
بسم الله الرحمن الرحيم

Applied Thermodynamics

Week_14

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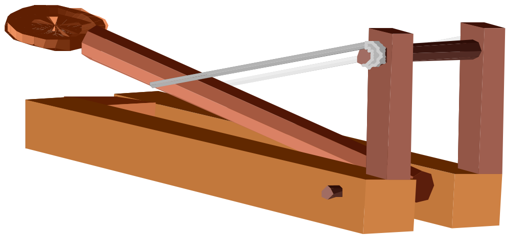
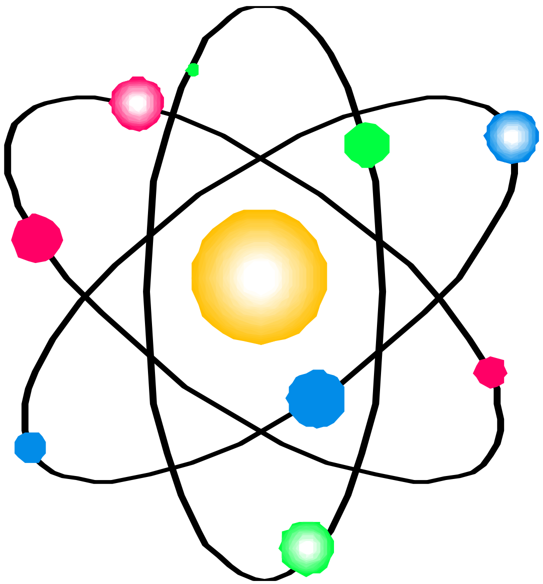
Mechanical Engineering Department

Heat Engine

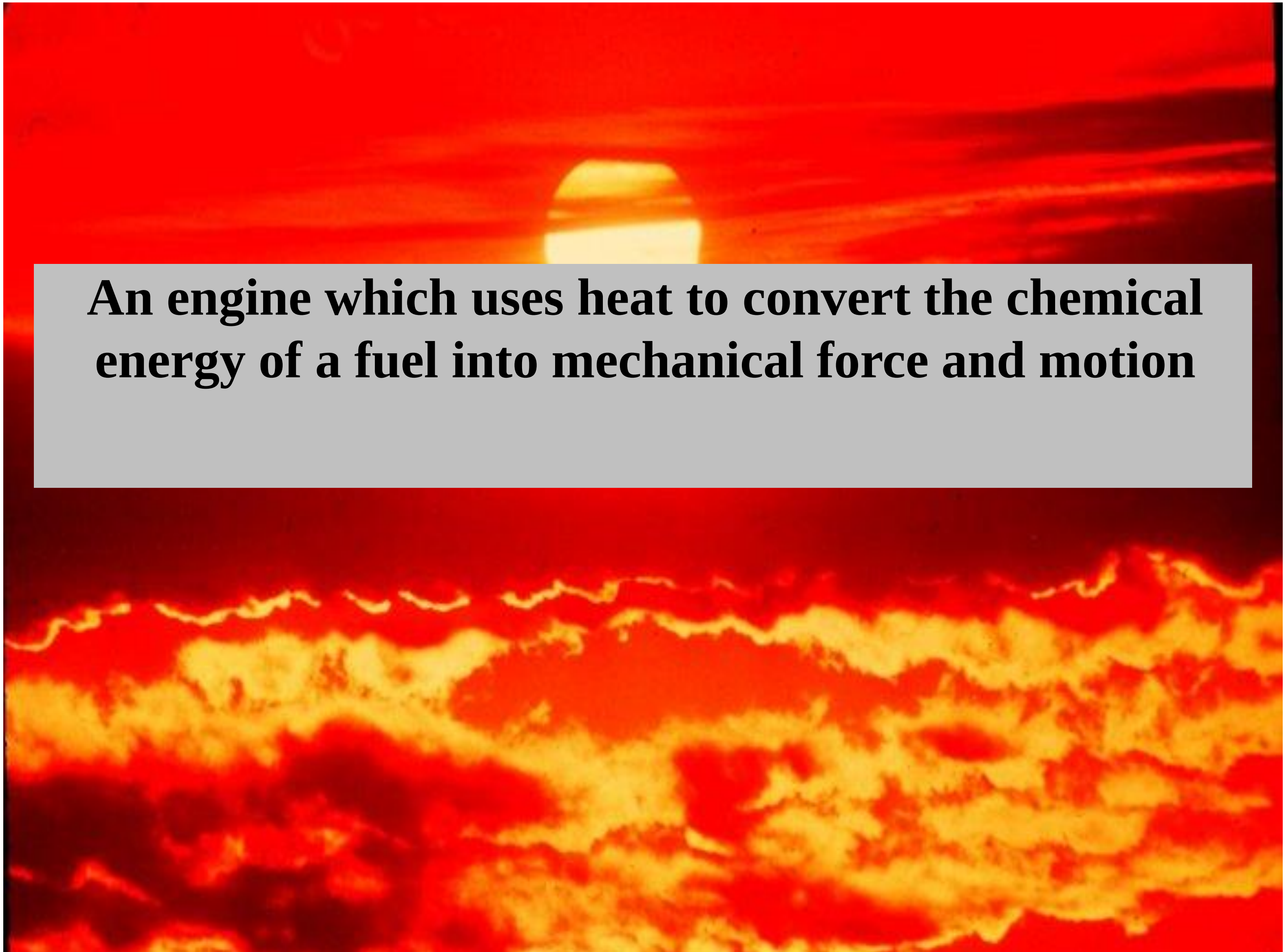
Engine

“A machine for converting energy into mechanical force and motion.”





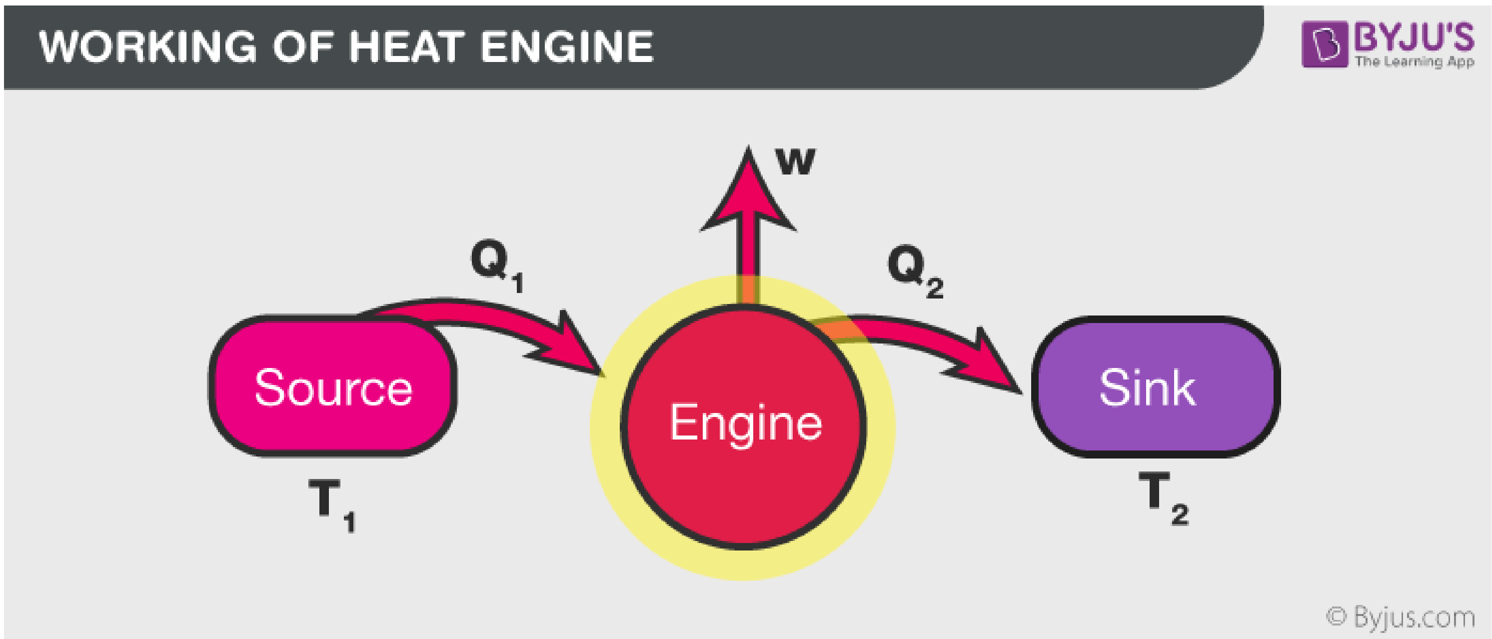
Heat Engine



An engine which uses heat to convert the chemical energy of a fuel into mechanical force and motion

