II- Gas cycles (Brayton) – stady of the turbojet

II.1. Definition

In this cycle, cold is obtained through the expansion of gases in a turbine. Heat is extracted from the system as mechanical work. It is used for open-cycle turbines (Fig. 1). Combustion and exhaust occur at constant pressure.

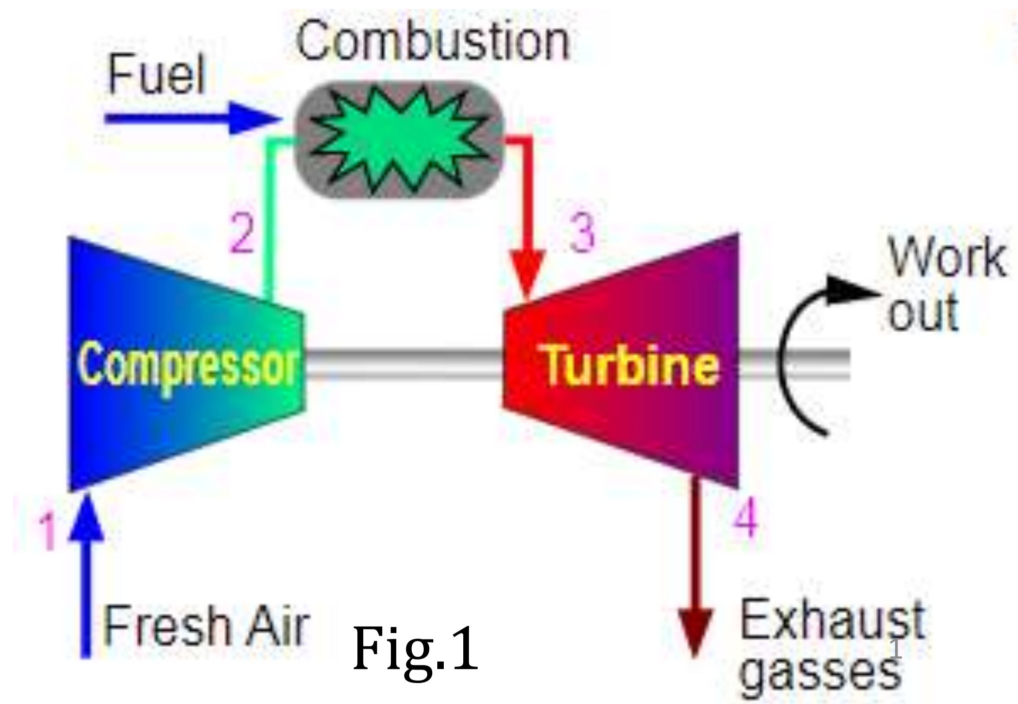


Fig.1

II- Gas cycles (Brayton) – stady of the turbojet

The open Brayton cycle can be modeled as a closed cycle (Fig. 2) as follows:

