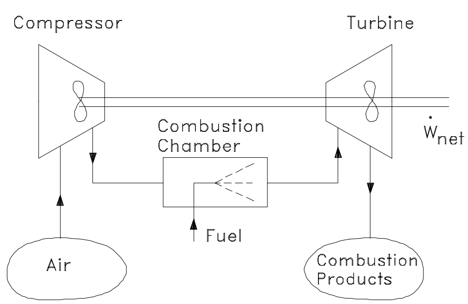
Week 8: Lecture 1

Open Cycle Gas Turbine Engines

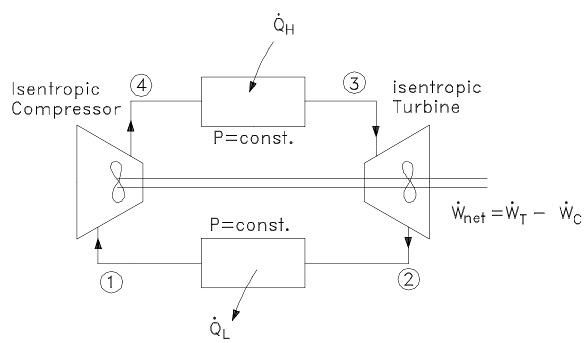
- after compression, air enters a combustion chamber into which fuel is injected
- the resulting products of combustion expand and drive the turbine
- combustion products are discharged to the atmosphere
- compressor power requirements vary from 40-80% of the power output of the turbine (remainder is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

Advantages

- can use different fuels
- simple in construction, easy to maintain
- small weight-to-power ratio



Open Cycle Gas Turbine

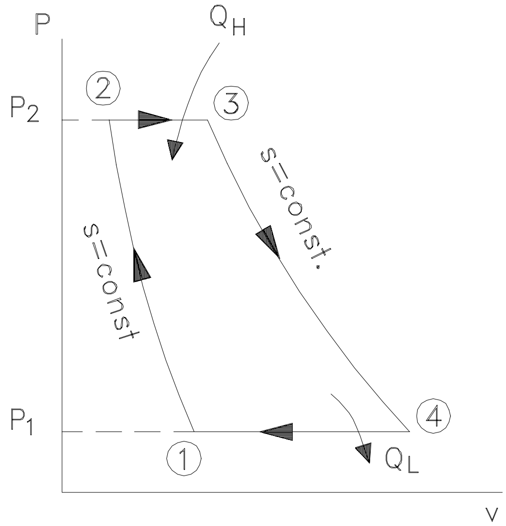


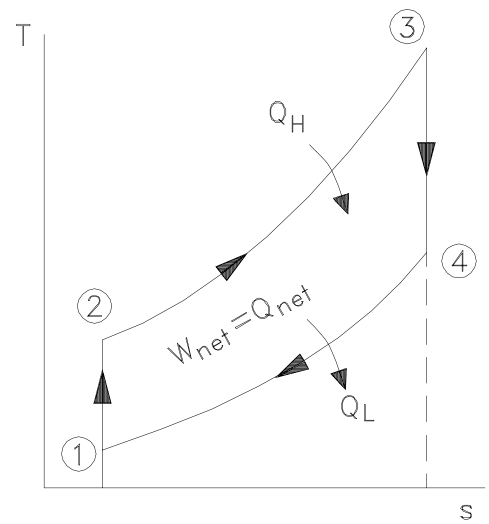
Air Standard Brayton Cycle

Idealized Air-standard Brayton Cycle

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

Week 8: Lecture 1





$$\text{Brayton cycle efficiency} \quad \Rightarrow \quad \boxed{\eta = 1 - (r_p)^{\frac{1-k}{k}}}$$

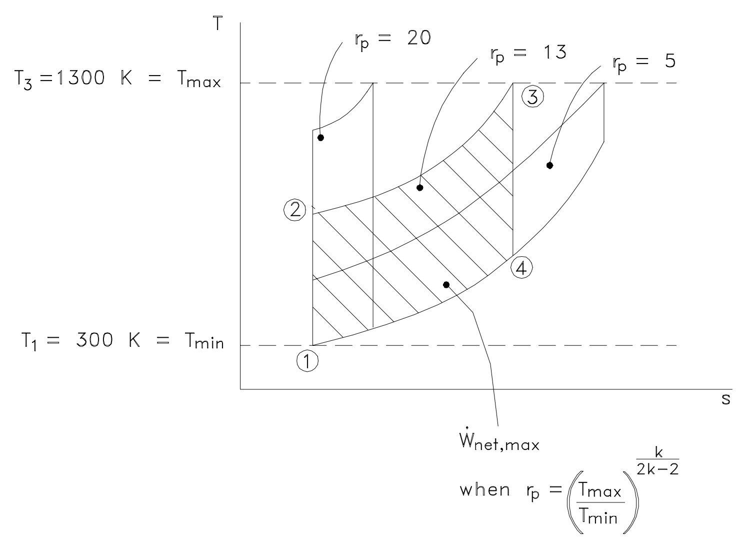
where $r_p = \dfrac{P_2}{P_1} = \dfrac{P_3}{P_4}$

The maximum temperature in the cycle (T_3) is limited by metallurgical conditions because the turbine blades cannot sustain temperatures above 1300 K. Higher temperatures (up to 1600 K can be obtained with ceramic turbine blades).

