

THERMODYNAMIC CYCLES

There is no general classification of thermodynamic cycle . The following types will be discussed as those are included in the course curriculum

1. Gas power cycles
 - a) Carnot cycle
 - b) Otto cycle
 - c) Diesel cycle
 - d) Dual cycle
 - e) Brayton cycle
2. Vapour power cycle
 - Rankine cycle
3. Refrigeration cycle :
 - a) Gas – compression refrigeration cycles
 - b) Vapour – compression refrigeration cycles

On gas power cycle :

Why was Diesel cycle invented ?

Though both Otto cycle and Diesel cycle works on engine , so the question raises why the diesel cycle was invented as there already exists an Otto cycle .

In Otto cycle air-fuel mixture enters into the cylinder . As the fuel is also there in the cylinder before it is ignited by the spark plug , compression is limited i.e. the compression of the mixture is limited by the fact is that the temperature rise due to compression should be less than the ignition temperature of the fuel in the mixture. So the mixture cannot be compressed so that it is ignited only by compression before the sparking. So the compression ratio cannot be increased beyond certain limit . As the compression ratio is not very large so the large work output cannot be attained . Hence such cycle cannot operate engine for heavy vehicles where greater work output is needed .If Otto cycle would be used for heavy vehicle engine the engine size would be very large . Moreover an engine operating on Otto cycle with high compression ratio would cause noise and engine problem called detonation .

So to overcome these limitations the Diesel cycle was employed. There is no spark ignition in the engine operating on diesel cycle. First only air is compressed and at end of compression , fuel is injected . So it is ignited only by compression . As only air is compressed , it can be compressed higher than in a Otto cycle as the chance of spontaneous ignition before fuel injection is less . A higher compression ratio can be attained and greater work output is achieved. Hence it can be used for heavy vehicle also . No trouble as detonation in Otto cycle operated engine is occurred.

How to increase the efficiency of a cycle ?

- a) By increasing the net work.
- b) By decreasing the amount of heat rejection.
- c) By increasing the mean temperature of heat addition or by decreasing the mean temperature of heat rejection.

As the mean temperature of heat addition increases the amount of heat addition increases . If the heat addition increases the efficiency will increase . As $\eta = 1 - \frac{Q_{out}}{Q_{in}}$

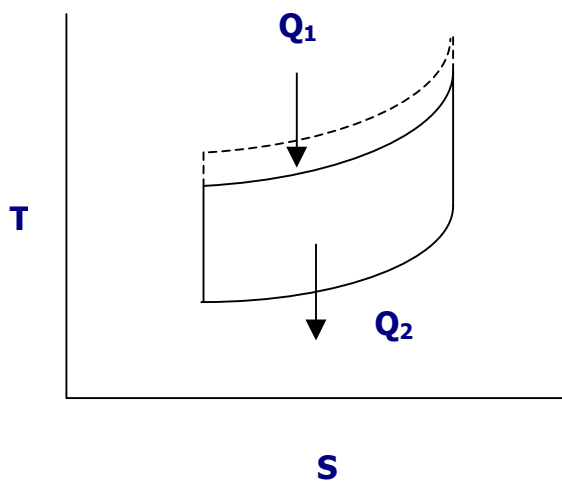


Fig 1: Increase in mean temperature of heat addition

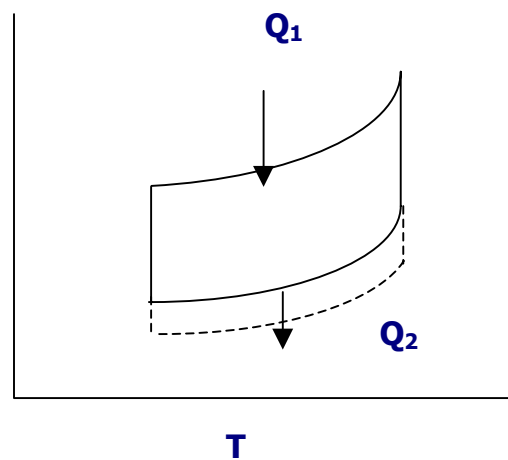
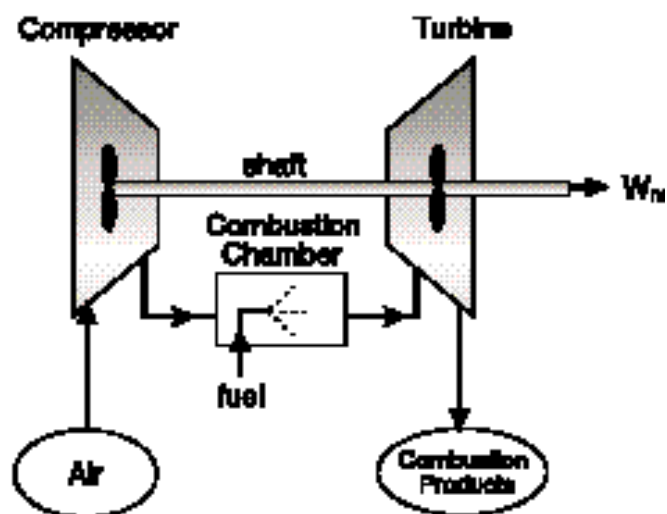