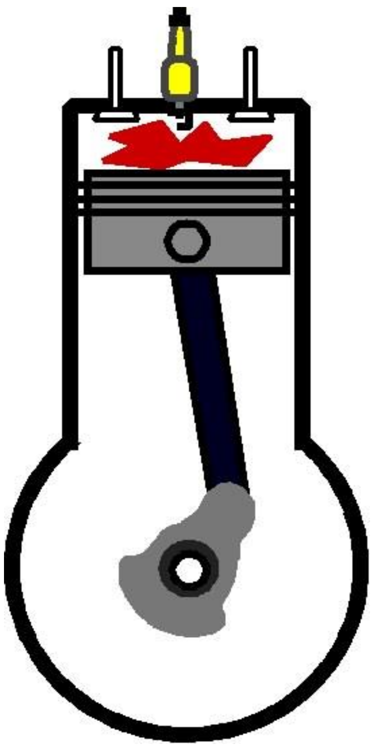
Heat Engine Cycle

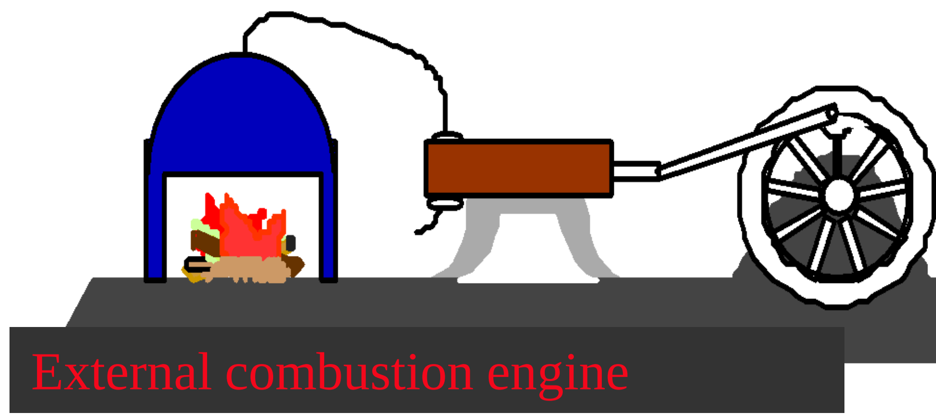
- A heat engine is a device that converts heat to work. It takes heat from a reservoir then does some work like moving a piston, lifting weight etc. and finally discharges some heat energy into the sink. Schematically it can be represented as:



Types of Heat Engine

- Two general categories based on design.





Internal combustion engine

Types Heat Engine

1. Internal Combustion Engines

This process includes the combustion of a fuel that takes place within the system. These types of engines take place where the fuel is burnt in the engine or where the fossil fuel combustion occurs. Pistons are mostly used in the internal combustion type of heat engines. These pistons move up and down within the cylinders that are present in the heat engines. When a single motion of a piston move in the upward or downward direction inside the cylinder is known as the stroke. For Example – Mostly Cars have four-stroke internal combustion heat engines that consist of an Intake stroke, power stroke, combustion stroke, and exhaust stroke.

Types Heat Engine

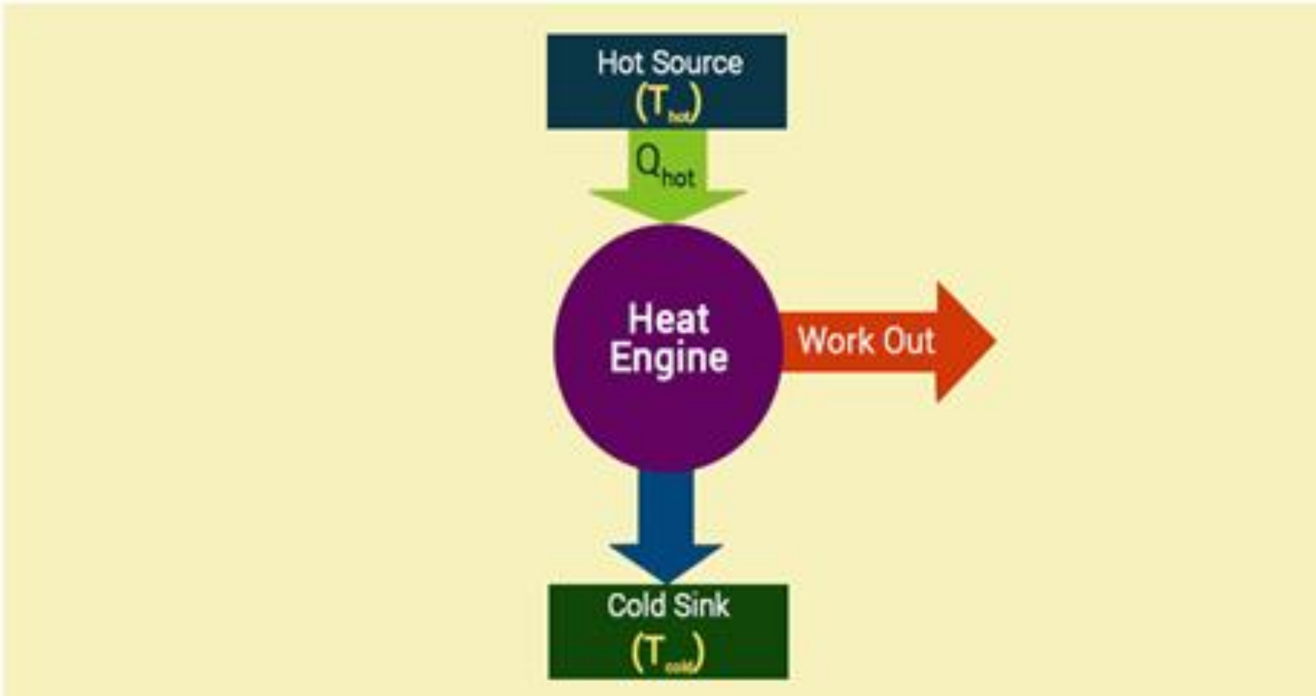
1. External Combustion Engines

These type of heat engines takes where the fuel is burnt outside the engine or where the fuel combustion occurs outside the engine. It is a heat engine where a working fluid is included internally and heated by combustion in an external source through the engine wall. This fluid then produced motion and usable work by expanding and acting on the mechanism of the engine.

Parts of Heat Energy

Heat energy is composed of three parts:

1. Working object
2. Source of heat at high temperature
3. Sink of heat at a lower temperature



How does a heat engine power a machine?

- A basic heat engine consists of a gas confined by the piston in a cylinder. When the gas is heated, it expands and moves the piston. This wouldn’t be possible in a practical engine because the motion stops once the gas reaches equilibrium. A practical engine goes through cycles in which the piston moves back and forth. When the gas gets heated, the piston moves upwards and when it is cooled it moves downward. A cycle of heating and cooling is necessary to make the piston move forward and backward.

How does a heat engine power a machine?

