COMBINED GAS–VAPOR POWER CYCLES

- A more popular modification involves a gas power cycle topping a vapor power cycle, which is called the combined gas–vapor cycle, or just the combined cycle. The combined cycle of greatest interest is the gas-turbine (Brayton) cycle topping a steam turbine (Rankine) cycle.

- Gas-turbine cycles typically operate at considerably higher temperatures than steam cycles. The maximum fluid temperature at the turbine inlet is about 620°C (1150°F) for modern steam power plants, but over 1425°C (2600°F) for gas-turbine power plants.

- The use of higher temperatures in gas turbines is made possible by recent developments in cooling the turbine blades and coating the blades with high-temperature-resistant materials such as ceramics. Because of the higher average temperature at which heat is supplied, gas-turbine cycles have a greater potential for higher thermal efficiencies. However, the gas-turbine cycles have one inherent disadvantage: The gas leaves the gas turbine at very high temperatures (usually above 500°C), which erases any potential gains in the thermal efficiency.

- The situation can be improved somewhat by using regeneration, but the improvement is limited. It makes engineering sense to take advantage of the very desirable characteristics of the gas-turbine cycle at high temperatures and to use the high temperature exhaust gases as the energy source for the bottoming cycle such in Figure (8).

- In this cycle, energy is recovered from the exhaust gases by transferring it to the steam in a heat exchanger that serves as the boiler. In general, more than one gas turbine is needed to supply sufficient heat to the steam. Also, the steam cycle may involve regeneration as well as reheating. Energy for the reheating process can be supplied by burning some additional fuel in the oxygen-rich exhaust gases.

- Recent developments in gas-turbine technology have made the combined gas–steam cycle economically very attractive. The combined cycle increases the efficiency without increasing the initial cost greatly. Consequently, many new power plants operate on combined cycles, and many more existing steam- or gas-turbine plants are being converted to combined-cycle power plants. Thermal efficiencies well over 40 percent are reported as a result of conversion. Some recent combined-cycle power plants have achieved efficiencies above 60 percent.
Example: Consider the combined gas–steam power cycle shown in Figure (9). The topping cycle is a gas-turbine cycle that has a pressure ratio of 8. Air enters the compressor at 300 K and the turbine at 1300 K. The isentropic efficiency of the compressor is 80 percent, and that of the gas turbine is 85 percent. The bottoming cycle is a simple ideal Rankine cycle operating between the pressure limits of 7 MPa and 5 kPa. Steam is heated in a heat exchanger by the exhaust gases to a temperature of 500°C. The exhaust gases leave the heat exchanger at 450 K.

Determine:

a. The ratio of the mass flow rates of the steam and the combustion gases and,

b. The thermal efficiency of the combined cycle.

Answer:-

A combined gas–steam cycle is considered. The ratio of the mass flow rates of the steam and the combustion gases and the thermal efficiency are to be determined. The $T$-$s$ diagrams of both cycles are given in figure (9).

Specific heat for air=$1.005$ kJ/kg K. Specific heat ratio of air=$1.4$

$r_p=8$ $T_5=300K$ $T_7=1300K$ Isentropic efficiency of turbine=$0.85$

Isentropic efficiency of compressor=$0.80$
Fig (9): Combined gas–steam power plant.

For gas cycle:

\[ \frac{T_3}{T_4} = r_p^{(k-1)/k} \]

\[ \frac{T_2}{T_1} = r_p^{(k-1)/k} \]

\[ \dot{Q}_{\text{in-gas}} = m_{\text{gas}} c_p (T_7 - T_6) \]
\[
\dot{Q}_{\text{out-gas}} = \dot{m}_{\text{gas}} c_p (T_8 - T_9)
\]

For steam cycle:

\[
\dot{Q}_{\text{in-steam}} = \dot{m}_{\text{steam}} (h_3 - h_2)
\]

For mass ratio:

\[
\dot{Q}_{\text{in-steam}} = \dot{Q}_{\text{out-gas}}
\]

\[
\dot{m}_{\text{steam}} (h_3 - h_2) = \dot{m}_{\text{gas}} c_p (T_8 - T_9)
\]

\[
\frac{\dot{m}_{\text{steam}}}{\dot{m}_{\text{gas}}} = \frac{c_p (T_8 - T_9)}{(h_3 - h_2)}
\]

\(\frac{\dot{m}_{\text{steam}}}{\dot{m}_{\text{gas}}}\): kg/s steam to kg/s gas.

Then the total net work output per kilogram of combustion gases becomes:

\[
W_{\text{net}} = W_{\text{net-gas}} + \frac{\dot{m}_{\text{steam}}}{\dot{m}_{\text{gas}}} W_{\text{net-steam}}
\]

Plant thermal efficiency = \(\frac{W_{\text{net}}}{q_{gas}}\)