Fig 2 . Decrease in mean temperature heat rejection

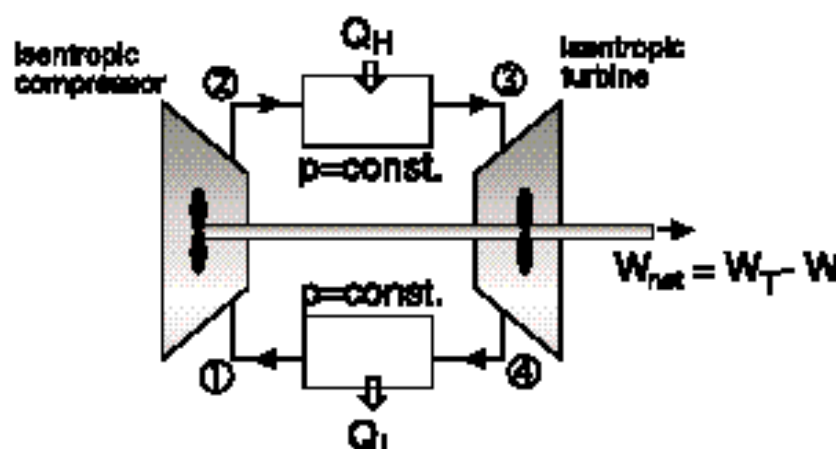
Again if the mean temperature of heat rejection decreases , the curve as shown in fig 2 comes down . So the amount of heat rejection decreases and increases in efficiency results.

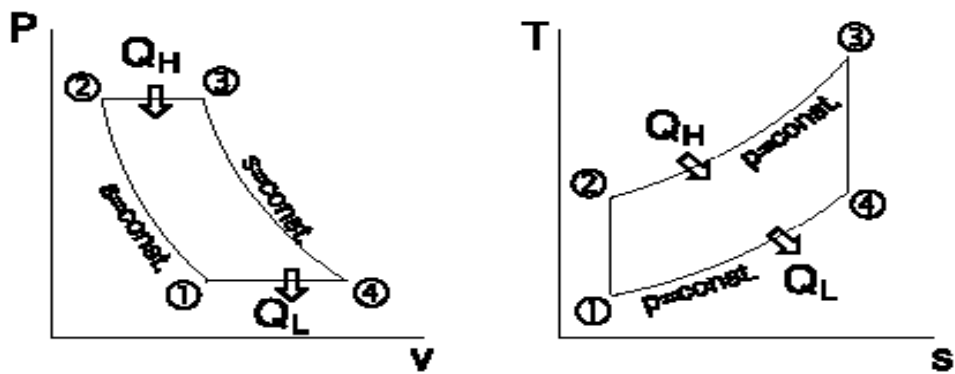
Open Cycle Gas Turbine Engines



- 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 \rightarrow 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

Closed cycle gas turbine:

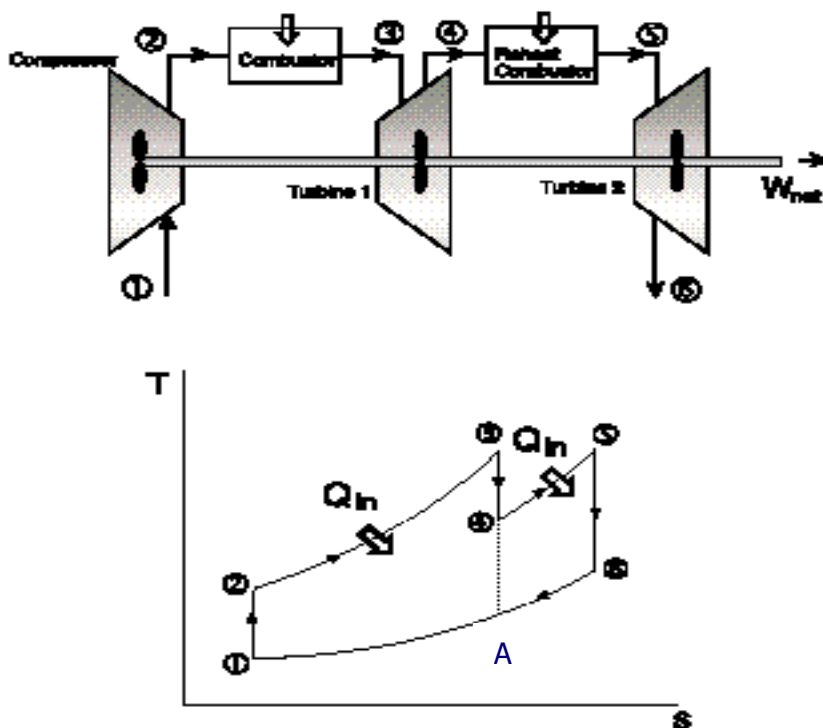




- closed loop
- constant pressure heat addition and rejection
- ideal gas with constant specific heats