1-2: Isentropic compression

2-3: Isobaric heat addition

3-4: Isentropic expansion

4-1: Isobaric heat rejection

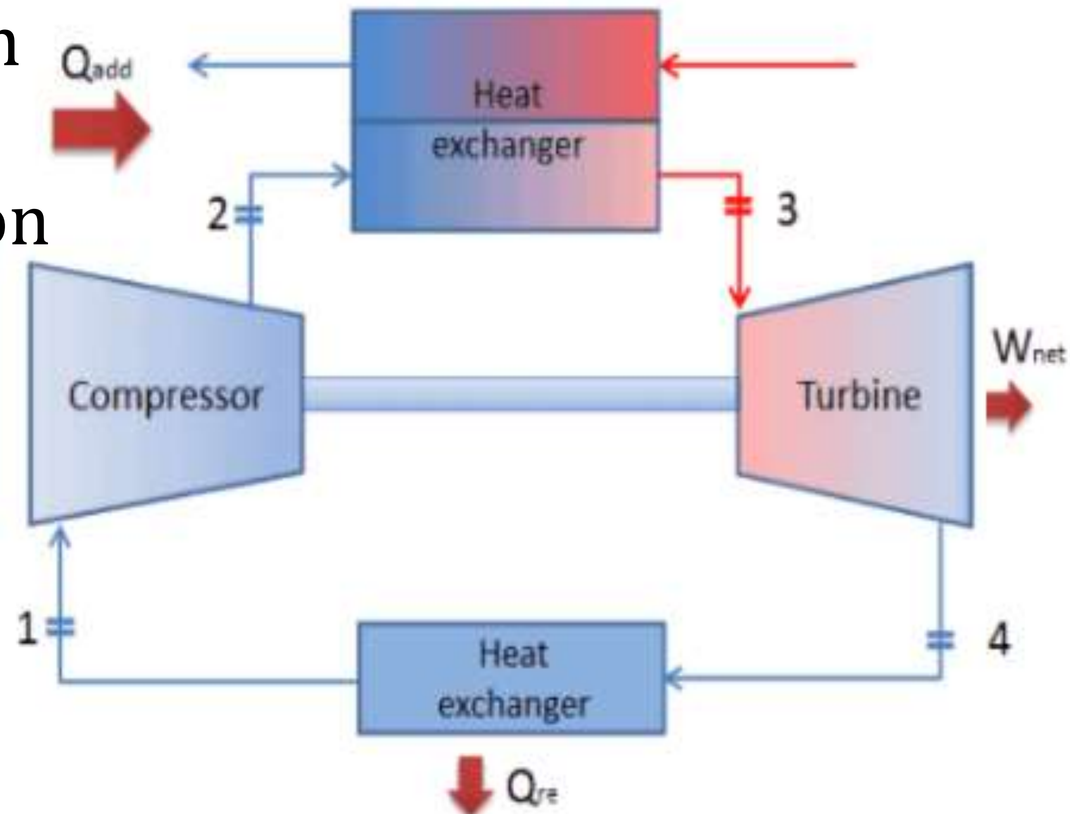


Fig.2

II- Gas cycles (Brayton) – stady of the turbojet

Expansion causes a decrease in pressure and, consequently, a significant temperature reduction, resulting in the production of liquid. The (T-S) diagram of this cycle is depicted in the figures. 3 and 4.