In a full cycle of heat engine, three things happen as follows:

1. Heat is added at a relatively high temperature; hence it can be called Q_H
2. Some part of the added energy is used to perform work
3. The unused energy is removed at a relatively cold temperature Q_C
4. An important measure of a heat engine is its efficiency. The efficiency of a heat engine depends on the ratio of the work obtained to the heat energy in the high temperature i.e. $e = W/Q_{high}$. The maximum possible efficiency e_{max} of an engine is

$$e_{max} = W_{max}/Q_{high} = (1 - T_{low} / T_{high}) = (T_{high} - T_{low})/T_{high}$$

Heat Engine Cycle-Carnot Cycle

THE CARNOT CYCLE: The Second law of Thermodynamics described That no heat engine can be more efficient Than a reversible heat engine working b/w The same Temperature limits. Carnot showed That The most efficient possible cycle is one in which all The heat supplied is supplied at one fixed temperature, and all The heat rejected is rejected at a lower fixed Temperature. The cycle Therefore consists of Two isoThermal processes joined by Two adiabatic processes.

Heat Engine Cycle-Carnot Cycle

Two isothermal processes joined by two adiabatic processes. Since all the processes are reversible, then the adiabatic processes in the cycle are also isentropic. The cycle is most conveniently represented on a T-S diagram as shown below.

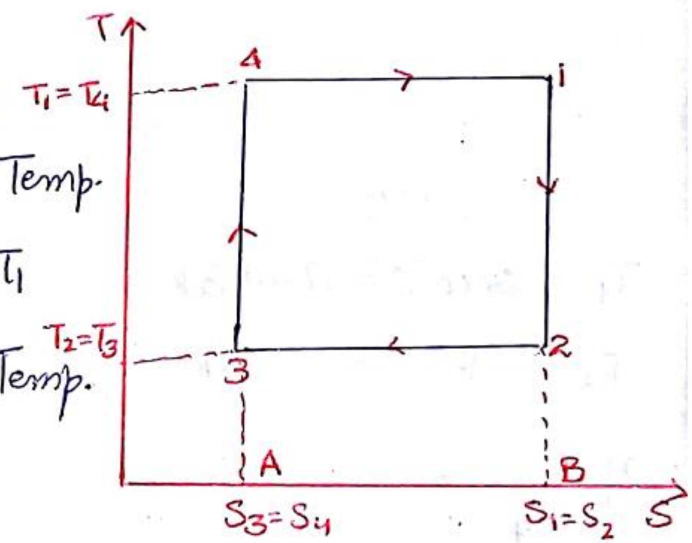
The Processes on T-S diagram are:

1-2: Isentropic expansion from T_1 to T_2

2-3: Isothermal Heat rejection at lower Temp.

3-4: Isentropic compression from T_2 to T_1

4-1: Isothermal Heat supply at higher Temp.



NOTE: The cycle is completely independent of the working substance used.

Heat Engine Cycle-Carnot Cycle

CYCLE EFFICIENCY: The cycle efficiency of a heat engine is given by the net work output divided by the gross heat supplied.

$$\text{Cycle Efficiency} = \eta = \frac{-\Sigma W}{Q_1} = \frac{\Sigma Q}{Q_1} \longrightarrow (1)$$

Now Gross heat Supplied $= Q_1 =$ Area $41B4A = T_1(S_B - S_A)$

Similarly Net heat supplied $= \Sigma Q =$ Area $41234 = (T_1 - T_2)(S_B - S_A)$

Hence Carnot Cycle Efficiency $= \eta_{carnot} = \dfrac{(T_1 - T_2)(S_B - S_A)}{T_1(S_B - S_A)} = \dfrac{T_1 - T_2}{T_1}$

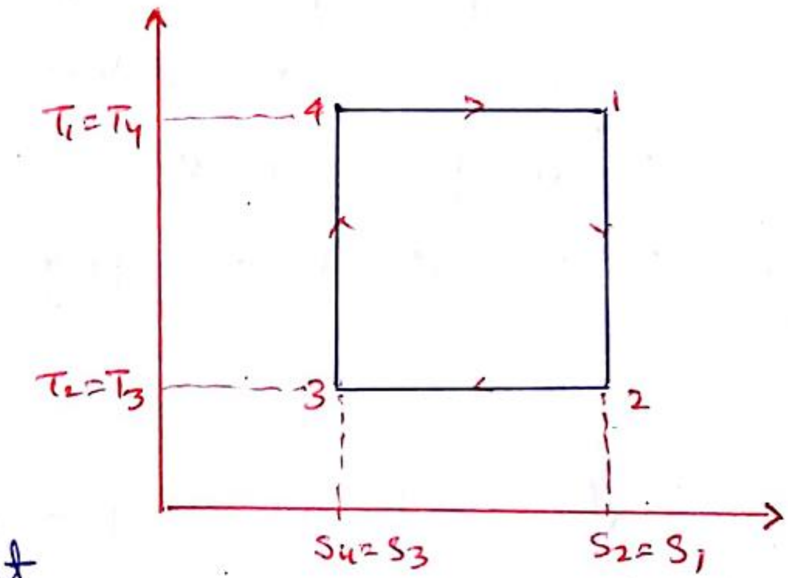
$$\Rightarrow \eta_{carnot} = \frac{T_1}{T_1} - \frac{T_2}{T_1} = 1 - \frac{T_2}{T_1} \longrightarrow (2)$$

Heat Engine Cycle-Carnot Cycle

If a heat sink for heat rejection is available at a fixed temperature "T_2", Then The ratio T_2/T_1 will decrease as The Temperature of The source T_1 is increased. And hence The Thermal efficiency will increases. Hence for a fixed lower Temperature for heat rejection, The upper Temperature at which heat is supplied must be made as high as possible. The maximum possible Thermal efficiency b/w any Two Temperatures is That of The carnot cycle.

Heat Engine Cycle-Carnot Cycle

EXAMPLE #5.1: What is the highest possible theoritical efficiency of a heat engine operating with a hot reservoir of furnace gases at 2000°C when the cooling water available is at 10°C.



GIVEN DATA:

$T_1 = 2000°C = 2273\,k.$

$T_2 = 10°C = 283\,k.$

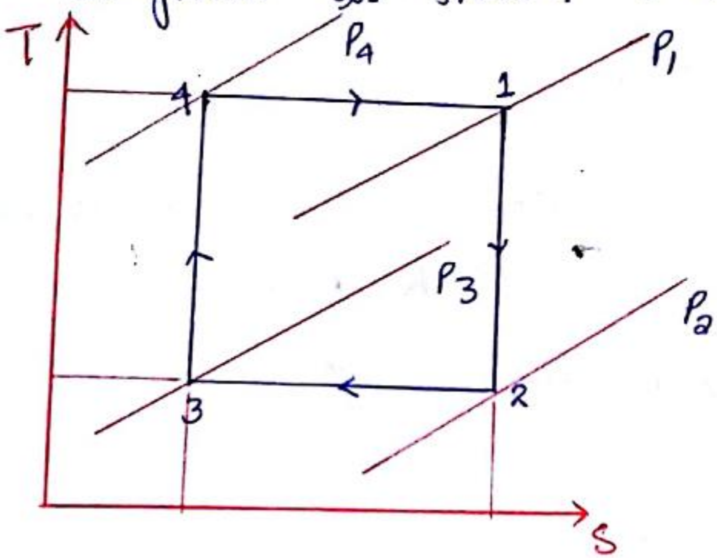
$\eta_{carnot} = ?$

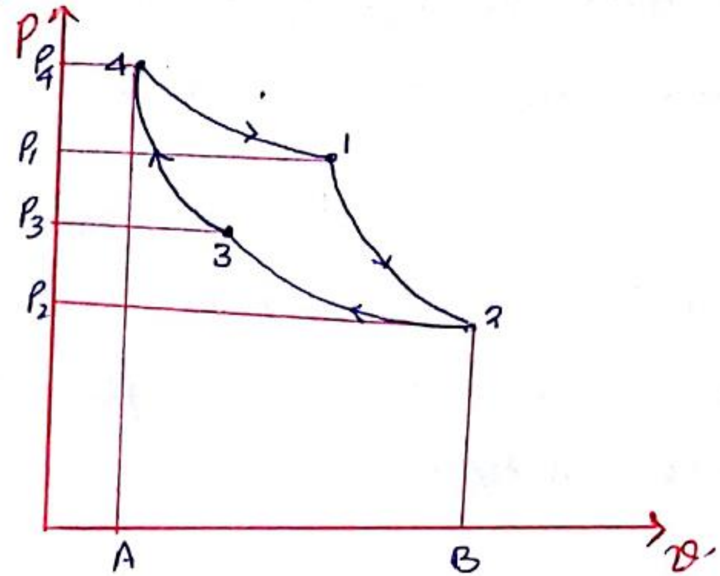
SOLUTION: Since we know that

$$\eta_{carnot} = 1 - \frac{T_2}{T_1} = 1 - \frac{283}{2273} = 1 - 0.1246 = 0.8754 = 87.54\%$$