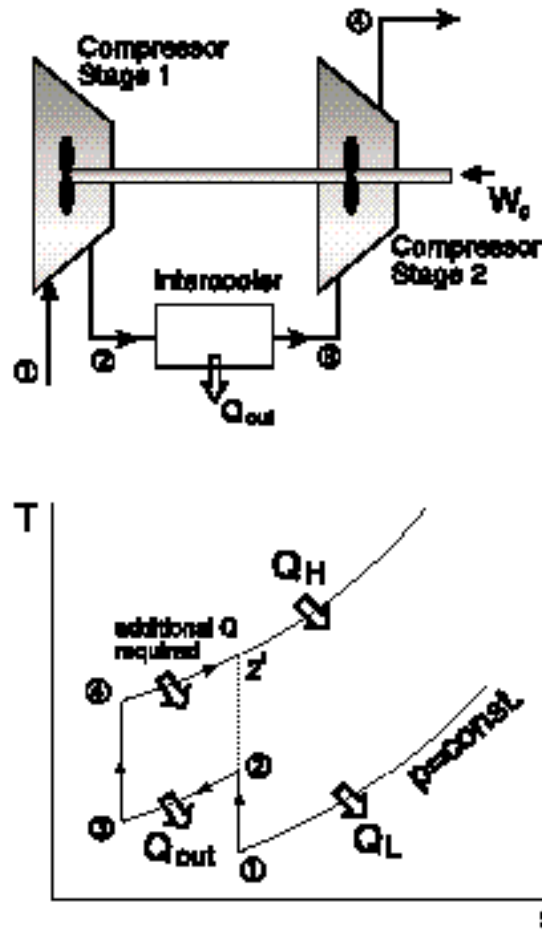
Brayton cycle with reheater :

- A reheater is employed in a Brayton cycle to increase the cycle efficiency .



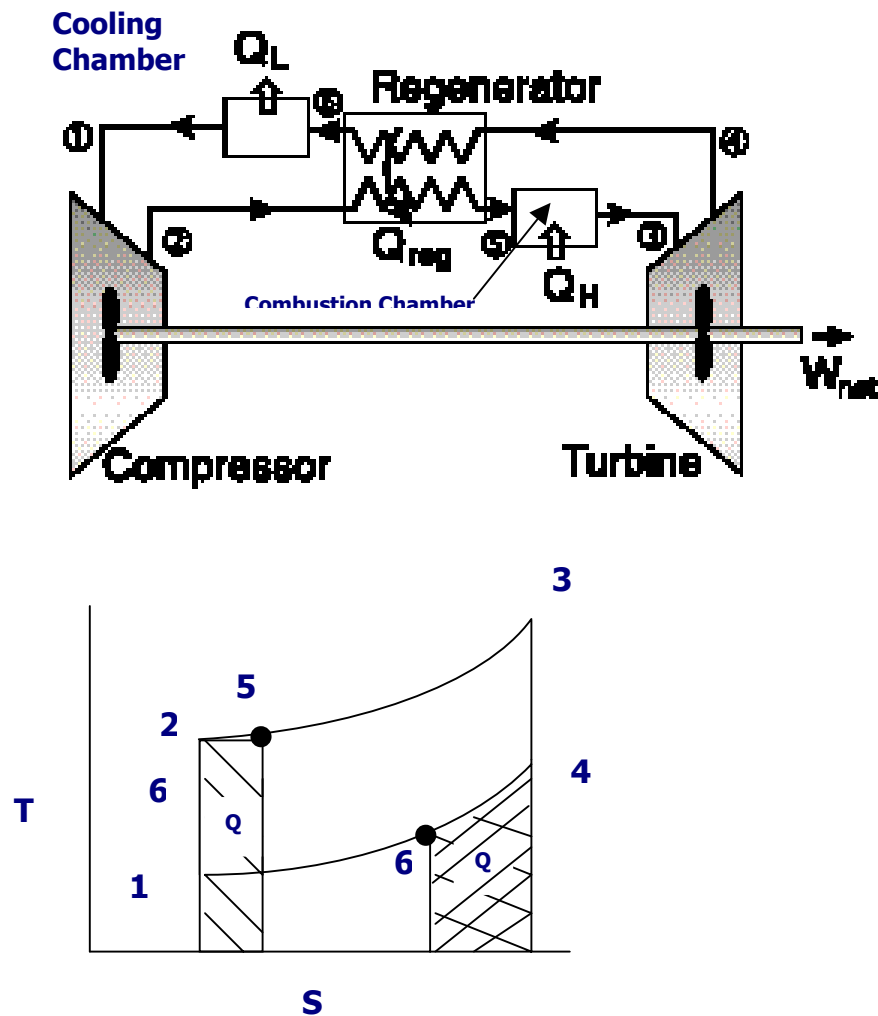
- But a reheater alone cannot increase the cycle efficiency rather it decreases it.
- More than one turbine is employed and it is called staging of turbines.
- In the figure two turbines are employed. So the air leaving the turbine 1 is heated and is taken to a temperature 5 which is about equal to the temperature at 3 i.e. the temperature at which air enters to the turbine 1. Then again temperature at turbine 2 decreases to a temperature 6.
- It is seen from the T-S diagram that the work output is increasing.
- But in this case as point 3 and 5 are at about in the same level the mean temperature of heat addition (MTHA) does not increase. It is also possible to make 5 is higher than 4 and so the mean temperature of heat addition does increase. But the problem for both cases is that the mean temperature of heat rejection (MTHR) also increases as temperature leaving the turbine increases from a temperature at the point A to a point 6. So (MTHA) remains the same (sometimes can increase also) and (MTHR) always increases. The net effect is that the efficiency does decrease.
- So using a reheater alone increase the net work of a Brayton cycle but the efficiency decreases.