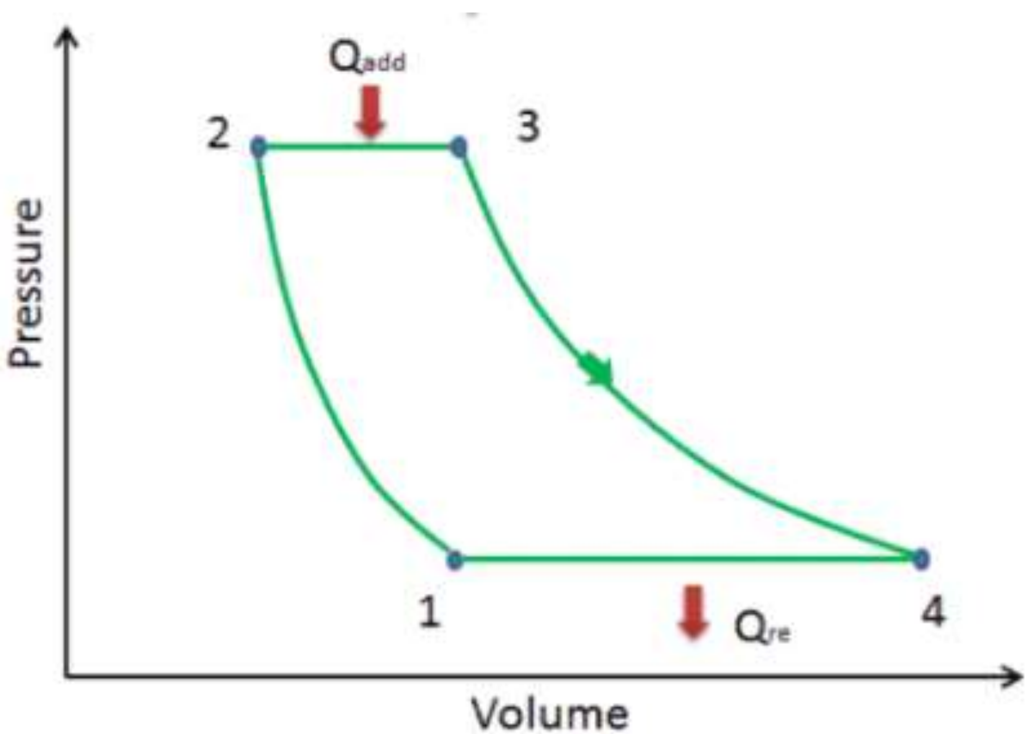


Fig. 3

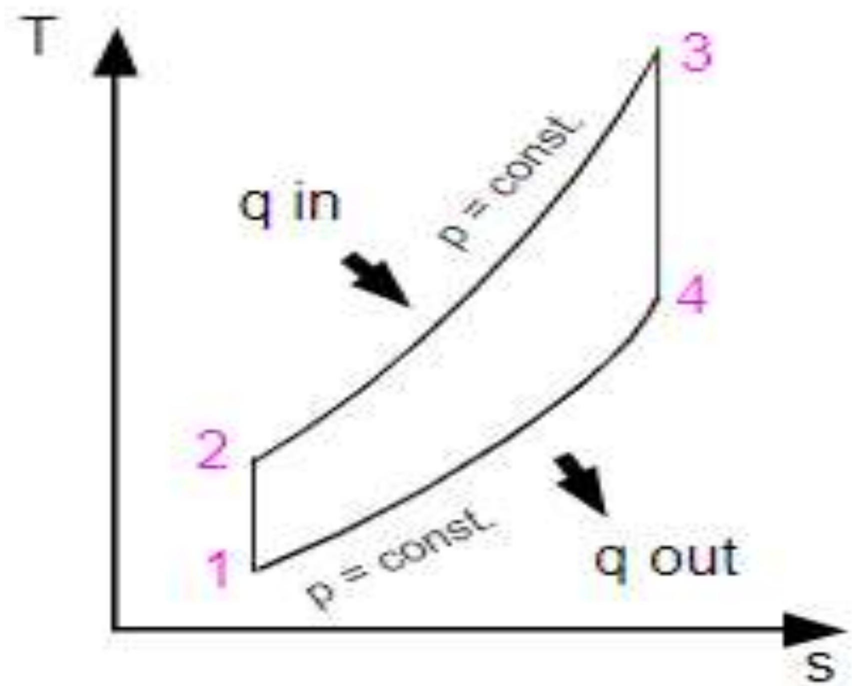


Fig. 4

II.2. Bilan énergétique

For the closed cycle, the variation in internal energy is zero.

$\Delta Ucyc=\sum W+\sum Q=0$

So

$$\Delta h = W + Q$$

$$h_2 - h_1 = W_C\,(RECU) = Cp(T_2 - T_1)$$

$$h_3 - h_2 = Q_2 = Cp(T_3 - T_2)$$

$$h_4 - h_3 = W_T\,(FOURNI) = Cp(T_4 - T_3)$$

$$h_1 - h_4 = Q_1 = Cp(T_1 - T_4)$$

On this cycle

$$W + Q_1 + Q_2 = 0$$

II- Gas cycles (Brayton) – stady of the turbojet

The thermal efficiency of the theoretical cycle

$$\eta_{th} = \frac{Q_2 - Q_1}{Q_2} = 1 + \frac{Q_1}{Q_2} = 1 + \frac{Cp(T_1 - T_4)}{Cp(T_3 - T_2)} = 1 + \frac{T_1 - T_4}{T_3 - T_2} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

For the isentropic transformations

$$\begin{cases} PV^{\gamma} = cte \\ T.V^{(\gamma-1)} = cte \\ TP^{\frac{(1-\gamma)}{\gamma}} = cte \end{cases} \quad avec \quad \begin{cases} Cp - Cv = R \\ \frac{Cp}{Cv} = \gamma \end{cases}$$

$$T_1 P_1^{\frac{1-\gamma}{\gamma}} = T_2 P_2^{\frac{1-\gamma}{\gamma}} \Rightarrow \frac{T_1}{T_2} = \left(\frac{P_2}{P_1}\right)^{\frac{1-\gamma}{\gamma}}$$

$$T_3 P_3^{\frac{1-\gamma}{\gamma}} = T_3 P_3^{\frac{1-\gamma}{\gamma}} \Rightarrow \frac{T_3}{T_4} = \left(\frac{P_4}{P_1}\right)^{\frac{1-\gamma}{\gamma}}$$

$$\begin{matrix} P_2 = P_3 \\ P_1 = P_4 \end{matrix} \Rightarrow \frac{T_4}{T_1} = \frac{T_3}{T_2}$$

II- Gas cycles (Brayton) – stady of the turbojet

$$\eta_{th} = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{T_1(\frac{T_4}{T_1} - 1)}{T_2(\frac{T_3}{T_2} - 1)} \Rightarrow \eta_{th} = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{P_2}{P_1}\right)^{\frac{1-\gamma}{\gamma}}$$

In general, increasing the pressure ratio is the most direct means to enhance the overall thermal efficiency of the Brayton cycle, as the cycle approaches the Carnot cycle. According to the Carnot principle, higher efficiencies can be achieved by raising the gas temperature. However, there are also limitations on the pressure ratios that can be employed in the cycle.

II- Gas cycles (Brayton) – stady of the turbojet

The highest temperature in the cycle occurs at the end of the combustion process and is limited by the maximum temperature that turbine blades can withstand. Typically, metallurgical considerations (around 1700 K) impose upper limits on thermal efficiency.

