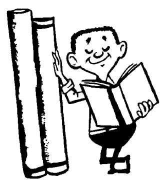
Brayton Cycle

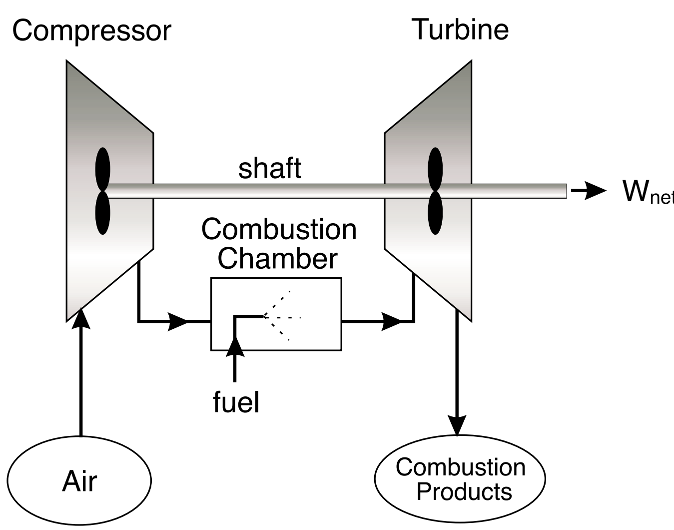


Reading	Problems
8-8 $\longrightarrow$ 8-10	8-76, 8-91, 8-92, 8-107, 8-141

Introduction

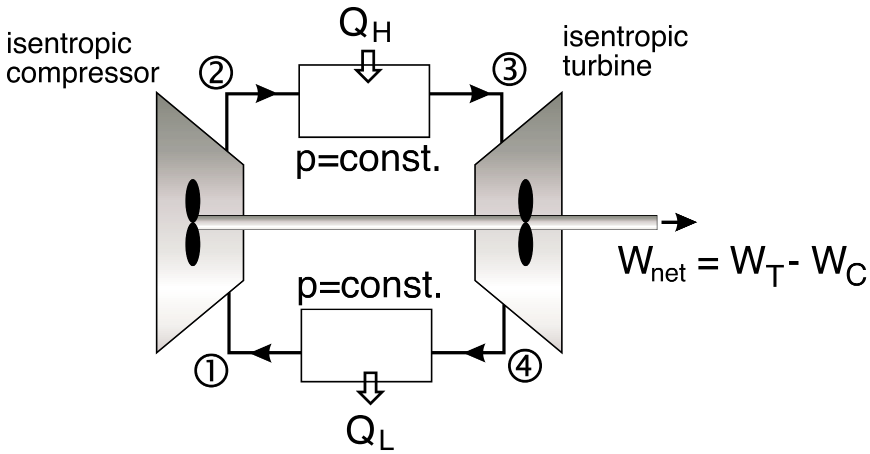
The gas turbine cycle is referred to as the Brayton Cycle or sometimes the Joule Cycle. The actual gas turbine cycle is an open cycle, with the intake and exhaust open to the environment.

