Title : Heat Engine & Carnot Cycle

Date: 23/03/2020

Name of Faculty: Mr. Ankursinh Solanki

Lecture No : 07

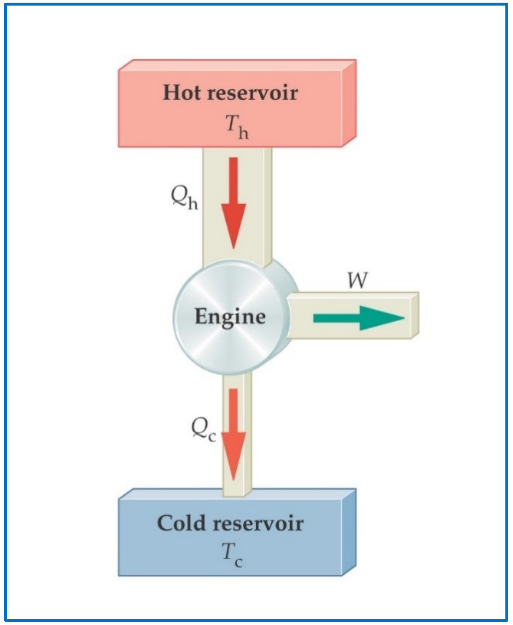
Source of information : Basics of Mechanical Engineering /

Tech-Neo Publications, Page No. 5-3 to 5-5

5.1 Heat engine cycle and heat engine

A device which can produce the work continuously at the expense of heat input is called a heat engine

Example:- Steam engine, Steam turbine power plants, Petrol & Diesel engines, gas turbines etc.



$$Q_h = Q_c + W$$

$$\eta = \frac{Work\ output}{Heat\ supply}$$

$$= \frac{W}{Q_h} = \frac{Q_h - Q_c}{Q_h} = 1 - \frac{Q_c}{Q_h}$$

Refrigerators & heat pumps

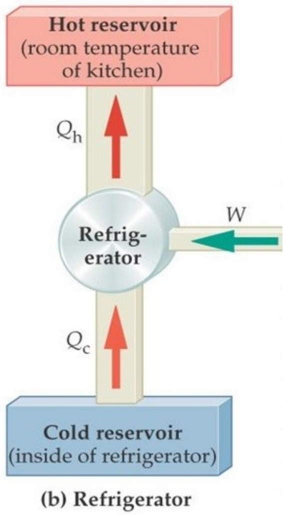


Fig. Refrigerator

A **Refrigeration** is a device operating on a cycle which removes heat form a low temperature body and reject it to a body at high temperature on the expense of external work supplied.

$$(COP)_{Ref} = \frac{Desire\ effect}{Energy\ input} = \frac{Q_c}{W} = \frac{Q_c}{Q_h - Q_c}$$

Heat pump :- If the objective the system is to deliver heat energy at higher temperature then the temperature corresponds to ambient temperature such a device is called heat pump.

$$(COP)_{pump} = \frac{Desire\ effect}{Energy\ input} = \frac{Q_h}{W} = \frac{Q_h}{Q_h - Q_c}$$