There are two (T-S) diagrams of Brayton cycles with the same turbine inlet temperature but different compressor pressure ratios in the image. As can be observed, for a fixed turbine inlet temperature, the net work output per cycle varies.

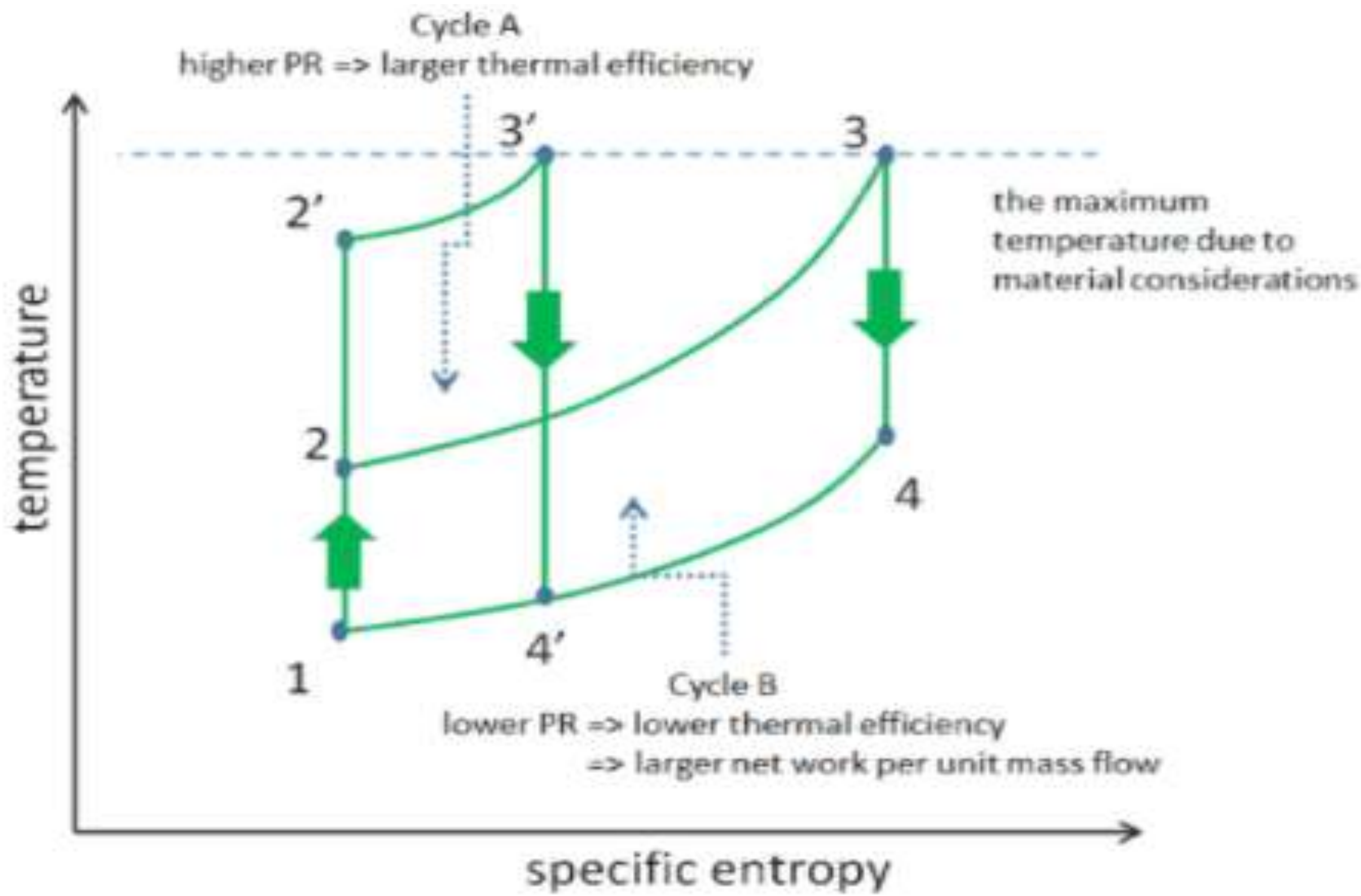
$(W_{net} = W_T - W_C)$ diminue

II- Gas cycles (Brayton) – stady of the turbojet

Cycle A has the highest efficiency. On the other hand, Cycle B has a greater net work output per cycle (enclosed area in the diagram) and thus a higher net output developed per unit mass flow rate. The work produced by the cycle, multiplied by the mass flow rate per cycle, equals the output power produced by the gas turbine.