Open Cycle Gas Turbine Engines

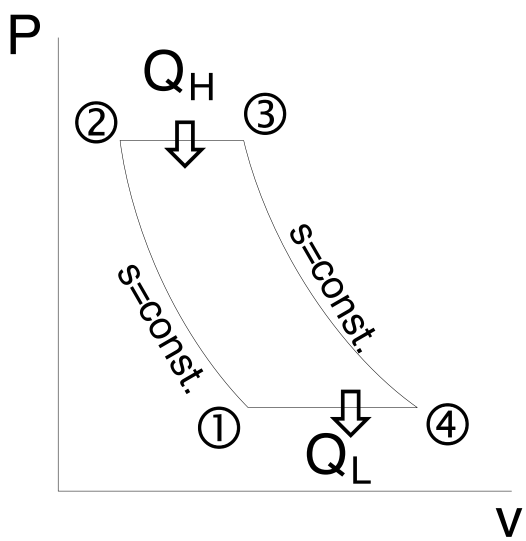


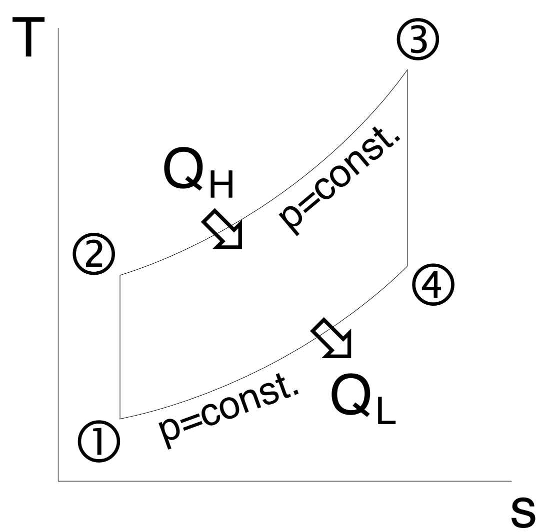
- after compression, air enters a combustion chamber into which fuel is injected
- the resulting products of combustion expand and drive the turbine
- combustion products are discharged to the atmosphere
- compressor power requirements vary from 40-80% of the power output of the turbine (remainder is net power output), i.e. back work ratio = 0.4 $\longrightarrow$ 0.8
- high power requirement is typical when gas is compressed because of the large specific volume of gases in comparison to that of liquids

Idealized Air Standard Brayton Cycle



- closed loop
- constant pressure heat addition and rejection
- ideal gas with constant specific heats

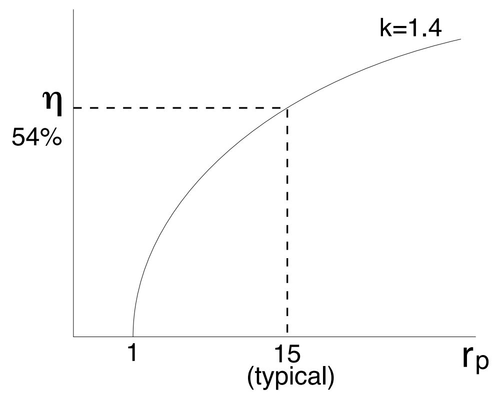




Brayton Cycle Efficiency

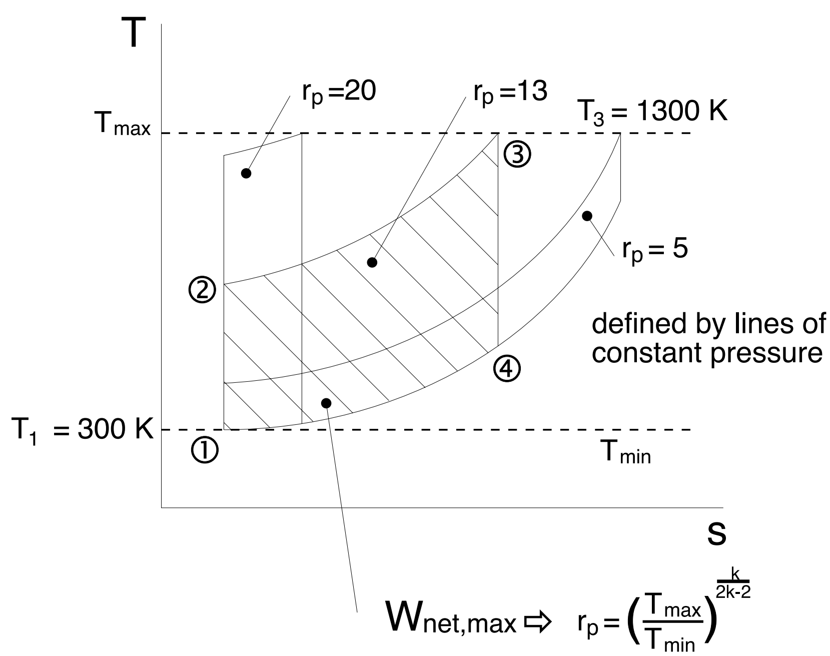
The efficiency of the cycle is given by the benefit over the cost or