5.2 Working substances

Source of heat

- Chemical Energy
- Atomic or Nuclear Energy
- Heat Energy

Working Substance

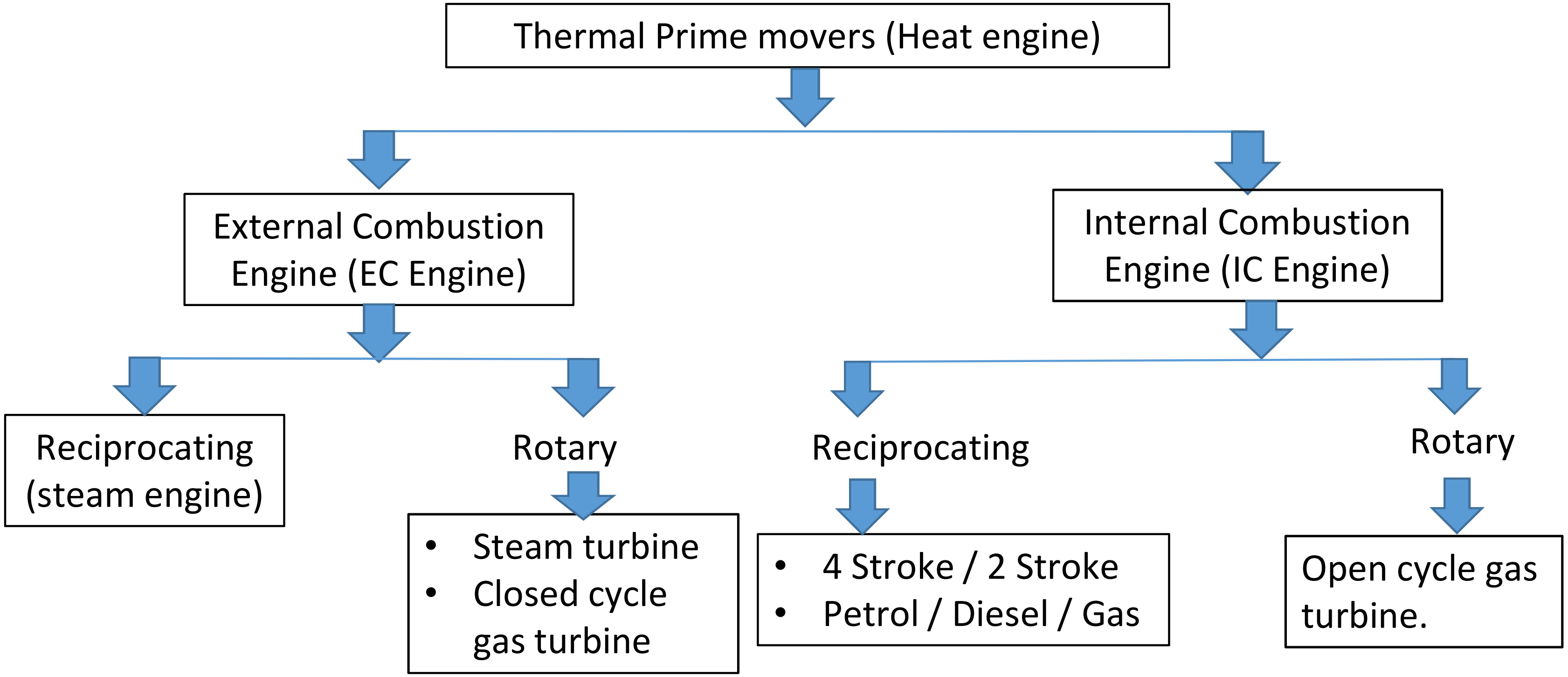
- Usually the steam and gas are used as working substance.
- Steam is used in steam engines, steam turbine, nuclear power plants
- Gas or air is used in I.C. engines, gas turbine power plants, jet engines etc.

Heat reservoir is defined as the source of infinite heat energy and a finite amount of heat absorbed or heat rejected from the heat reservoir will not affect its temperature i.e. the temperature of heat reservoir remains constant.

- Example :- Ocean, Atmosphere.

- A heat reservoir which supplies heat to a system is called **Source.**
- A heat reservoir which absorbs heat form the system is called **Sink.**

5.3 Classification of heat engines



- **Air Standard efficiency** or **Ideal efficiency**

The efficiency of the theoretical cycle with working medium as air is called air standard efficiency. Theoretical

$$\text{Air Standard efficiency} = \frac{\text{Ideal (Theoretical) work done}}{\text{Heat supply}}$$

- **Thermal efficiency**

$$\text{Thermal efficiency} = \frac{\text{Actual work done}}{\text{Heat supply}}$$

- **Relative efficiency**

$$\text{Relative efficiency} = \frac{\text{Thermal efficiency}}{\text{Air Standard efficiency}}$$

$$= \frac{\text{Actual work done}}{\text{Ideal (Theoretical) work done}}$$

5.4 Carnot cycle

- Working substance is **gas**

Assumption:-

1) Piston cylinder arrangement is weightless and frictionless
2) Heat transfer takes place with the help of reservoirs.
3) The walls of cylinder and piston are perfectly insulated.
4) Compression and Expansion are reversible.