Therefore, with less work per cycle (Cycle A), a larger mass flow rate (thus a larger system) is needed to maintain the same output power, which may not be economical. This is a key consideration in gas turbine design, as engineers must balance thermal efficiency and compactness. In most common designs, the pressure ratio of a gas turbine varies from around 11 to 16.

II- Gas cycles (Brayton) – stady of the turbojet



Cycles de Brayton idéaux avec différents rapports de pression et la même température d'entrée de turbine.

Fig. 5

II.3. Turbojet

II.3. Definition

A turbojet engine is composed of a tube within which multiple-stage compressor blades, a combustion chamber arranged on the same axis, a gas turbine, and an exhaust nozzle are arranged.(Fig. 6).

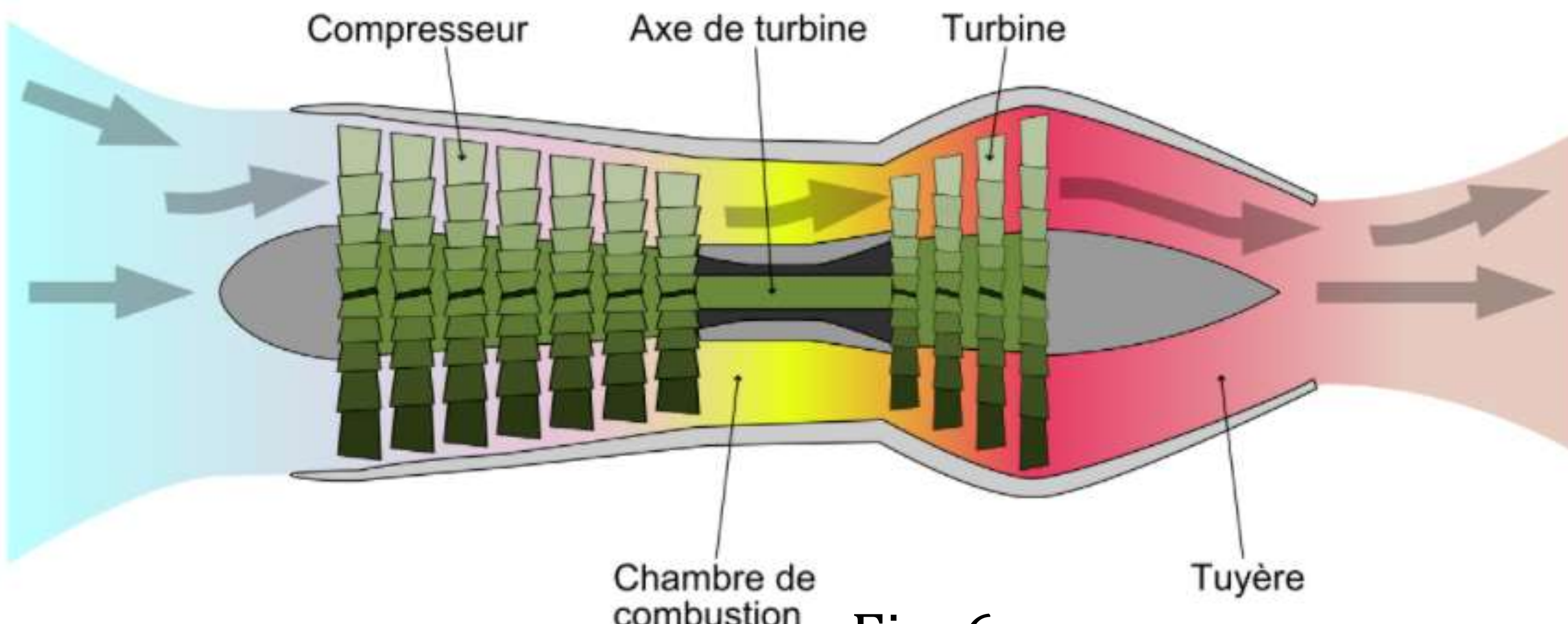


Fig. 6

II.3.2. Operating principle

A jet engine, or turbojet, operates on a similar principle. Air enters the engine through the inlet nozzle located at the front. It is first compressed and directed towards the combustion chamber, where it is mixed with kerosene and then ignited. The difference in speed between incoming and outgoing air causes the engine to move, utilizing the principles of gas turbines that form the basis of thrust.

II- Gas cycles (Brayton) – stady of the turbojet

The thermodynamic cycle of the turbojet engine can be represented by the Pressure/Volume diagram.(Fig. 7)