$$\eta = \frac{W_{net}}{Q_H} = 1 - (r_p)^{(1-k)/k}$$

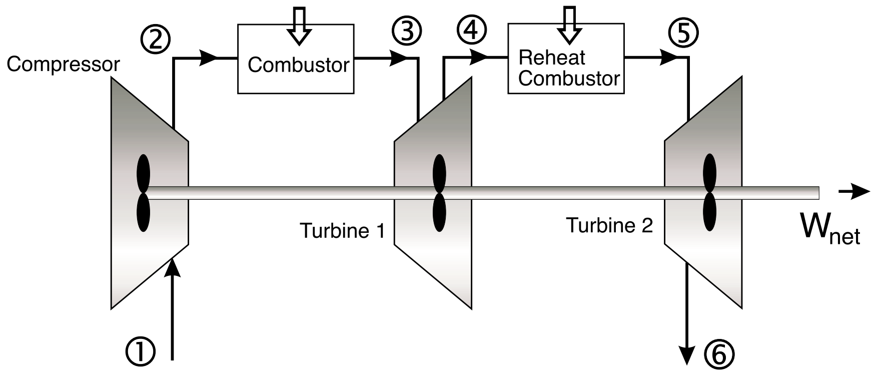


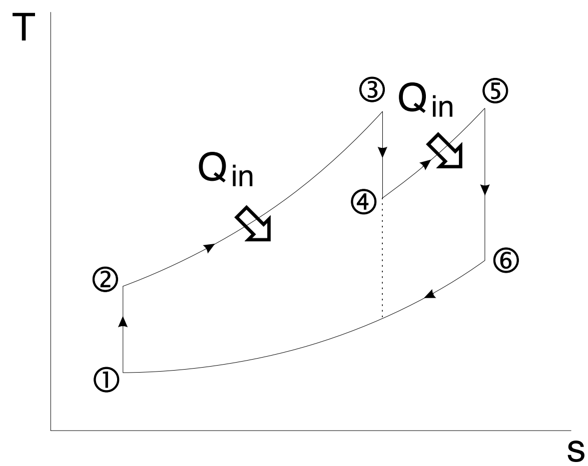
Maximum Pressure Ratio

Given that the maximum and minimum temperature can be prescribed for the Brayton cycle, a change in the pressure ratio can result in a change in the work output from the cycle.



Brayton Cycle with Reheat

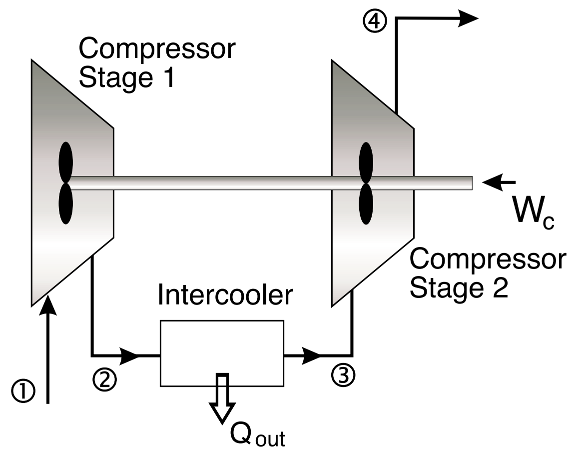


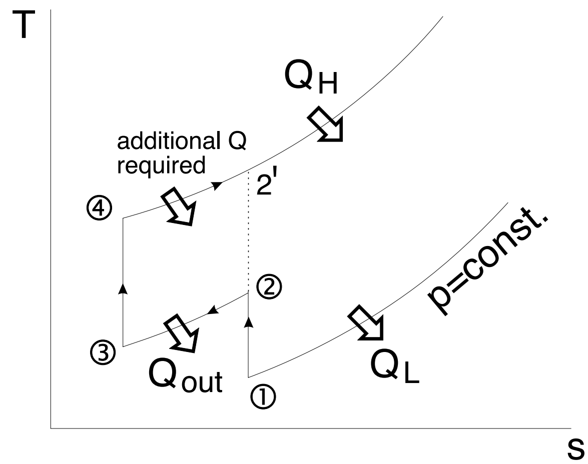


- the maximum temperature at T_3 entering the turbine is limited due to metallurgical constraints
- excess air is extracted and fed into a second stage combustor and turbine
- total work is increased
- but additional heat input is required

Compression with Intercooling

- the work required to compress in a steady flow device can be reduced by compressing in stages
- cooling the gas reduces the specific volume and in turn the work required for compression





How Can We Improve Efficiency?