Heat Engine Cycle-Carnot Cycle

THE CARNOT CYCLE FOR A PERFECT GAS: The carnot cycle for a perfect gas is shown on a T-S diagram and P-v diagram as shown below. (3)





Heat Engine Cycle-Carnot Cycle

The Processes on T-S diagram and Pv diagram are as follows:

1-2: Isentropic Expansion process from higher Temperature and Pressure T_1 and P_1 to a lower Temperature and Pressure T_2 and P_2.

2-3: Isothermal Heat rejection from Pressure P_2 to P_3.

3-4: Isentropic compression process from lower Temperature and Pressure T_3 and P_3 to higher Temperature and Pressure T_4 and P_4.

4-1: Isothermal Heat supply from Pressure P_4 to P_1

Heat Engine Cycle-Carnot Cycle

REASONS FOR NOT USING CARNOT CYCLE FOR A HEAT ENGINE

1:- In practice it is much more convenient to heat a gas at approximately constant pressure or at constant volume, hence it is difficult to attempt to operate an actual heat engine on a carnot cycle using gas as a working substance.

2:- The net work output of the cycle is given by (4) The area 12341. This is a small quantity compared with the gross work output of the expansion processes of the cycle given by the area 234AB2.

Heat Engine Cycle-Carnot Cycle

3:- The ratio of the net work output to the gross work output of the system is called the work ratio. The carnot cycle, despite its high thermal efficiency, has a low work ratio.

Heat Engine Cycle-Carnot Cycle

EXAMPLE#5.2: A hot reservoir at 800°C and a cold reservoir at 15°C are available. Calculate the Thermal efficiency and the work ratio of the carnot cycle using air as the working fluid, if the maximum and minimum pressures in the cycle are 210 bar and 1 bar.

GIVEN DATA:

$T_1 = 800°C = 1073K$

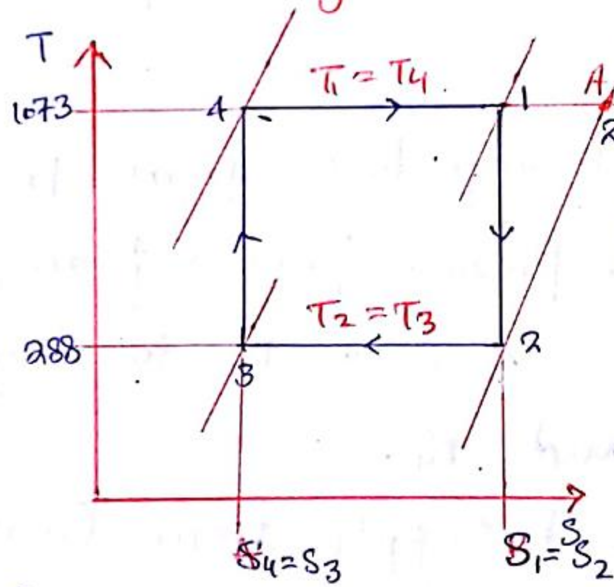
$T_2 = 15°C = 288K$

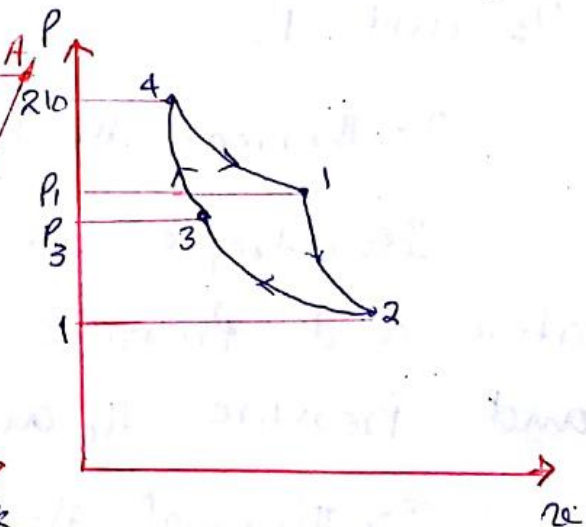
$P_A = 210 \text{ bar}$

$P_2 = 1 \text{ bar}$

Thermal Efficiency $= \eta = ?$

Work ratio $= W_r = ?$





Heat Engine Cycle-Carnot Cycle

SOLUTION: Since we know that for a Carnot cycle;

Thermal Efficiency $= \eta_{carnot} = 1 - \frac{T_2}{T_1} = 1 - \frac{288}{1073} = 0.732 = 73.2\%$

Similarly we know that;

Work Ratio $= W_r = \frac{\text{Net work out put}}{\text{Gross work out put}} \longrightarrow (1)$ (5)

In order to find out the work ratio we have to calculate the entropy change $(S_1 - S_4)$.

$\Rightarrow S_1 - S_4 = (S_A - S_4) - (S_A - S_2) = R \ln\left[\frac{P_4}{P_2}\right] - C_p \ln\left[\frac{T_1}{T_2}\right]$

$\Rightarrow S_1 - S_4 = 0.287 \ln\left[\frac{210}{1}\right] - 1.005 \ln\left[\frac{1073}{288}\right]$

$\Rightarrow S_1 - S_4 = 1.535 - 1.321 = 0.214 \text{ kJ/kgK.}$

Heat Engine Cycle-Carnot Cycle

Net work out put = $W_{net} = (T_1 - T_2)(S_1 - S_4) = (1073-288)(0.214)$

Net work out put = W_{net} = 168 kJ/kg.

Gross Work output = $W = W_{41} + W_{12}$

Gross work output = $W = T_1(S_1 - S_4) + C_v(T_1 - T_2)$

Gross work output = $W = 1073(0.214) + 0.718(1073 - 288)$

Gross work output = $W = 229.6 + 563.6 = 793.2$ kJ/kg

Now By Putting all values in Equation (1) we have;

$$\text{Work Ratio} = \frac{W_{net}}{W} = \frac{168}{793.2} = 0.212.$$

Heat Engine Cycle-Constant Pressure Cycle

THE CONSTANT PRESSURE CYCLE: In this cycle the heat supply and heat rejection processes occure reversibly at constant pressure. The expansion and compression processes are isentropic. This cycle was one time used as a ideal basis for a hot air reciprocating engine, and the cycle was known as the Joule or Brayton cycle. Now a days this cycle is the ideal for closed cycle gas turbine.

A Simple line diagram of the plant is shown in Fig. 1 while the corresponding Pv and TS diagrams are shown in Fig. 2 and 3. The working substance is air which flows in steady flow round the cycle.