Process:-

It consist **two isothermal** and **two reversible adiabatic** processes. (STST)

5.4 Carnot cycle

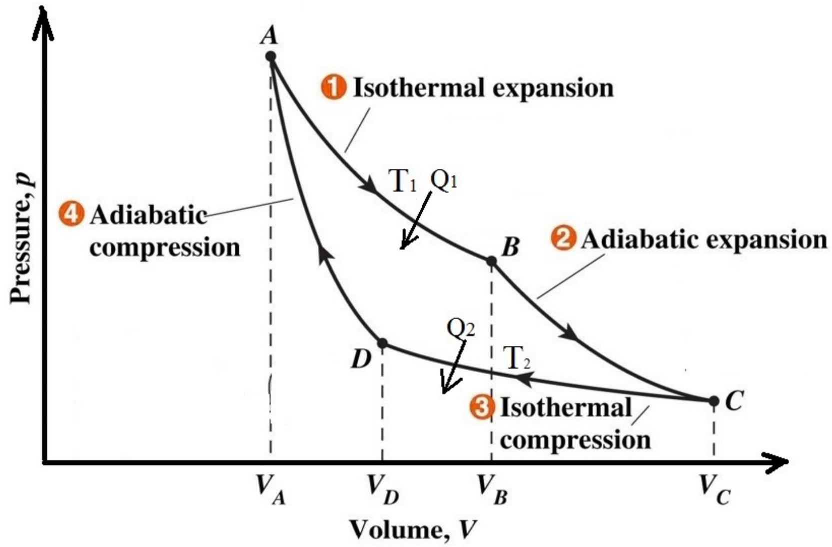
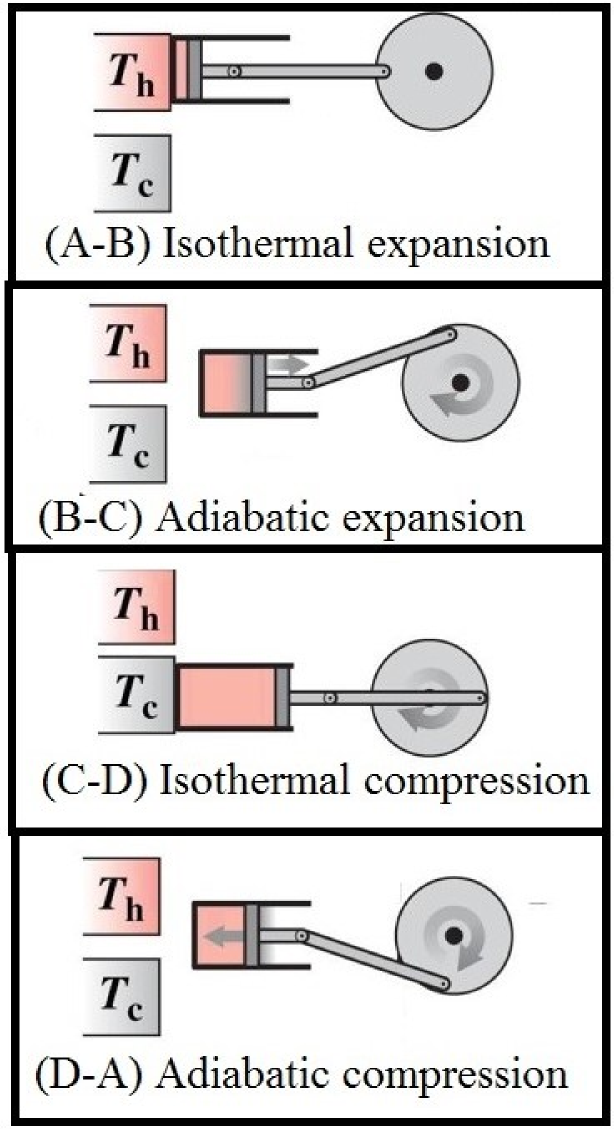