Brayton cycle with Intercooling:



- More than one compressor is employed. In the figure two compressor is shown.
- It is called staging of compressor.
- The intercooler cools the air leaving compressor 1 and again supply the cooled air to the compressor 2.
- In the compressor 1 the temperature rises to point 2 instead of point Z' . And then cooled in the cooling chamber to temperature at the point 3. Then again it is compressed and temperature rises to a point 4 then it enters to the combustion chamber.
- It is seen from the T-S diagram that the work input is decreasing as area under the curve 1- Z' is less than the area under the curve 1-2-3-4. So the net work is increased.
- MTHA is decreased as the temperature during entering to the combustion chamber reduces from Z' to 4. MTHR remains the same and sometimes may decrease as point 1 and 5 remains in same level or sometimes 5 decreases a little more. But the decrease in MTHA is more than the decrease in MTHR. The net effect results a decrease in efficiency.
- Intercooler alone decreases the thermal efficiency of Brayton cycle though the work input decreases.

Brayton cycle with Regenerator :



- Regenerator is a kind of heat exchanger.
- Regenerator uses the part of heat rejected at the cooling chamber to heat the air living the compressor and so a higher temperature air enters to the combustion chamber.
- As shown in the T-S diagram Q heat rejected at the cooling chamber, area under the curve 4-6, is used as a part of input heat.
- So the MTHA increases as point 2 rises to point 5 and MTHR decreases as temperature at point 4 drops down to the point 6. So efficiency increases.
- Decrease in input heat and rejected heat are the same. But this also increases the efficiency. As

$$\eta_{without} = 1 - \frac{Q_{out}}{Q_{in}}$$

$$\eta_{with} = 1 - \frac{Q_{out} - Q}{Q_{in} - Q}$$

As reduction of same quantity from denominator and numerator decreases the ratio. So

$$\eta_{with} > \eta_{without}$$

- So a regenerator alone can increase the efficiency of the Brayton cycle.
- Fuel consumption is reduced as input heat is reduced.
- $Effectiveness = \frac{T_5 - T_2}{T_4 - T_2}$

Where,

T_5 = Air temperature at the inlet of the combustion chamber **with** regenerator

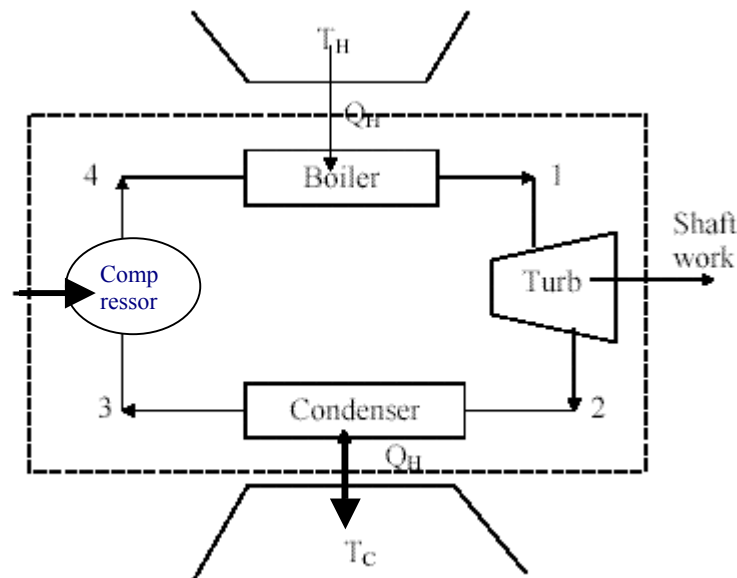
T_2 = Air temperature at the inlet of the combustion chamber **without** regenerator

T_4 = Air temperature at the inlet of the cooling chamber **without** regenerator

ABOUT VAPOUR POWER CYCLE

- In the gas power cycles, the working fluid remains gas throughout the entire cycle. But in vapor cycles the working fluid is alternately vaporized and condensed.
- Steam is the most common working fluid in vapor power cycles since it has several desirable characteristics, such as low cost, availability and high enthalpy of vaporization.
- Steam power plants are referred to as coal plants, nuclear plants, or natural gas plants depending on the type of fuel used to supply heat to the steam. But steam goes through the same basic cycle in all of them .

Carnot Vapor power cycle :



4-1) Reversible Isothermal heat input from boiler.

1-2) Reversible Isentropic expansion in turbine.

2-3) Reversible Isothermal heat exhaust from condenser to surroundings.

4-1) Reversible Isentropic Compression in compressor/pump.

Why not the Carnot vapor power cycle is used?