Heat Engine Cycle-Constant Pressure Cycle

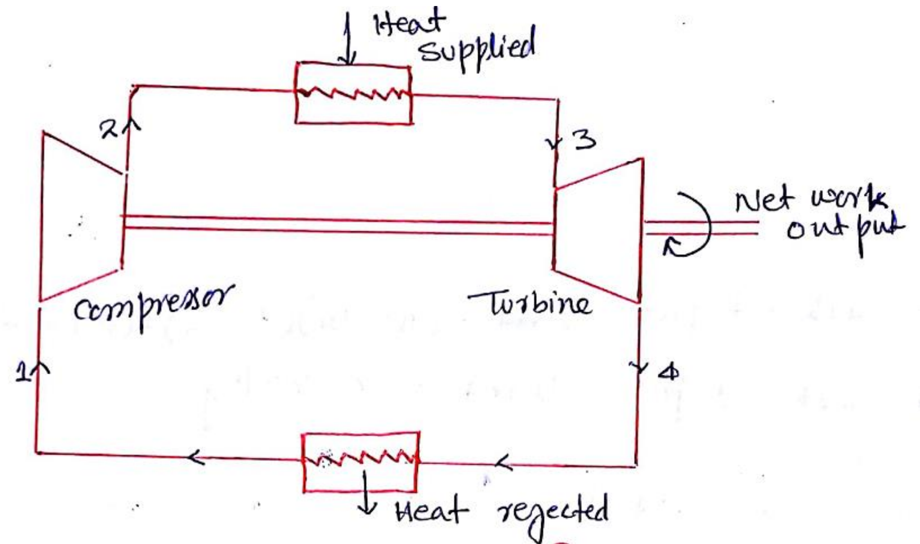


Fig.1: Closed Cycle Gas Turbine

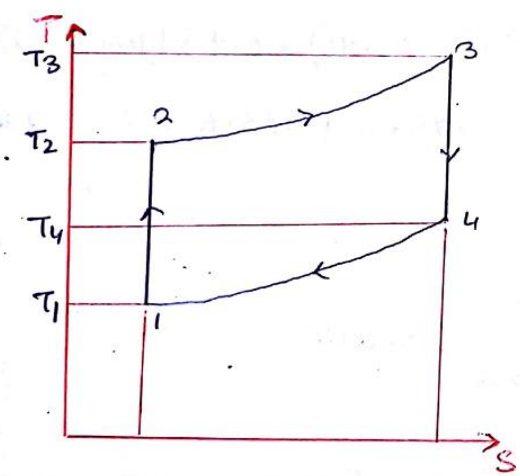


Fig.2: T-S diagram

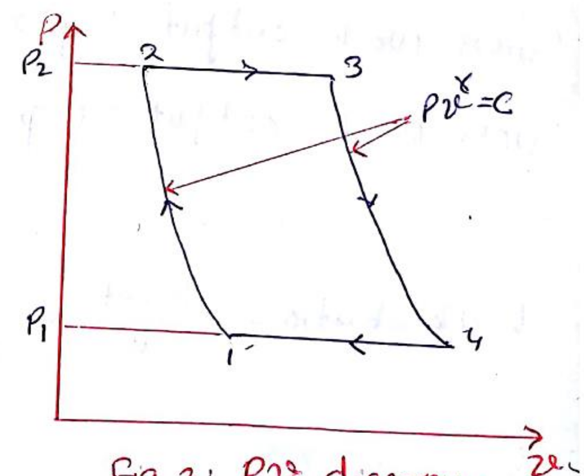


Fig.3: PV diagram

Heat Engine Cycle-Constant Pressure Cycle

The Processes on PV and TS diagram are:

1-2: Isentropic compression in the compressor. Both the Temperature and pressure of the fluid increases.

Work input to compressor $= W_c = h_2 - h_1 = C_p(T_2 - T_1$

2-3: constant Pressure heat supplied in heater. The Temp. of the fluid increases. (7)

Heat supplied in Heater $= Q_1 = h_3 - h_2 = C_p(T_3 - T_2)$.

Heat Engine Cycle-Constant Pressure Cycle

3-4: Isentropic expansion of fluid in Turbine. Both the Pressure and Temperature of fluid decreases.

Work output from Turbine $= W_T = h_3 - h_4 = C_p(T_3 - T_4)$

4-1: Constant Pressure heat rejection in cooler. The Temperature of the fluid decreases.

Heat rejected in cooler $= Q_2 = h_4 - h_1 = C_p(T_4 - T_1)$.

Heat Engine Cycle-Constant Pressure Cycle

THERMAL EFFICIENCY OF SYSTEM: since we know That the thermal efficiency of a System is given by relation

$$\eta = \frac{\Sigma Q}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = \frac{C_p(T_3 - T_2) - C_p(T_4 - T_1)}{C_p(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_1} \rightarrow (1)$$

Now for isentropic processes b/w 1-2 and 3-4 we have

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = r_p^{\frac{\gamma-1}{\gamma}} \quad ; \quad \frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = r_p^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow T_2 = T_1 r_p^{\frac{\gamma-1}{\gamma}} \rightarrow (a) \quad ; \quad T_3 = T_4 r_p^{\frac{\gamma-1}{\gamma}} \rightarrow (b)$$

$$\Rightarrow T_3 - T_2 = T_4 r_p^{\frac{\gamma-1}{\gamma}} - T_1 r_p^{\frac{\gamma-1}{\gamma}} = r_p^{\frac{\gamma-1}{\gamma}}(T_4 - T_1) \rightarrow (2)$$

Heat Engine Cycle-Constant Pressure Cycle

Now By Putting equation ② in eq① we have.

$$\eta = 1 - \frac{T_4 - T_1}{(T_4 - T_1) r_p^{\frac{\gamma-1}{\gamma}}} = 1 - \frac{1}{r_p^{\frac{\gamma-1}{\gamma}}} \longrightarrow ③$$

Hence for a constant Pressure cycle the cycle. ⑧ efficiency depends only on the pressure ratio. In ideal case the value of 'γ' for air is constant and equal to 1.4.

Heat Engine Cycle-Constant Pressure Cycle

WORK RATIO OF CYCLE: The work ratio of constant pressure cycle may be found as follows.

$$\text{work Ratio} = \frac{\text{Net work output}}{\text{Gross work output}} = \frac{W_{net}}{W}$$

$$\Rightarrow \text{Work Ratio} = \frac{C_p(T_3 - T_4) - C_p(T_2 - T_1)}{C_p(T_3 - T_4)} = 1 - \frac{T_2 - T_1}{T_3 - T_4} \rightarrow (4)$$

Now for isentropic processes b/w 1-2 and 3-4 we have

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = r_p^{\frac{\gamma-1}{\gamma}} \quad ; \quad \frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = r_p^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow T_2 = T_1 \, r_p^{\frac{\gamma-1}{\gamma}} \rightarrow (c) \quad ; \quad T_4 = T_3 / r_p^{\frac{\gamma-1}{\gamma}} \rightarrow (d)$$

Heat Engine Cycle-Constant Pressure Cycle

Now By Putting values of T_2 and T_4 in eq (4) we have

$$\text{work ratio} = 1 - \frac{T_1\, r_p^{\frac{\gamma-1}{\gamma}} - T_1}{T_3 - T_3/r_p^{\frac{\gamma-1}{\gamma}}} = 1 - \frac{T_1}{T_3}\left[\frac{\cancel{r_p^{\frac{\gamma-1}{\gamma}} - 1}}{\cancel{\left(r_p^{\frac{\gamma-1}{\gamma}} - 1\right)}/r_p^{\frac{\gamma-1}{\gamma}}}\right]$$

$$\Rightarrow \text{work ratio} = 1 - \frac{T_1}{T_3}\, r_p^{\frac{\gamma-1}{\gamma}} \longrightarrow (5)$$

It can be seen from equation (5) that the work ratio depends not only on the pressure ratio but also on the ratio of the minimum and maximum Temperatures. For a given inlet Temperature T_1, the maximum Temperature T_3 must be made as high as possible for a high work ratio.

Heat Engine Cycle-Constant Pressure Cycle

EXAMPLE # 5.3: In a gas Turbine Unit air is drawn in at 1.02 bar and 15°C, and is compressed to 6.12 bar. Calculate the Thermal efficiency and the work ratio of the ideal constant Pressure cycle, when the maximum cycle Temperature is 800°C.

