CHAPTER 8

COMBINED CYCLE POWER PLANTS

Section 1. TYPlCAL PLANTS AND CYCLES

8-1. Introduction

a. Definition. In general usage the term ' 'combined cycle power plant" describes the combination of gas turbine generator(s) (Brayton cycle) with turbine exhaust waste heat boiler(s) and steam turbine generator(s) (Rankine cycle) for the production Of electric power. If the steam from the waste heat boiler is used for process or space heating, the term "co-generation" is the more correct terminology (simultaneous production of electric and heat energy).

b. General description.

(1) Simple cycle gas turbine generators, when operated as independent electric power producers, are relatively inefficient with net heat rates at full load of over 15,000 Btu per kilowatt-hour. Consequently, simple cycle gas turbine generators will be used only for peaking or standby service when fuel economy is of small importance.

(2) Condensing steam turbine generators have full load heat rates of over 13,000 Btu per kilowatt-hour and are relatively expensive to install and operate. The efficiency of such units is poor compared to the 8500 to 9000 Btu per kilowatt-hour heat rates typical of a large, fossil fuel fired utility generating station.

(3) The gas turbine exhausts relatively large quantities of gases at temperatures over 900 "F, In combined cycle operation, then, the exhaust gases from each gas turbine will be ducted to a waste heat boiler. The heat in these gases, ordinarily exhausted to the atmosphere, generates high pressure superheated steam. This steam will be piped to a steam turbine generator. The resulting "combined cycle" heat rate is in the 8500 to 10,500 Btu per net kilowatt-hour range, or roughly one-third less than a simple cycle gas turbine generator.

(4) The disadvantage of the combined cycle is that natural gas and light distillate fuels required for low maintenance operation of a gas turbine are expensive. Heavier distillates and residual oils are also expensive as compared to coal.

8-2. Plant details

a. Unfired boiler operation. For turbines burning natural gas or light distillate oil, the boiler will be of the compact, extended surface design with either natural or forced circulation with steam generated at approximately 650 psig and 825°F. The addition of the waste heat boiler-steam turbine generator combinations increases power output over the simple gas turbine.

b. Fired boiler operation. The exhaust from a gas turbine contains large amounts of excess air. This exhaust has an oxygen content close to fresh air, and will be utilized as preheated combustion air for supplementary fuel firing. Supplementary fuel firing permits increasing steaming of the waste heat boiler. Burners will be installed between the gas turbine exhaust and the waste boiler to elevate the exhaust gases to the heat absorption limitations of the waste heat boiler. Supplementary burners also permit generation when the gas turbine is out of service.

c. Other types of combined cycle plants. Variations of combined cycle plants areas follows:

(1) Back pressure operation of the steam turbine. This may include either unfired or fired boiler operation. The steam turbine used is a non-condensing machine with all of the exhaust steam utilized for heating or process at a lower pressure level.

(2) Controlled (automatic) extraction operation of the steam turbine. This may also include either unfired or fired boiler operation. A controlled extraction steam turbine permits extraction steam flow to be matched to the steam demand. Varying amounts of steam can be used for heating or process purposes. Steam not extracted is condensed. This type of steam turbine will only be used when electrical requirements are very large (see Chapter 1).

Section II. GENERAL DESIGN PARAMETERS

8-3. Background

A combined cycle power plant is essentially comprised of standard equipment derived from both gas turbine and steam turbine power plants. The waste heat boiler is different in design, however, from a normal fossil fueled boiler. Feedwater heating is usually less complex. Power plant controls must take into account the simultaneous operation of gas turbine, boiler and steam turbine.

8-4. Design approach

a. Operating differences. The following items should be given consideration:

(1) *Turndown.* Gas turbine mass flows are fairly constant, but exhaust temperature falls off rapidly as load is reduced. Therefore, decreasing amounts of steam are generated in the waste heat boiler. Variations in gas turbine generator output affect the output from the steam turbine generator unless supplementary fuel is fired to adjust the temperature. Supplementary fuel firing, however, decreases combined cycle efficiency because of the increased boiler stack gas losses associated with the constant mass flow of the turbine.

(2) *Exhaust gas flows.* For the same amount of steam produced, gas flows through a combined cycle boiler are always much higher than for a fuel fired boiler.

(3) *Feedwater temperatures.* With a combined cycle plan, no air preheater is needed for the boiler. Hence, the only way to reduce final stack gas exit temperature to a sufficiently low (efficient) level is to absorb the heat in the feedwater with economizer recovery equipment. Inlet feedwater temperature must be limited (usually to about 250°F) to do this.

b. Approaches to specialized problems:

(1) *Load following.* Methods of varying loads for a combined cycle include:

(a) Varying amount of fuel to a gas turbine will decrease efficiency quickly as output is reduced from full load because of the steep heat rate curve of the gas turbine and the multiplying effect on the steam turbine. Also, steam temperature can rapidly fall below the recommended limit for the steam turbine.

(b) Some supplementary firing may be used for a combined cycle power plant full load. Supplementary firing is cut back as the load decreases; if load decreases below combined output when supplementary firing is zero, fuel to the gas turbine is also cut back. This will give somewhat less efficiency at combined cycle full load and a best efficiency point at less than full load; i.e., at 100 percent waste heat operation with full load on the gas turbine.

(c) Use of a multiple gas turbine coupled with a waste heat boiler will give the widest load range with minimum efficiency penalty. Individual gas turbine-waste heat units can be shut down as the load decreases with load-following between shutdown steps by any or both of the above methods.