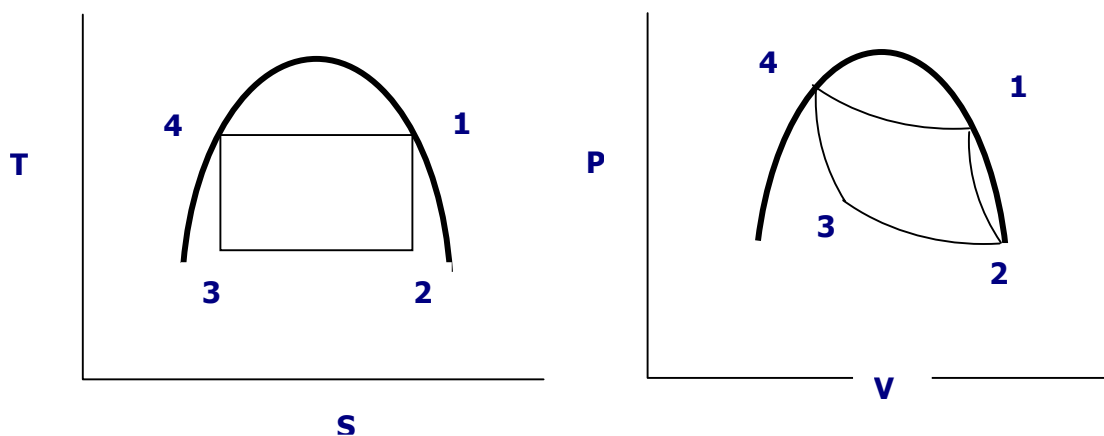


Fig 1 : P-V and T-S diagram within liquid-vapor region

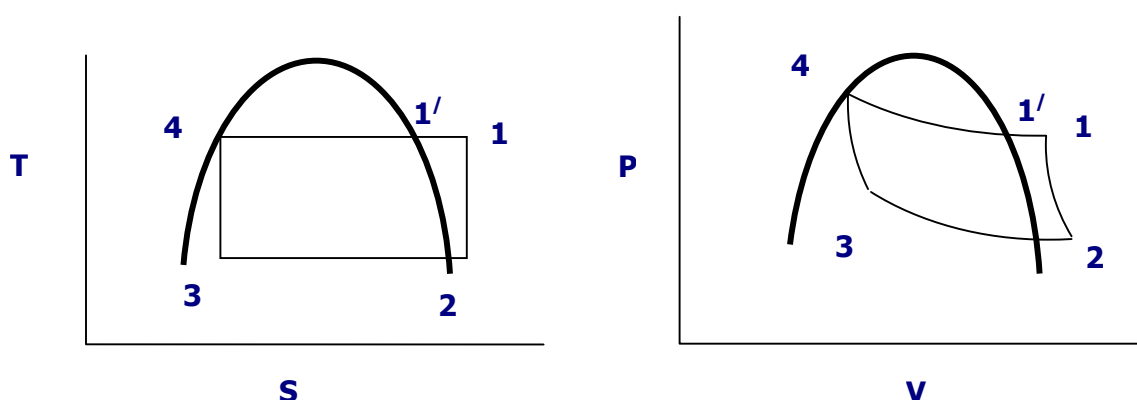
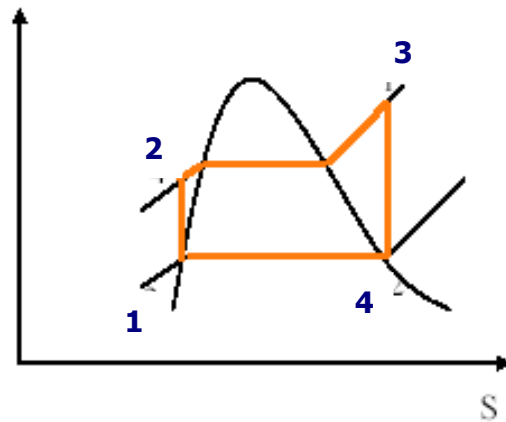


Fig 2 : P-V and T-S diagram when fluid goes to superheated region

There are two reasons for why Carnot cycle is not used to operate a vapour power engine:

- As shown in the fig .1 , the compression takes place between 3-4 , which is in liquid – vapor region . It is difficult for a compressor or a pump to work with two phase mixture.
- If the cycle cross the saturation vapor line i.e. enters to the superheated region as in the fig 2 then the problem arises to keep the temperature constant between state 1'-1. Because it is in the superheated region . Moreover pressure is also dropping . So it is impossible to add heat and keep the temperature constant at the same time.

To overcome these two difficulties Rankine cycle is employed.