Heat Engine Cycle-Constant Pressure Cycle

GIVEN DATA:

$P_1 = P_4 = 1.02 \text{ bar}$

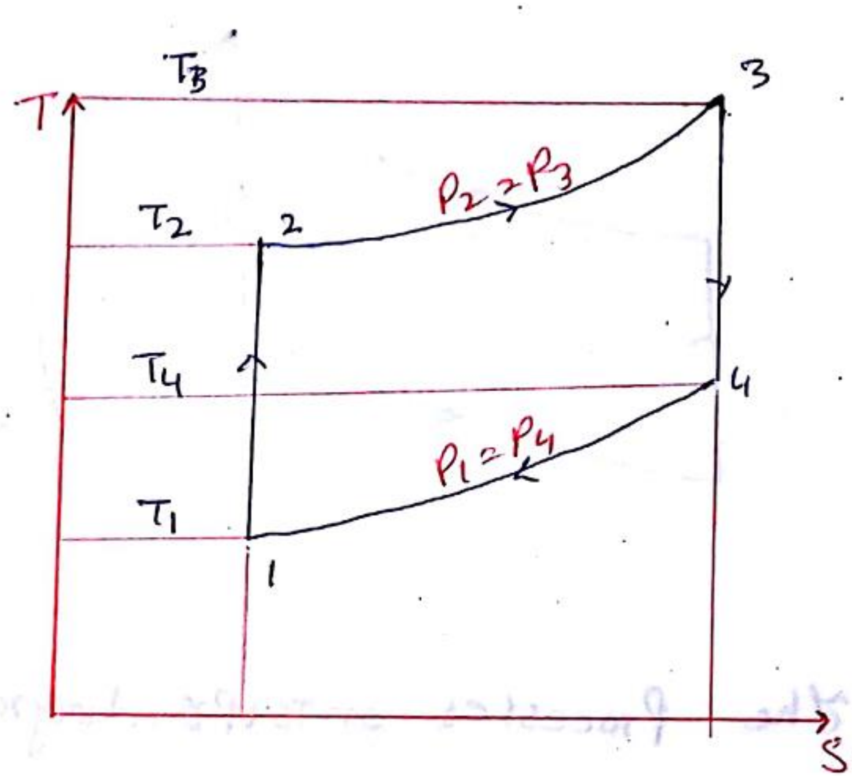
$T_1 = 15^\circ C = 288 K$

$P_2 = P_3 = 6.12 \text{ bar}$

$T_3 = 800^\circ C = 1073 K.$

Thermal efficiency $= \eta = ?$

work ratio $= W_r = ?$



Heat Engine Cycle-Constant Pressure Cycle

SOLUTION: Since for an ideal constant pressure cycle we know that:

$$\text{Thermal Efficiency} = \eta = 1 - \frac{1}{r_p^{\frac{\gamma-1}{\gamma}}} = 1 - \frac{1}{(P_2/P_1)^{\frac{\gamma-1}{\gamma}}}$$

$$\text{Thermal Efficiency} = \eta = 1 - \frac{1}{\left(\frac{6.12}{1.02}\right)^{\frac{1.4-1}{1.4}}} = 1 - \frac{1}{1.669} =$$

$$\text{Thermal Efficiency} = \eta = 1 - 0.599 = 0.401 = 40.1\%$$

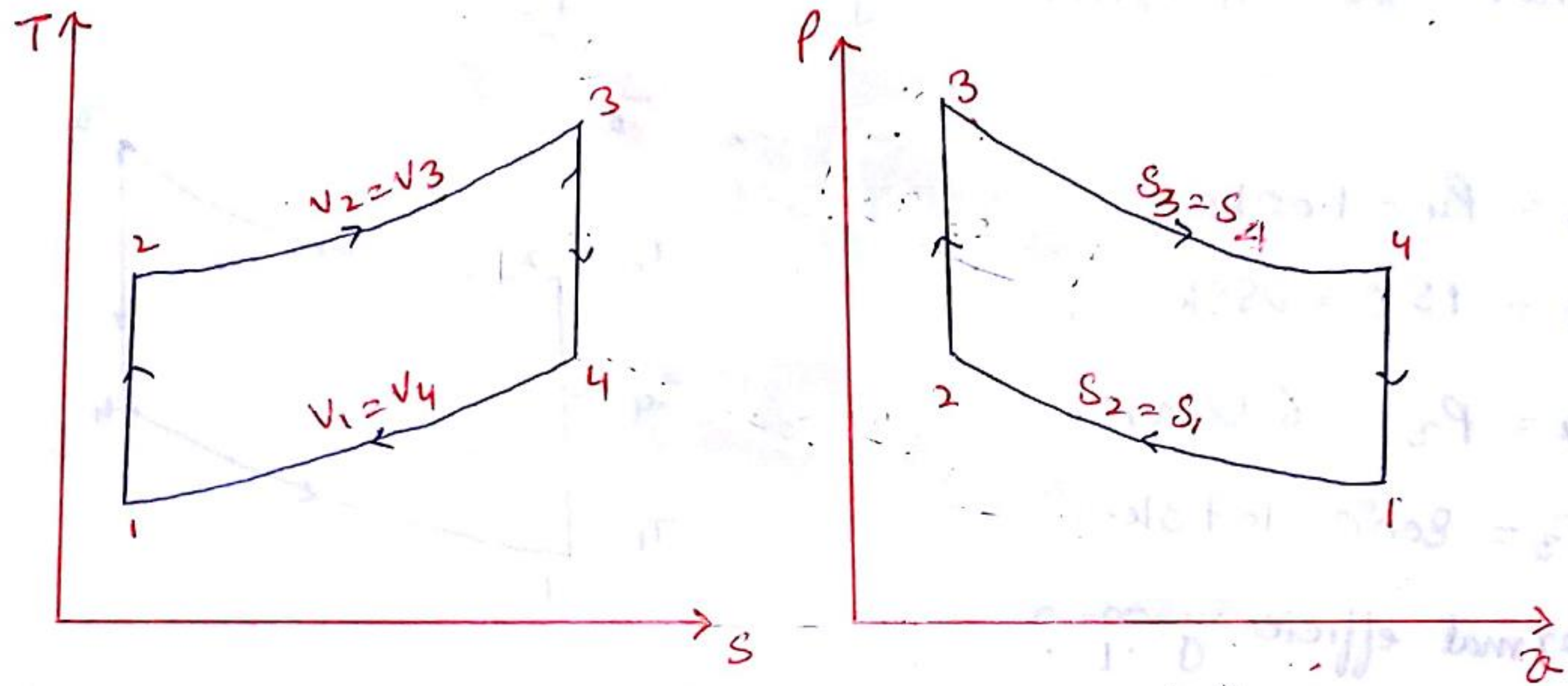
Similarly for constant Pressure cycle we have

$$\text{Work Ratio} = W_r = 1 - \frac{T_1}{T_3} r_p^{\frac{\gamma-1}{\gamma}} = 1 - \frac{288}{1073}\left[\frac{6.12}{1.02}\right]^{\frac{1.4-1}{1.4}}$$

$$\text{Work Ratio} = W_r = 1 - 0.4480 = 0.5520$$

Heat Engine Cycle-Otto Cycle

The Otto cycle is the ideal air standard cycle for the Petrol engine, the gas engine, and the high speed oil engine. The cycle is shown on P-v & T-s diagrams as below



Heat Engine Cycle-Otto Cycle

The Processes on TS & PV-diagram are as follows:

1-2: Isentropic compression of fluid.

Work Input = $W_{in} = U_2 - U_1 = C_v(T_2 - T_1)$

2-3: Reversible constant volume heating

Heat supplied = $Q_1 = U_3 - U_2 = C_v(T_3 - T_2)$

3-4: Isentropic Expansion of fluid.

Work output = $W_{out} = U_3 - U_1 = C_v(T_3 - T_4)$

4-1: Reversible constant volume cooling of fluid.

