7 COMBINED CYCLE POWER PLANTS

Abstract

The excellent efficiencies reached today by combined cycle power plants (above 60% LHV), are the result of integration into a single production unit of two complementary technologies in terms of temperature levels: gas turbines, which operate at high temperature (in a aero-derivative turbine gases typically enter at 1300 °C in the expansion turbine, and come out at around 500 °C), and steam plants, which operate at lower temperatures (between 450 °C and 30 °C in this case).

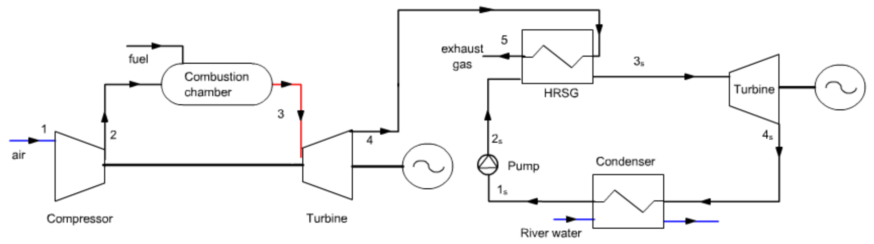

Figure 7.1.1: Sketch of a combined cycle

The principle of a combined cycle is to operate in cascade one or more gas turbines, followed by a steam power plant whose heat source is the cold source of gas turbines (Figure 7.1.1). Under these conditions, the gas turbine exhaust gas is recovered in a recovery boiler that produces steam that is then expanded in a condensing turbine. The combined cycle thus obtained is a particularly successful marriage in the search for improved thermal performance: with currently available machines, efficiencies exceed 55% and are higher than those we can hope, even in the medium term, of the most advanced future steam plants.

As we shall see next section, in a simple combined cycle of the type described below, the gas turbine provides two-thirds of the total capacity. The steam turbine, fueled by superheated steam conditions of 85 to 100 bar and 510 - 540 °C, provides the remaining third.

7.1 COMBINED CYCLE WITHOUT AFTERBURNER

The simplest combined cycle (that is to say, without afterburner) is shown in Figure 7.1.2: as the temperature of the gas turbine exhaust gas can exceed 550 °C, the maximum temperature level reached in a steam cycle, it is quite possible to recover the enthalpy available at the output of a gas turbine to heat a steam cycle.

With some simplifying assumptions, it is possible to construct an entropy chart allowing, for a set of suitable scales, to superimpose the two thermodynamic cycles (Figure 7.1.2). In this diagram, where the work done is proportional to the area of the cycle, the gas turbine provides more power than the steam engine (two-thirds of the total in practice).

We can sometimes improve the cycle efficiency by using the various changes discussed during the presentation of the steam cycle: reheat and extractions.

However, as discussed below, the problem of steam cycle optimization differs substantially from that of large steam power plants, due to the pinch that appears in the heat recovery steam generator (HRSG).

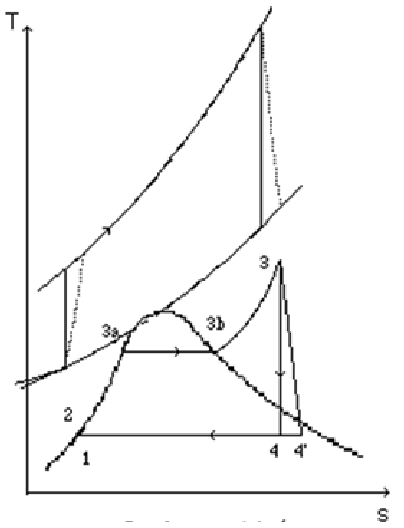

Figure 7.1.2: Combined cycle in the entropy chart

7.1.1 OVERALL PERFORMANCE

The enthalpy exchange in a combined cycle can be summarized by the diagram in Figure 7.1.3.

- the gas turbine receives heat Q_g from the hot source. It provides on the one hand a useful work τ_g, and secondly a heat $(Q_v + Q_p)$. The first term is the heat supplied to the steam cycle, the second losses;
- the steam cycle produces useful work τ_v, and the condenser rejects heat Q_c.

