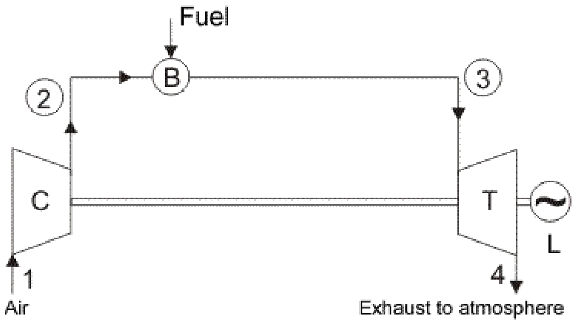
Joule or Brayton Cycle

The ideal cycle for the simple gas turbine is the Joule or Brayton cycle which is represented by the cycle 1234 in the p-v and T-S diagram (Figure 4.3). The cycle comprises of the following process.

1-2 is the isentropic compression occuring in the compressor, 2-3 is the constant pressure heat addition in the combustion chamber, 3-4 is the isentropic expansion in the turbine releasing power output, 4-1 is the rejection of heat at constant pressure - which closes the cycle. Strictly speaking, the process 4-1 does not occur within the plant. The gases at the exit of the turbine are lost into the atmosphere; therefore it is an open cycle.



C- Compressor
B- Burner or Combustion Chamber
T- Turbine
L- Load

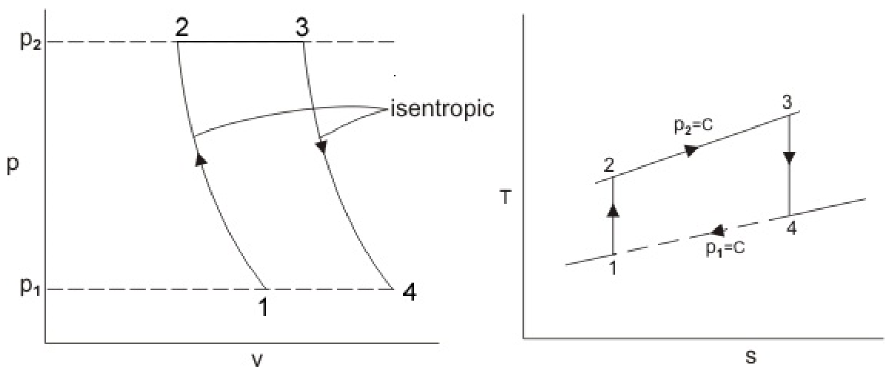


Figure 4.3 Simple gas turbine cycle.

In a steady flow isentropic process,

$$dW = dh = C_p dT$$

Thus, the

Compressor work per kg of air $W_{12} = h_2 - h_1 = C_p(T_2 - T_1)$

Turbine work per kg of air $W_{34} = h_3 - h_4 = C_p(T_3 - T_4)$

Heat supplied per kg of air $Q_{23} = h_3 - h_2 = C_p(T_3 - T_2)$

The cycle efficiency is, $\eta = \dfrac{\text{net work output}}{\text{heat supplied}} = \dfrac{W_{34} - W_{12}}{Q_{23}} = \dfrac{C_p(T_3 - T_4) - C_p(T_2 - T_1)}{C_p(T_3 - T_2)}$

or, $\eta = 1 - \dfrac{T_4 - T_1}{T_3 - T_2}$

Making use of the isentropic relation , we have,

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} = (r)^{\frac{\gamma-1}{\gamma}}$$

Where, r is pressure ratio. The cycle efficiency is then given by,

$$\therefore \ \eta = 1 - \left(\frac{1}{r}\right)^{\frac{\gamma-1}{\gamma}}$$

Thus, the efficiency of a simple gas turbine depends only on the pressure ratio and the nature of the gas.
Figure 4.4 shows the relation between η and r when the working fluid is air (γ =1.4), or a monoatomic gas such as argon(γ =1.66).

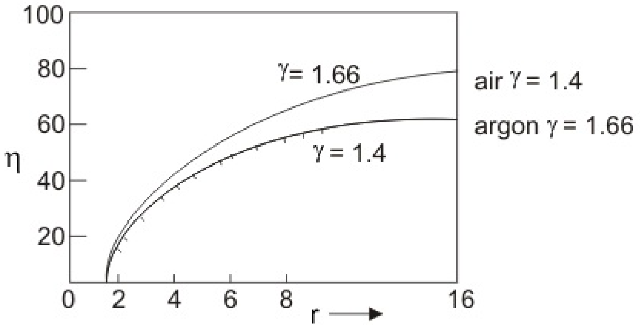


Figure 4.4 Efficiency of a simple gasturbine cycle

The specific work output w, upon which the size of plant for a given power depends, is found to be a function not only of pressure ratio but also of maximum cycle temperature T_3.

Thus, the specific work output is,

$$W = C_p(T_3 - T_4) - C_p(T_2 - T_1)$$

$$= C_p T_1\left[\frac{T_3}{T_1}\left(1 - \frac{T_4}{T_3}\right) - \left(\frac{T_2}{T_1} - 1\right)\right]$$

$$= C_p T_1\left[\frac{T_3}{T_1}\left\{1 - \frac{1}{(\gamma)^{\gamma-1/\gamma}}\right\} - \left\{(\gamma)^{\gamma-1/\gamma} - 1\right\}\right]$$