Heat Rejected = $Q_2 = U_1 - U_1 = C_v(T_4 - T_1)$

Heat Engine Cycle-Otto Cycle

THERMAL EFFICIENCY OF SYSTEM: Since we know that the thermal efficiency of a system is given by the relation,

$$\therefore \eta = \frac{\Sigma Q}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = \frac{C_v(T_3 - T_2) - C_v(T_4 - T_1)}{C_v(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2} \rightarrow (1)$$

Heat Engine Cycle-Otto Cycle

Now for Isentropic processes b/w 1-2 and 3-4 we have;

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1} = r_v^{\gamma-1} \quad ; \quad \frac{T_3}{T_4} = \left(\frac{v_4}{v_3}\right)^{\gamma-1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1} = r_v^{\gamma-1}.$$

$$\Rightarrow \quad T_2 = T_1 r_v^{\gamma-1} \longrightarrow (a) \quad ; \quad T_3 = T_4 r_v^{\gamma-1} \longrightarrow (b)$$

$$\Rightarrow \quad T_3 - T_2 = T_4 r_v^{\gamma-1} - T_1 r_v^{\gamma-1} = r_v^{\gamma-1}(T_4 - T_1) \longrightarrow (2)$$

Now by putting Equation (2) in equation (1) we have

$$\eta = 1 - \frac{T_4 - T_1}{(T_4 - T_1) r_v^{\gamma-1}} = 1 - \frac{1}{r_v^{\gamma-1}} \longrightarrow (3)$$

Heat Engine Cycle-Otto Cycle

It can be seen from Equation (3) that the thermal efficiency of the otto cycle depends only on the compression ratio, r_v.

Heat Engine Cycle-Otto Cycle

EXAMPLE #5.4: Calculate the ideal air standard cycle efficiency based on the otto cycle for a petrol engine with a cylinder bore of 50mm, a stroke of 75mm, and a clearence volume of 21.3 cm³.

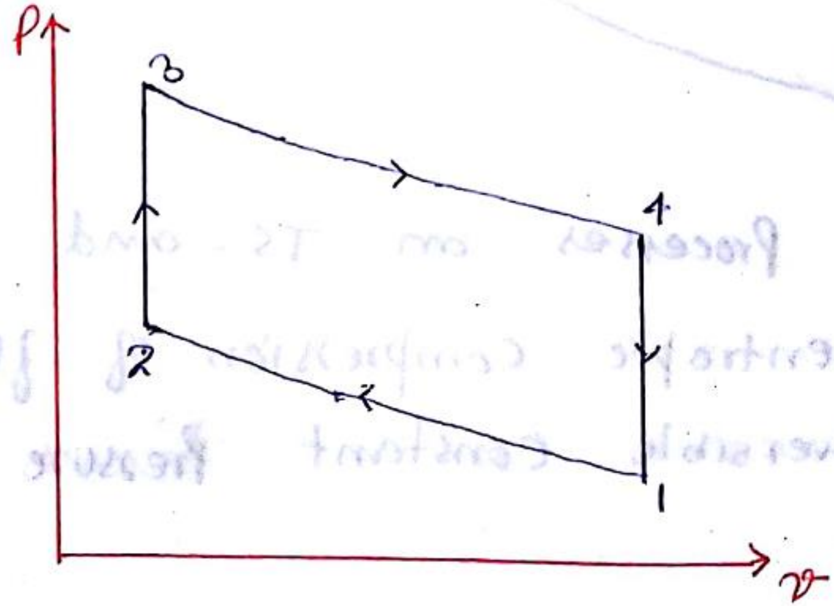
GIVEN DATA:

$D = 50mm$

$L = 75mm$

$V_c = 21.3\,cm^3$

$\eta = ?$



Heat Engine Cycle-Otto Cycle

SOLUTION: Since we know That : ⑫

Swept Volume $= V_s = \frac{\pi}{4} D^2 L = \frac{\pi}{4} \times 50^2 \times 75 = 147200\,mm^3 = 147.2\,cm^3$

Compression ratio $= r_v = \frac{V_1}{V_2} = \frac{V_s + V_c}{V_c} = \frac{147.2 + 21.3}{21.3} = 7.914$

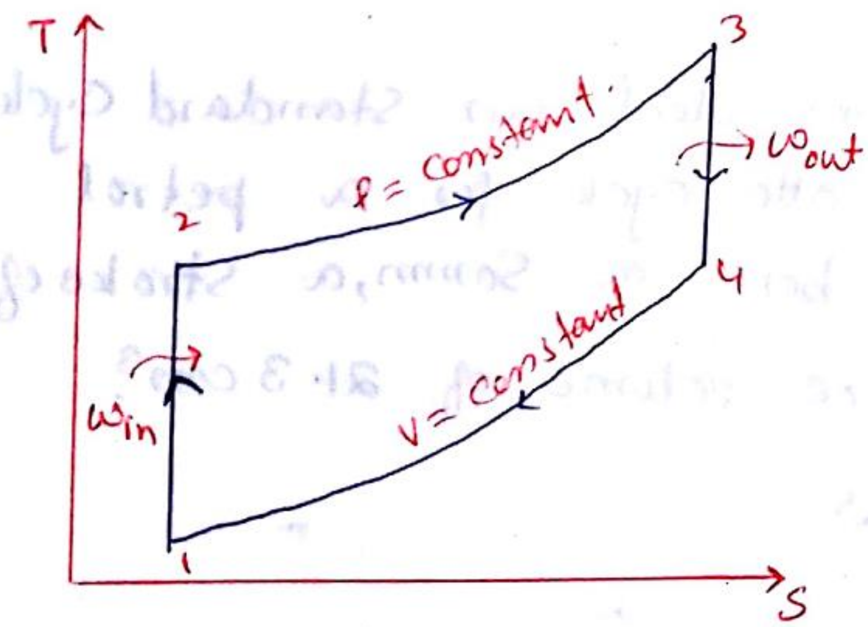
Cycle efficiency $= \eta = 1 - \frac{1}{r_v^{\gamma - 1}} = 1 - \frac{1}{(7.914)^{1.4-1}} = 0.563 = 56.3\%$

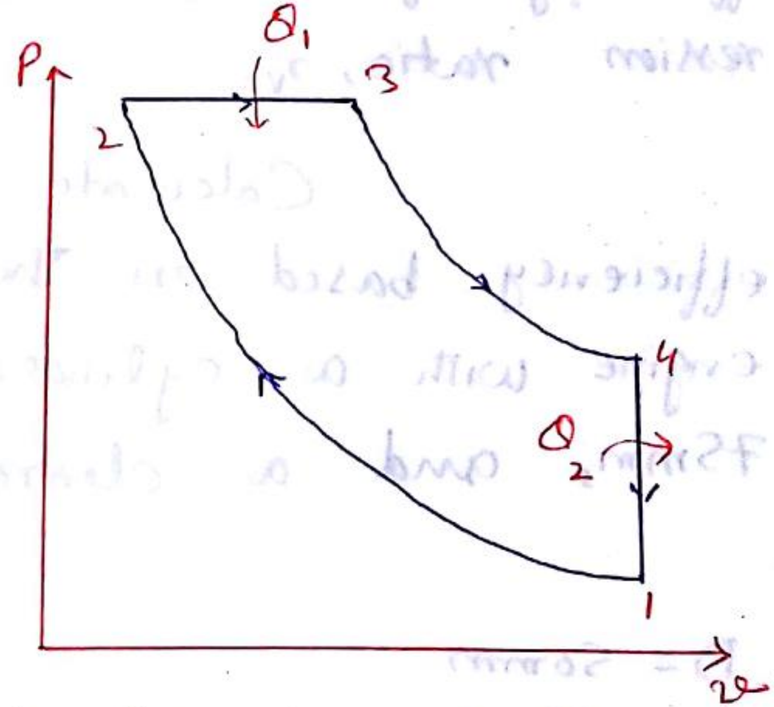
Heat Engine Cycle-Diesel Cycle

THE DIESEL CYCLE: Diesel engine works on the idea of spontaneous ignition of Powdered coal, which was blasted into the cylinder by compressed air. oil became the acceptable fuel used in compression ignition engines, and the oil was originally blasted into the cylinder in the same way as that diesel engine had intended to inject the coal in powdered form. The diesel cycle is show on pv and TS diagram as below.