Optimum Work Output

The maximum work output can be achieved when the pressure ratio is:

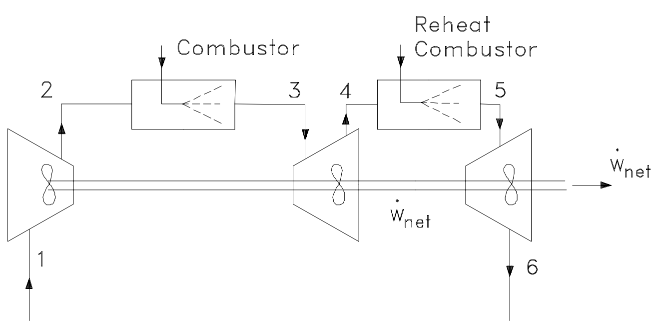
$$r_p = \left(\frac{T_{max}}{T_{min}}\right)^{\frac{k}{2k-2}}$$

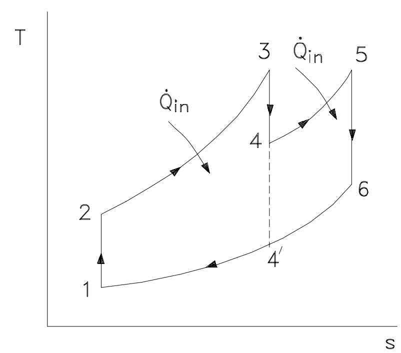


Week 8: Lecture 2

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
- net efficiency may or may not increase
- turbine outlet temperature is increased with reheat, therefore potential for regeneration is enhanced

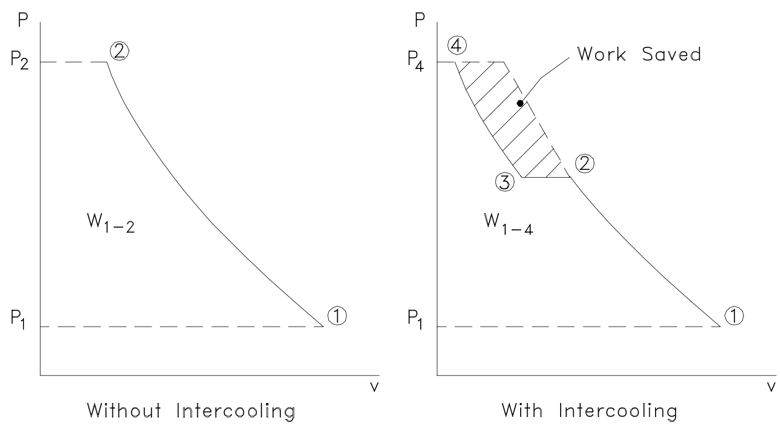




Week 8: Lecture 2

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
- by itself compression with intercooling does not provide a significant increase in efficiency
- the lower temperature at the compressor exit enhances the potential for regeneration



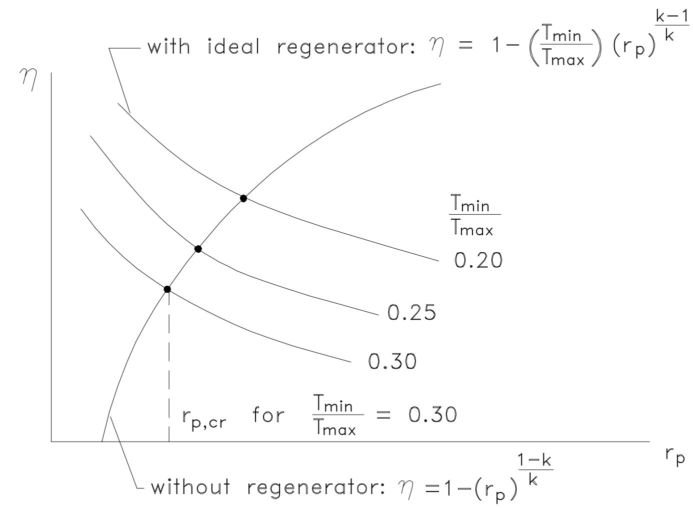
Week 8: Lecture 3

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 is given by

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

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



The regenerator effectiveness can be defined as

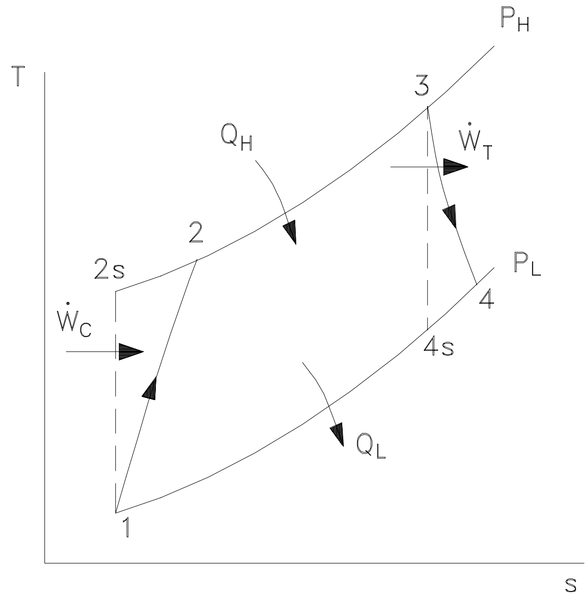
$$\epsilon = \frac{\dot{Q}_{reg,actual}}{\dot{Q}_{reg,ideal}}$$

Typical values of effectivenes are ≤ 0.7

Repeated intercooling, reheating and regeneration will provide a system that approximates the Ericsson Cycle which has Carnot efficiency ($\eta = 1 - \frac{T_L}{T_H}$).

Week 8: Lecture 3

Compressor and Turbine Efficiencies



Isentropic Efficiencies

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

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

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

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.