Rankine cycle is the ideal cycle for vapor power plants and consists of the following four processes:

- 1-2 Isentropic compression in a pump
- 2-3 Constant pressure heat addition in a boiler
- 3-4 Isentropic expansion in a turbine
- 4-1 Constant pressure heat rejection in a condenser

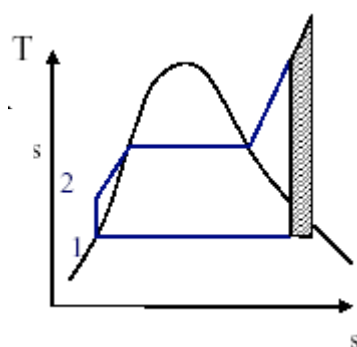
- Water enters the pump at state 1 as saturated liquid and is compressed isentropically to the operating pressure of the boiler. There is slight increase in water temperature during the compression process.
- Water enters the boiler as a compressed liquid at state 2 and leaves as a superheated vapor at state 3. The boiler is basically a heat exchanger where water is heated at constant pressure.
- The superheated vapor at state 3 enters the turbine, where it expands isentropically and produces work by rotating shaft connected to an electric generator. The pressure and the temperature of the steam drop during this process to the values at state 4.
- Steam enters the condenser at state 4. At this state steam is usually a saturated liquid-vapor mixture with a high quality. It is condensed at constant pressure and leaves the condenser as a saturated liquid.

Problems associates with Carnot cycle is solved:

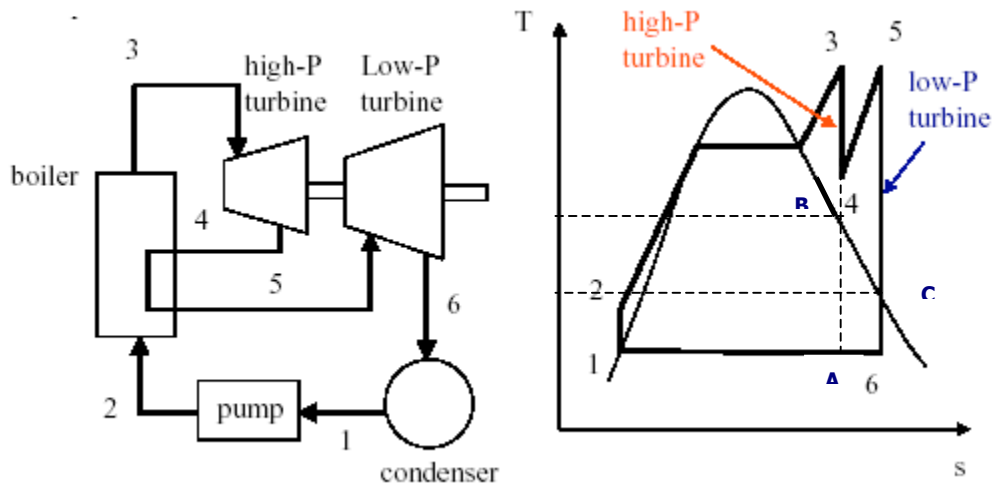
- As compression process takes place between 1-2 are in liquid region. So replacing the compressor in the Carnot cycle is possible by a small feed pump. As the phase is completely liquid pump can work properly.

Effect of increasing superheating temperature :

If the superheating temperature is raised then mean temperature of heat addition is increased and work output increases as well as seen in the figure . So the efficiency can be increased .