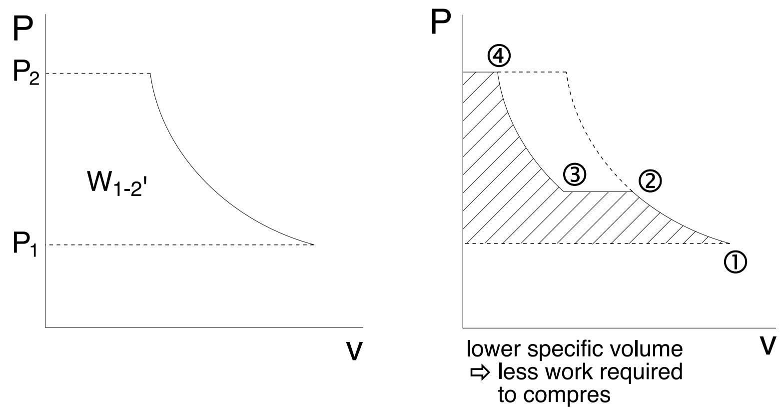
We know the efficiency of a Brayton cycle engine is given as

$$\eta = \frac{\dot{W}_{net}}{\dot{Q}_H} = \frac{\dot{W}_{turbine} - \dot{W}_{compressor}}{\dot{Q}_H}$$

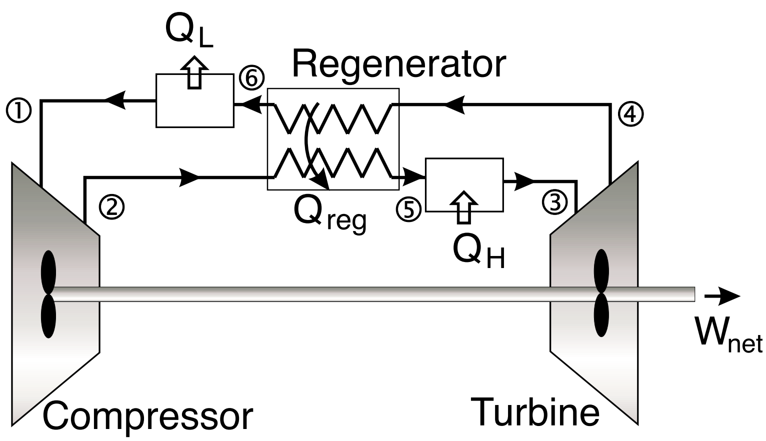
There are several possibilities, for instance we could try to increase $\dot{W}_{turbine}$ or decrease $\dot{W}_{compressor}$.

Recall that for a SSSF, reversible compression or expansion

$$\frac{\dot{W}}{\dot{m}} = \int_{in}^{out} v\, dP \quad \Rightarrow \quad \textbf{keep } v \uparrow \textbf{ in turbine, keep } v \downarrow \textbf{ in compressor}$$



