to be fully compatible, the Cheng Cycle cogeneration plants are the most efficient, flexible, and cost effective units available in their range of capacity.

REFERENCES