Let us call η_g the gas turbine efficiency, η_v that of the steam cycle, η_{cc} that of the combined cycle, and ε the HRSG effectiveness, that is to say the ratio of Q_v to $Q_p + Q_v$:

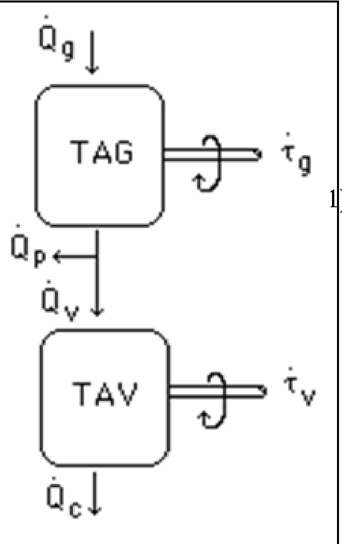

Figure 7.1.3: Block diagram of a combined cycle

$$\varepsilon = \frac{Q_v}{Q_p + Q_v} = \frac{Q_g}{Q_p + Q_v}\frac{Q_v}{Q_g} = \frac{1}{1 - \eta_g}\frac{Q_v}{Q_g}$$

$$\eta_{cc} = \frac{\tau_g + \tau_v}{Q_g} = \eta_g + \eta_v \frac{Q_v}{Q_g} = \eta_g + \varepsilon\,(1 - \eta_g)\,\eta_v$$

$$\eta_{cc} = \eta_g + \varepsilon\,(1 - \eta_g)\,\eta_v \qquad 1)$$

The combined cycle efficiency is equal to the sum of that of the gas turbine and the product of its complement to 1 by the HRSG effectiveness and the steam cycle efficiency.

For example, with $\eta_g = 0.29$, $\eta_v = 0.32$, $\varepsilon = 0.83$, we obtain $\eta_{cc} = 0.48$.

7.1.2 REDUCED EFFICIENCY AND POWER

The reduced power introduced section 2.1.4.2 can also be expressed here as:

$$W_0 = \eta_{cc}\,\frac{\theta - r^{\beta c}}{\theta - 1} \qquad (7.1.2)$$

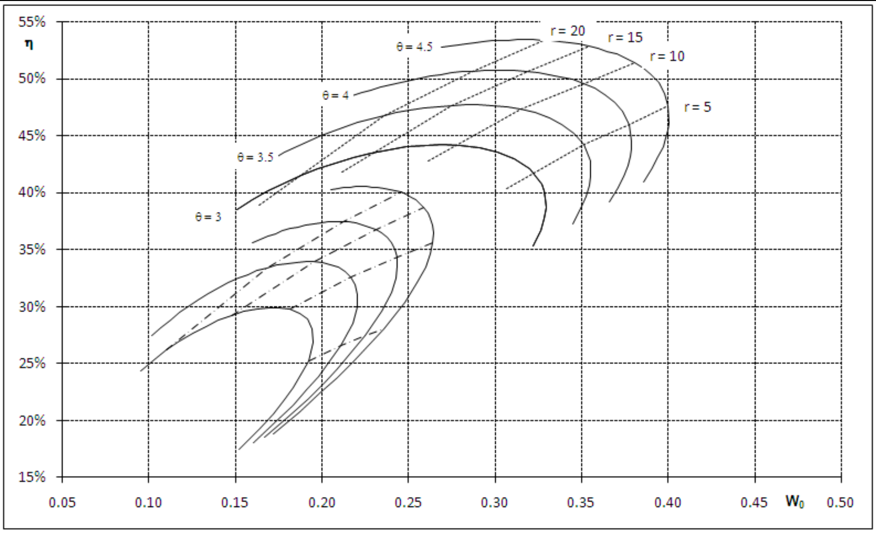

Figure 7.1.4: Efficiency and useful work of a combined cycle

Assuming at first approximation that the steam cycle efficiency varies linearly with gas turbine exhaust temperature, we obtain in terms of overall efficiency and power the abacus shown in Figure 7.1.4. We can recognize the lower left part corresponding to the gas turbine alone (Figure 2.1.13). The contribution of the steam cycle is particularly significant: 50 to 60% more capacity and efficiency gains of 30-50% depending on temperature and compression ratio.

7.2 COMBINED CYCLE WITH AFTERBURNER

It is also possible to perform an afterburning of gas turbine exhaust, to have more power in the steam cycle, and especially to better control the combined cycle. This is called combined cycle with afterburner (Figure 7.2.1). The efficiency drops slightly because of course the heat generated by the afterburner is not valued in the GT. In this case, the total power is divided about equally between each machine.

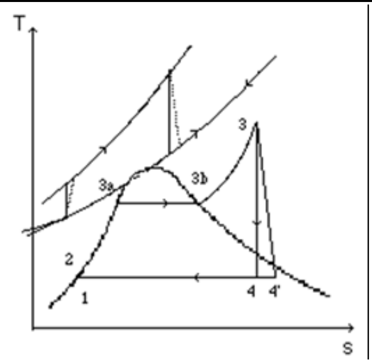

Figure 7.2.1: Combined cycle with afterburner

This type of cycle is mainly appropriate when converting conventional steam plants in combined cycle plants, by adding a topping gas cycle. The conventional plant having its boiler, afterburning can be achieved without needing large investment.