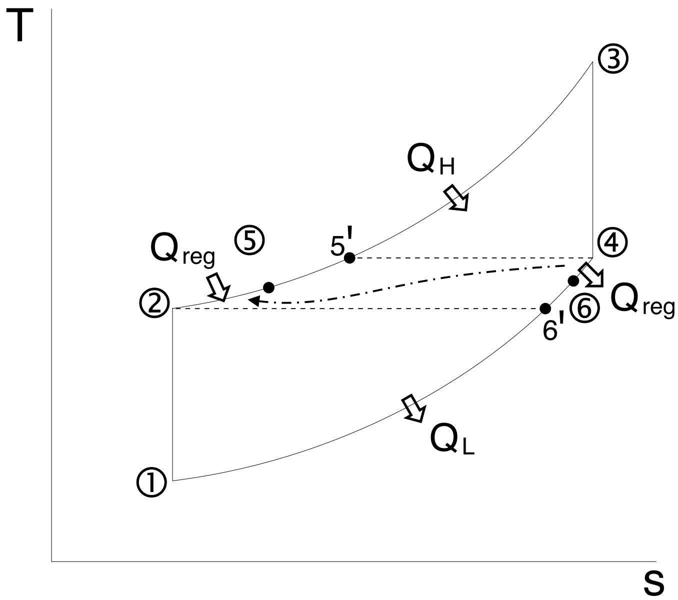
Brayton Cycle with Regeneration



- a regenerator (heat exchanger) is used to reduce the fuel consumption to provide the required $\dot{Q}_H$
- the efficiency with a regenerator can be determined as:

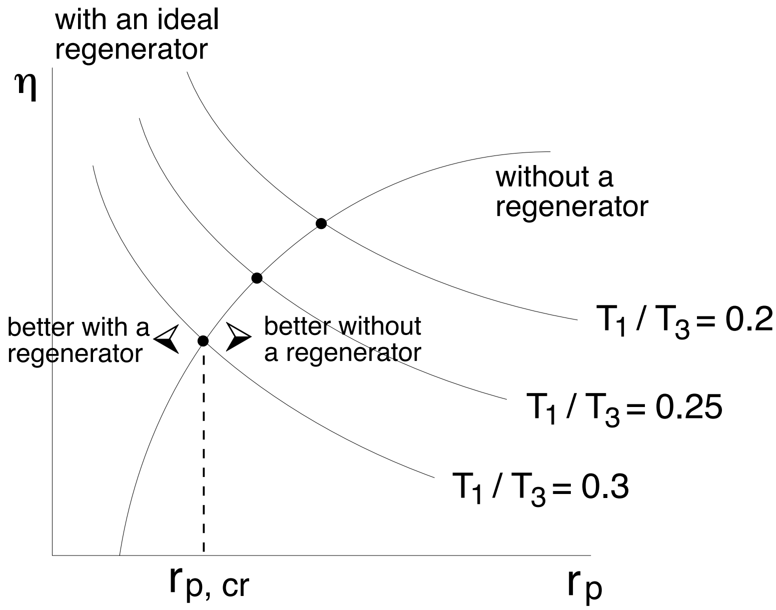
$$\begin{aligned}
\eta = \frac{\dot{W}_{net}}{\dot{Q}_H} &= 1 - \frac{\dot{Q}_L}{\dot{Q}_H} \\
&= 1 - \frac{c_p(T_6 - T_1)}{c_p(T_3 - T_5)} \quad \Rightarrow \quad (for\ a\ real\ regenerator) \\
&= 1 - \frac{c_p(T_6' - T_1)}{c_p(T_3 - T_5')} \quad \Rightarrow \quad (for\ an\ ideal\ regenerator) \\
&= 1 - \frac{c_p(T_2 - T_1)}{c_p(T_3 - T_4)}
\end{aligned}$$