Fig. Carnot Cycle P-V diagram



1) Process (A-B) :- **Isothermal Expansion**
   Q_1 heat supply at constant temperature T_1

2) Process (B-C) :- **Reverse adiabatic expansion,**
   Temperature decrease from T_1 to T_2

3) Process (C-D) :- **Isothermal Compression**
   3) Q_2 heat remove at constant temperature T_2

4) Process (D-A) :- **Reverse adiabatic compression,** Temperature increase from T_2 to T_1

5.4 Carnot cycle

$$\eta_{carnot} = \frac{Net\ Work\ Output}{Heat\ input} = \frac{W_{net}}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} \quad ...(1)$$

1) Process (A-B) :- Q_1 heat supply at constant temperature T_1

- $\Delta U = m\, C_v\, \Delta T = 0$ (from ch.3, $\Delta T = 0$)
- $\frac{V_b}{V_a} = \frac{P_a}{P_b}$ (from Eq. of state) ...(2)
- $Q_1 = m\, R\, T_1 \ln \frac{V_b}{V_a}$ (from ch.3) ...(3)

2) Process (B-C) :- Reverse adiabatic expansion, Temperature decrease from T_1 to T_2

3) Process (C-D) :- Q_2 heat remove at constant temperature T_2

- $\Delta U = m\, C_v\, \Delta T = 0$ (from ch.3, $\Delta T = 0$) ...(4)
- $Q_2 = -m\, R\, T_2 \ln \frac{V_d}{V_c} = m\, R\, T_2 \ln \frac{V_c}{V_d}$ (from ch.3) ...(5)

3) Process (D-A) :- Reverse adiabatic compression, Temperature increase from T_2 to T_1

5.4 Carnot cycle

From reversible adiabatic processes (B-C) & (D-A) $PV^{\gamma} = Const$

$$PV^{\gamma} = Const$$

$$(PV)V^{\gamma-1} = const$$

$$(mRT)V^{\gamma-1} = Const$$

$$T\,V^{\gamma-1} = Cont \qquad ...(6)$$

For Process B-C

$$T_b {V_b}^{\gamma-1} = T_c {V_c}^{\gamma-1} \qquad \text{(From eq. (6))}$$

$$\frac{T_b}{T_c} = \left(\frac{V_c}{V_b}\right)^{\gamma-1} \qquad ...(7)$$

For Process D-A

$$T_a {V_a}^{\gamma-1} = T_d {V_d}^{\gamma-1} \qquad \text{(From Eq.(6))}$$

$$\frac{T_a}{T_d} = \left(\frac{V_d}{V_a}\right)^{\gamma-1} \qquad ...(8)$$

5.4 Carnot cycle

In Isothermal Processes

$T_a = T_b = T_1$ & $T_c = T_d = T_2$

$$\left(\frac{V_c}{V_b}\right)^{\gamma-1} = \left(\frac{V_d}{V_a}\right)^{\gamma-1}$$ (From eq. (7) & (8))

$$\frac{V_c}{V_b} = \frac{V_d}{V_a}$$

$$\frac{V_c}{V_d} = \frac{V_b}{V_a}$$ ...(9)

In the equation of efficiency

$$\eta_{carnot} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{mR\,T_2 \ln\frac{V_c}{V_d}}{mR\,T_1 \ln\frac{V_b}{V_a}} = 1 - \frac{T_2 \ln\frac{V_c}{V_d}}{T_1 \ln\frac{V_b}{V_a}} = 1 - \frac{T_2}{T_1}$$ ...(10)

From above equation, $\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$

"The heat transfer from a heat reservoir is proportional to its temperature. It is called **carnot's principle**"

Assignment : 02

1. Define Heat engine and explain the essential elements of a heat engine.
2. Give classification of heat engine.
3. Explain Carnot cycle and derive expression for the efficiency of the Carnot cycle.

Note:- Kindly write the above assignment in Separate notebook which you have prepared for 1st assignment and submit it on 31/3/2020.

- If any query regarding above topic kindly contact me on my mobile no.:-8758034606

Mr. Ankursinh Solanki
Mobile No. 8758034606

Thank You