Heat Engine Cycle-Diesel Cycle

diesel cycle is show on Pv and TS diagrams as below.





Heat Engine Cycle-Diesel Cycle

The Processes on TS- and Pv diagram are as follows.

1-2: Isentropic compression of fluid.

2-3: Reversible constant Pressure heat supply.

Heat supplied $= Q_1 = h_3 - h_2 = C_p(T_3 - T_2)$

3-4: Isentropic Expansion of fluid.

4-1: Reversible constant volume cooling.

Heat Rejected $= Q = U_4 - U_1 = C_v(T_4 - T_1)$

Heat Engine Cycle-Diesel Cycle

THERMAL EFFICIENCY OF SYSTEM: Since we know that the thermal efficiency of a system is given by the relation;

$$\eta = \frac{\Sigma Q}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = \frac{C_p(T_3 - T_2) - C_v(T_4 - T_1)}{C_p(T_3 - T_2)} = 1 - \frac{C_v(T_4 - T_1)}{C_p(T_3 - T_2)}$$

$$\eta = 1 - \frac{T_4 - T_1}{\gamma(T_3 - T_2)} = 1 - \frac{T_1}{\gamma T_2}\left[\frac{T_4/T_1 - 1}{T_3/T_2 - 1}\right] \longrightarrow (1)$$

Now for isentropic processes b/w 1-2 and 3-4 we have;

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = r_v^{\gamma-1} \quad ; \quad \frac{T_3}{T_2} = \frac{V_3}{V_2} = \beta \quad ; \quad \frac{T_4}{T_1} = \frac{P_4}{P_1} = ?$$

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Now to calculate the ratio T_4/T_1 we will use PV-diagram and the following relations. Since from PV-diagram;

$$P_1 v_1^{\gamma} = P_2 v_2^{\gamma} \Rightarrow P_1 = P_2 \cdot \left(\frac{v_2}{v_1}\right)^{\gamma} = P_3 \left(\frac{v_2}{v_1}\right)^{\gamma} \rightarrow (a)$$

$$P_4 v_4^{\gamma} = P_3 v_3^{\gamma} \Rightarrow P_4 = P_3 \left(\frac{v_3}{v_4}\right)^{\gamma} = P_3 \left(\frac{v_3}{v_1}\right)^{\gamma} \rightarrow (b)$$

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Now By dividing equation (a) and (b) we have

$$\frac{P_4}{P_1} = \frac{P_3 (v_3/v_1)^{\gamma}}{P_3 (v_2/v_1)^{\gamma}} = \left(\frac{v_3}{v_2}\right)^{\gamma} = \beta^{\gamma}$$

Now Equation (1) can be written as:

$$\eta = 1 - \frac{(\beta^{\gamma} - 1)}{\gamma\, r_v^{\gamma-1} (\beta - 1)} \rightarrow (2)$$ where β is cut off ratio

Equation (2) shows that thermal efficiency not only (w) depends upon compression ratio, but also on the heat supplied b/w 2-3, which fixes the ratio v_3/v_2.

Heat Engine Cycle-Diesel Cycle

EXAMPLE # 5.5: A diesel engine have an inlet Temperature and pressure of 15°C and 1 bar respectively. The compression ratio is 12/1 and The maximum cycle Temp. is 1100°C. Calculate The air standard Thermal efficiency based on The diesel cycle.

GIVEN DATA:

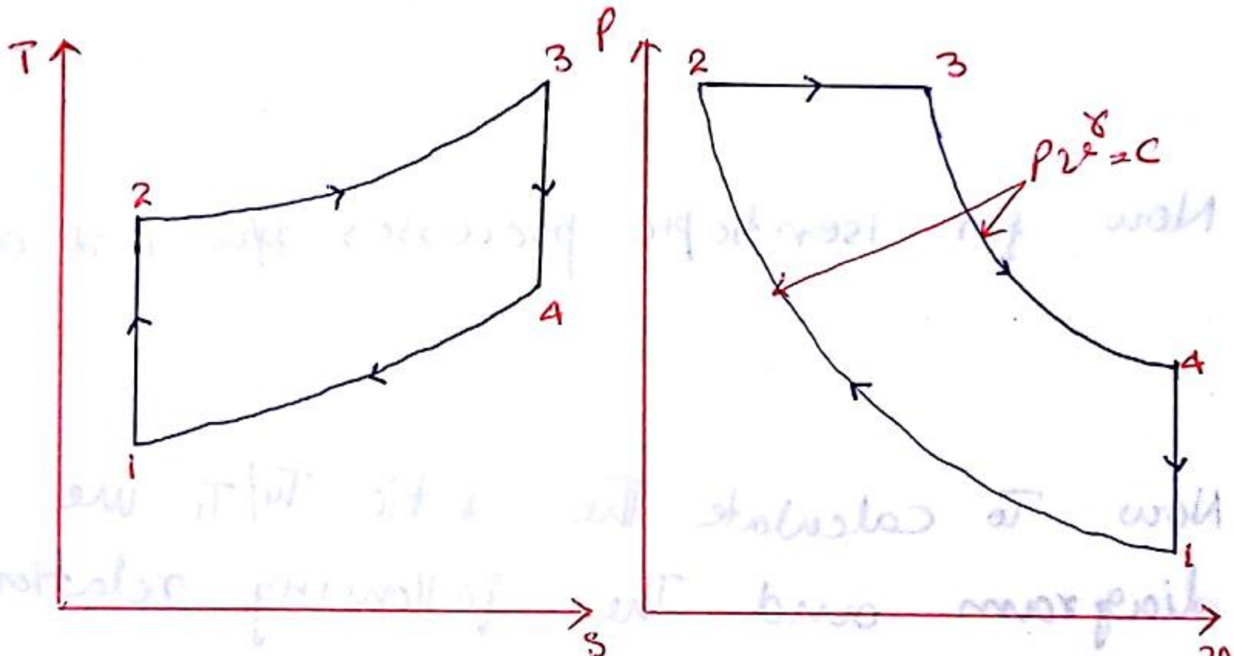
$T_1 = 15°C = 288K$

$P_1 = 1 bar$

$\frac{v_1}{v_2} = \frac{12}{1}$

$T_3 = 1100°C = 1373K$

$\eta = ?$



Heat Engine Cycle-Diesel Cycle

SOLUTION: Since first we calculate Temp. at all points.

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1} = r_v^{\gamma-1} = \left[\frac{12}{1}\right]^{1.4-1} = 12^{0.4} = 2.7 \Rightarrow T_2 = 288 \times 2.7 = 778K$$

Since from 2-3 The process is constant Pressure. Hence for a perfect gas undergoing constant Pressure process from equation of state $Pv = RT$ we have;

$$\frac{T_3}{T_2} = \frac{v_3}{v_2} \Rightarrow \frac{v_3}{v_2} = \frac{1373}{778} = 1.765$$

Now we can write for process b/w 3-4

$$\frac{V_4}{V_3} = \frac{V_4}{V_2} \cdot \frac{V_2}{V_3} = \frac{V_1}{V_2} \cdot \frac{V_2}{V_3} = \frac{12}{1} \cdot \frac{1}{1.765} = 6.80$$

Heat Engine Cycle-Diesel Cycle

Now, ∴ $\frac{T_3}{T_4} = \left[\frac{V_4}{V_3}\right]^{\gamma-1} = (6.8)^{1.4-1} = 6.8^{0.4} = 2.153 \Rightarrow T_4 = \frac{1373}{2.153} = 638K$ (15)

Heat Supplied $= Q_1 = C_p(T_3 - T_2) = 1.005[1373 - 778] = 598 \text{ kJ/kg}$

Heat Rejected $= Q_2 = C_v(T_4 - T_1) = 0.718[638 - 288) = 251 \text{ kJ/kg}$

∴ Thermal Efficiency $= \eta = \frac{\Sigma Q}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = \frac{598 - 251}{598} = 0.58 = 58\%$

Heat Engine Cycle

Exercise Problems: 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9


Thank You!