(d) Installation of gas dampers to bypass variable amounts of gas from turbine exhaust directly to atmosphere. With this method, gas turbine exhaust and steam temperatures can be maintained while steam flow to steam turbine generator is decreased as is the load. This has the added advantage that if both atmospheric bypass and boiler dampers are installed, the gas turbine can operate while the steam turbine is down for maintenance. Also, if full fuel firing for the boiler is installed along with a standby forced draft fan, steam can be produced from the boiler while the gas turbine is out for maintenance. This plan allows the greatest flexibility when there is only one gas turbine-boiler-steam turbine train. It does introduce equipment and control complication and is more costly; and efficiency decreases as greater quantities of exhaust gas are by passed to atmosphere.

(2) *Boiler design.*

(a) Waste heat boilers must be designed for the greater gas flows and lower temperature differentials inherent in combined cycle operation. If a standby forced draft fan is installed, the fan must be carefully sized. Gas turbine full load flow rates need not be maintained,

(b) If the fuel to be fired, either in the gas turbine or as supplementary fuel, is residual oil, bare tubes should be used in the boiler with extended surface tubes used in the economizer only. This increases the boiler cost substantially but will preclude tube pass blockages. Soot blowers are required for heavy oil fired units.

(3) Feedwater *heating and affect on steam generator design.*

(a) Because of the requirement for relatively low temperature feedwater to the combined cycle boiler, usually only one or two stages of feedwater heating are needed. In some cycles, separate economizer circuits in the steam generator are used to heat and deaerate feewater while reducing boiler exit gas to an efficient low level.

(b) For use in military installations, only cogeneration combined cycles will be installed. A typical cycle diagram is shown in Figure 8-1.

(4) *Combined cycle controls.* There is a wide variation in the controls required for a combined cycle unit which, of course, are dependent on the type of unit installed. Many manufacturers have developed their own automated control systems to suit the standardized equipment array which they have developed.

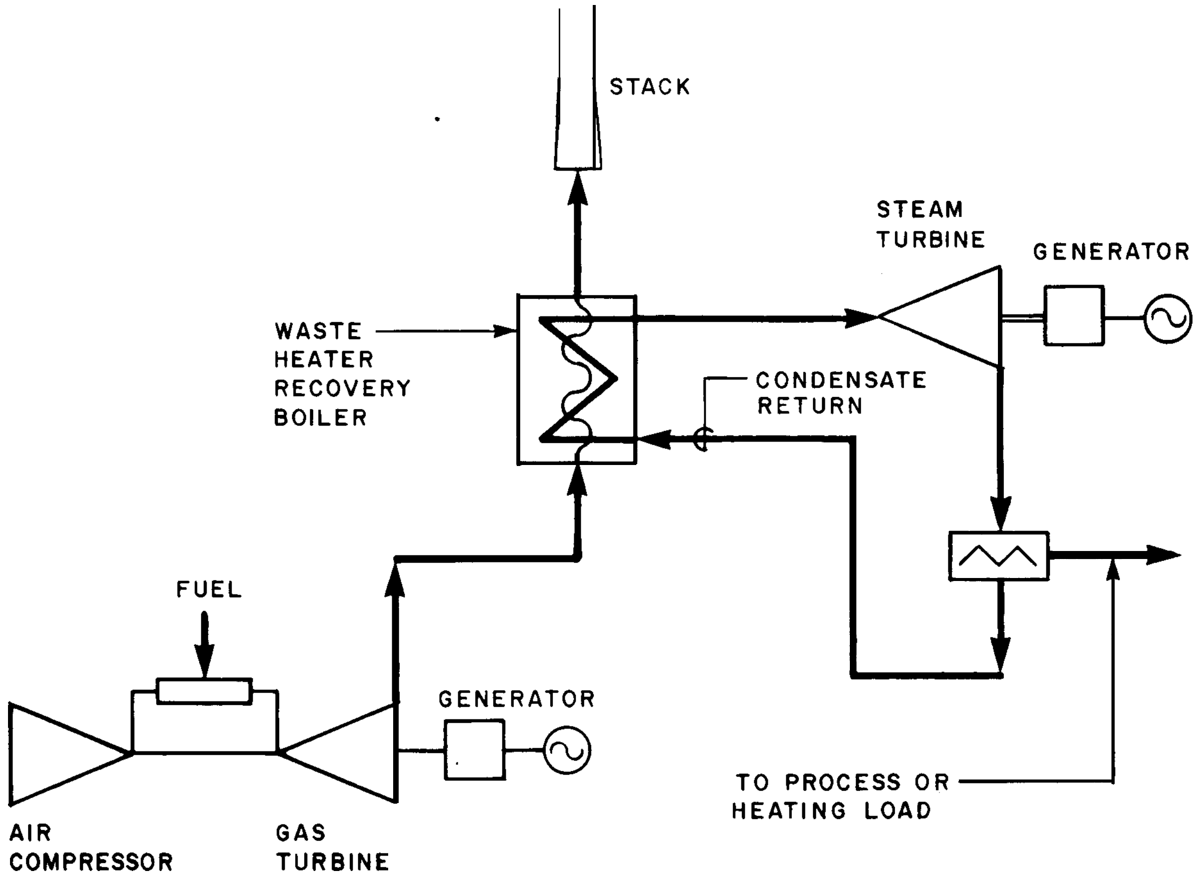

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Figure 8-1. Combined cycle diagram.