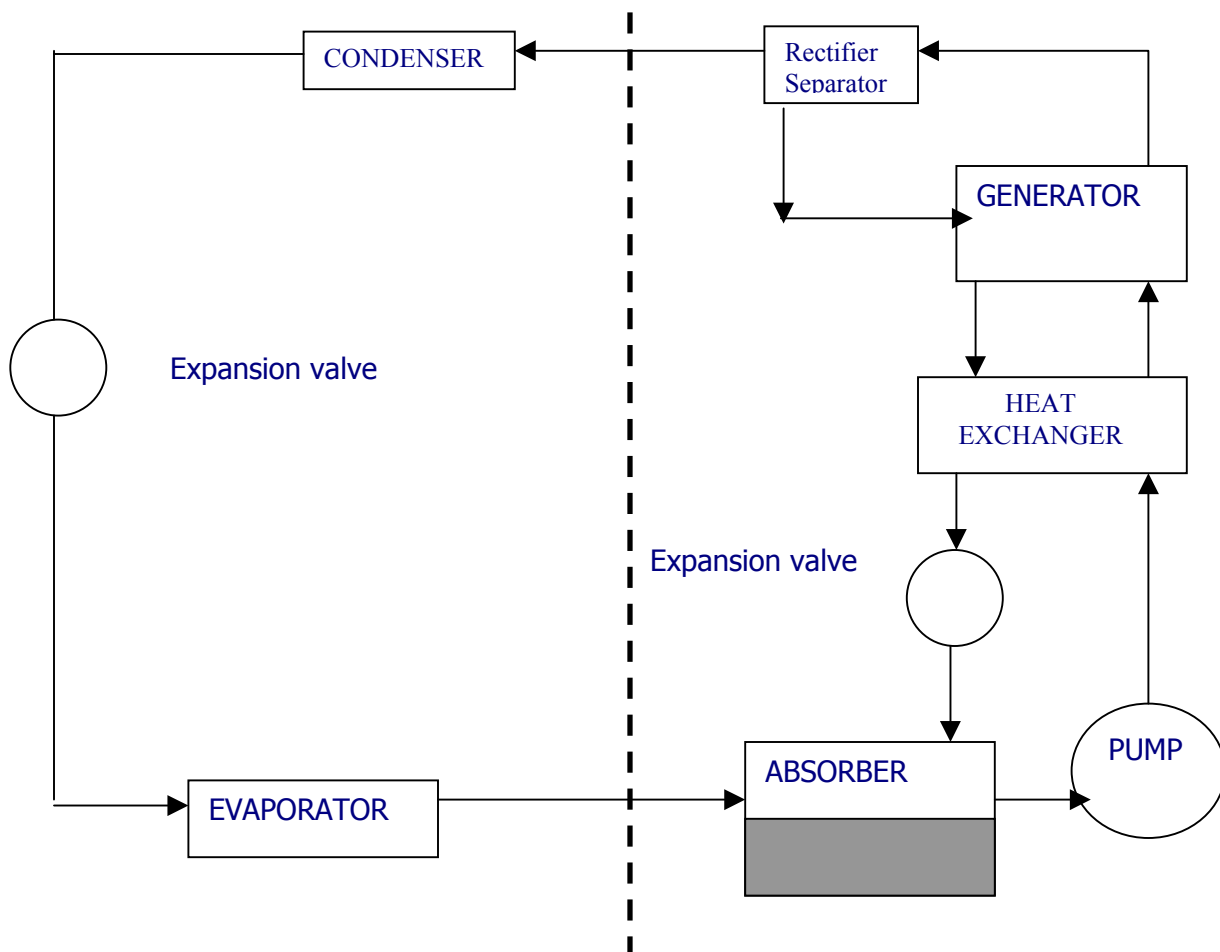


Effect of reheating :



- In a normal Rankine cycle (1-2-3-A) , as the temperature in the turbine falls , water droplets starts to form which is harmful for turbine blade. As shown in the figure in a normal cycle droplets forms between point B to A. By reheating distance between this two points can be minimized . So the amount of moisture formation will be less and turbine blade erosion will be minimized.
- For this turbine are staged by employing more than one turbine. In this case two turbines are used. Superheated vapor enters the high pressure turbine first at 3.
- Then it enters to the boiler and reheated to a temperature from 4 to 5 .
- At 5 vapor enters to the low pressure turbine and expansion takes place again.
- The result is that the moisture formation region minimized between point C-6 from a region B-A in case of normal Rankine cycle .
- So quantity of moisture formation is minimized by reheating arrangement in a Rankine cycle.

VAPOR ABSORPTION REFRIGERATION CYCLE

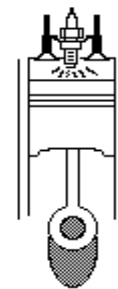
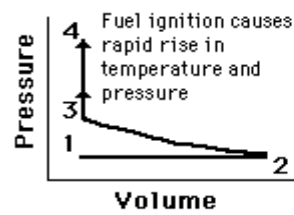
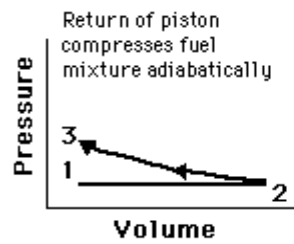
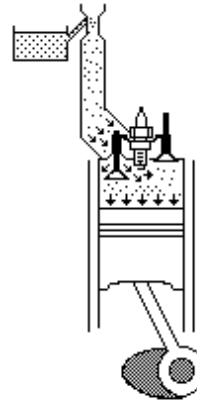
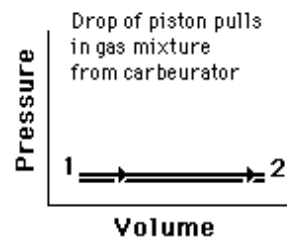


- Vapor absorption refrigeration system(VARS) is employed to replace the compressor used in a vapor compression refrigeration (VCRS) as compressor needs larger work input and it is noisy.
- The arrangement of the left of the dotted line in the figure is as same as a VCRS arrangement , the arrangement to the right is employed to replace the compressor.
- The refrigeration system employed are
 - a) Ammonia-water refrigeration system
 - b) Water-lithium bromide refrigeration system
 - c) Water –lithium chloride refrigeration system

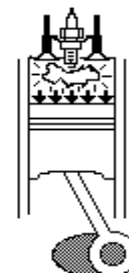
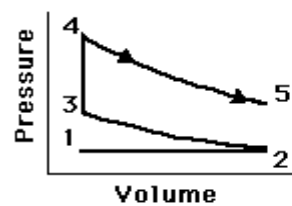
Here Ammonia-water refrigeration system is discussed.

- Ammonia vapor leaves the evaporator and enters to the absorber.
- There is ammonia solution of water in the absorber. It absorbs the ammonia vapor and strong ammonia solution leaves the absorber.
- Strong ammonia solution enters to the pump . The pump thus pumps this complete liquid phase solution to the generator through the heat exchanger .
- In the generator the solution is heated at high pressure and temperature. Thus ammonia is separated from the solution. Weak solution left in the generator flows back to the absorber through the heat exchanger and the expansion valve.
- Then ammonia vapor flows through the rectifier separator that separates any more water particle in the vapor . The only pure ammonia vapor enters to the condenser. The separated water by the rectifier is flows back to the generator.
- The remaining processes in the condenser , expansion valve and evaporator are the same as VARS.