and

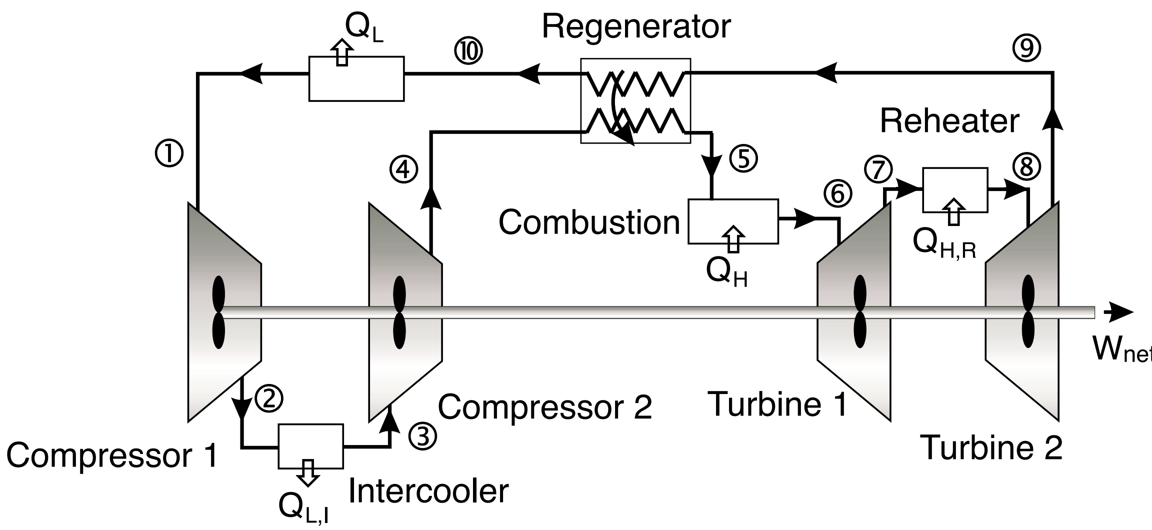


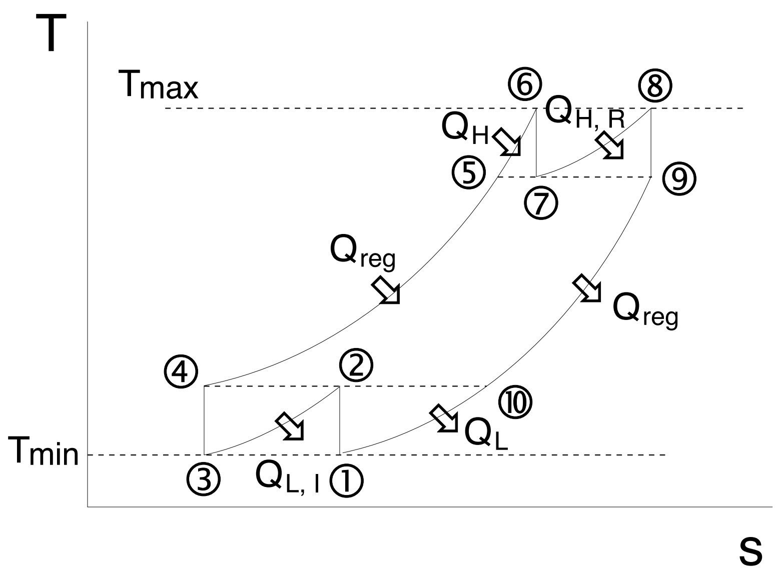
$$\eta = 1 - \left(\frac{T_{min}}{T_{max}}\right) (r_p)^{(k-1)/k}$$

- for a given T_{min}/T_{max}, the use of a regenerator above a certain r_p will result in a reduction of η



Brayton Cycle With Intercooling, Reheating and Regeneration





Compressor and Turbine Efficiencies

Isentropic Efficiencies

(1) $$\eta_{comp} = \frac{h_{2,s} - h_1}{h_2 - h_1} = \frac{c_p(T_2, s - T_1)}{c_p(T_2 - T_1)}$$

(2) $$\eta_{turb} = \frac{h_3 - h_4}{h_3 - h_{4,s}} = \frac{c_p(T_3 - T_4)}{c_p(T_3 - T_{4,s})}$$

(3) $$\eta_{cycle} = \frac{W_{net}}{Q_H} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{c_p(T_4 - T_1)}{c_p(T_3 - T_2)}$$

Given the turbine and compressor efficiencies and the maximum (T_3) and the minimum (T_1) temperatures in the process, find the cycle efficiency (η_{cycle}).

(4) Calculate T_{2s} from the isentropic relationship,

$$\frac{T_{2,s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}.$$

Get T_2 from (1).

(5) Do the same for T_4 using (2) and the isentropic relationship.

(6) substitute T_2 and T_4 in (3) to find the cycle efficiency.