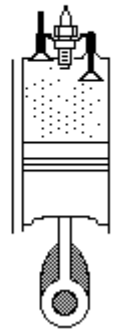
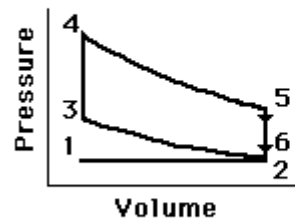
OTTO CYCLE



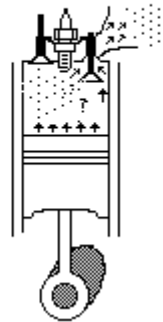
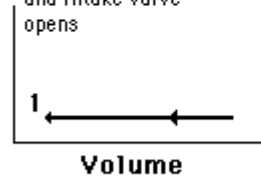
The power stroke: the adiabatically expanding gases do work on the piston



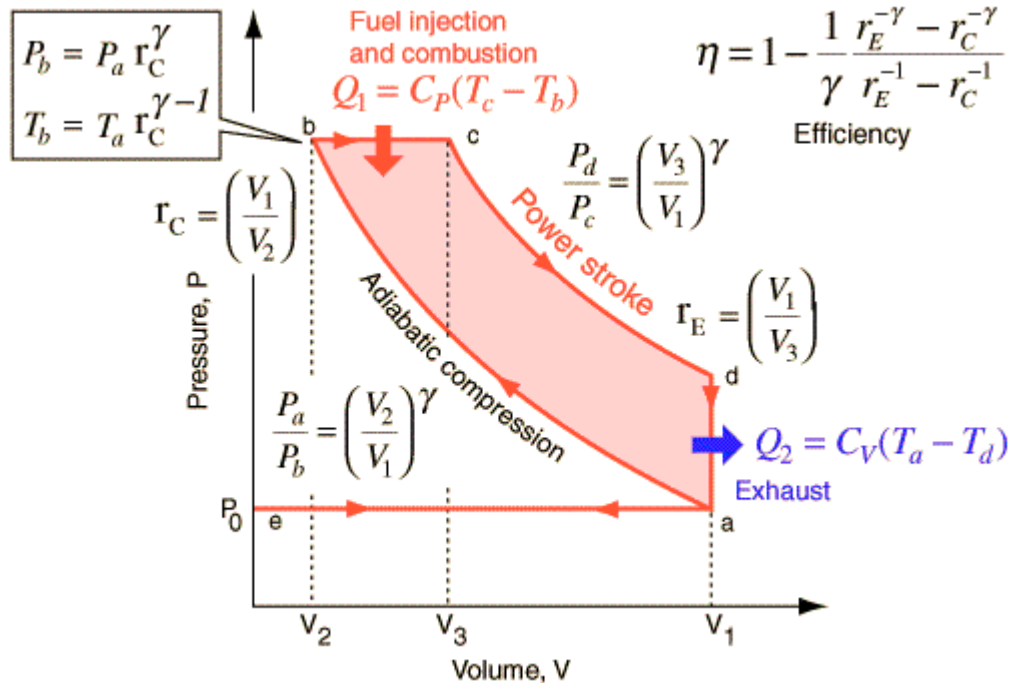
The exhaust valve opens as the piston reaches the bottom of its travel, dropping the pressure to atmospheric pressure.



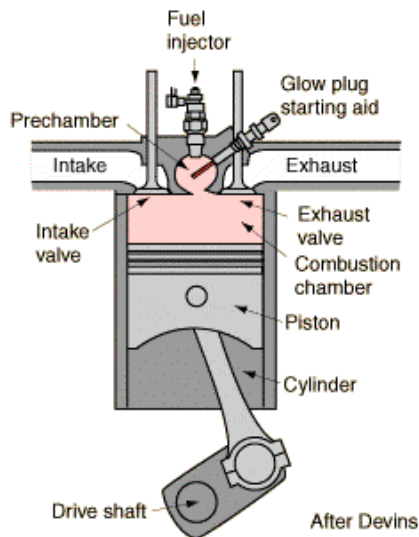
Rise of piston drives out burned gases. Exhaust valve closes at 1 and intake valve opens



DIESEL CYCLE



The term "compression ignition" is typically used in technical literature to describe the modern engines commonly called "Diesel engines". This is in contrast to "spark ignition" for the typical automobile gasoline engines that operate on a cycle derived from the Otto cycle. Rudolph Diesel patented the compression-ignition cycle which bears his name in the 1890s.



$$\eta = 1 - \frac{1}{\gamma} \frac{r_E^{-\gamma} - r_C^{-\gamma}}{r_E^{-1} - r_C^{-1}}$$

The diesel internal combustion engine differs from the gasoline powered **Otto cycle** by using a higher compression of the fuel to ignite the fuel rather than using a spark plug ("compression ignition" rather than "spark ignition").

In the diesel engine, air is compressed adiabatically with a compression ratio typically between 15 and 20. This compression raises the temperature to the ignition temperature of the fuel mixture which is formed by injecting fuel once the air is compressed.

The ideal air-standard cycle is modeled as a **reversible adiabatic compression** followed by a **constant pressure combustion process**, then an **adiabatic expansion** as a power stroke and an **isovolumetric exhaust**. A new air charge is taken in at the end of the exhaust, as indicated by the processes a-e-a on the diagram

Angel