Second law of thermodynamics

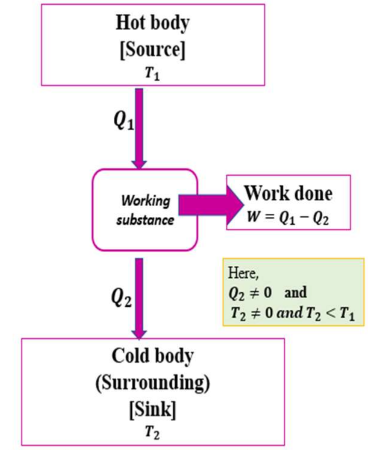

Fig: Block diagram of working of Heat Engine

Efficiency of heat engine:

$$\eta = \frac{W}{Q_1} = 1 - \frac{Q_2}{Q_1} \qquad W = Q_1 - Q_2$$

- For efficiency to be 1 (or 100%), $Q_2 = 0$, Which is not possible for a heat engine.

Carnot engine: The hypothetical (ideal) heat engine which is free from all the imperfections (like frictional loss, radiation loss and others)

$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$$

For Carnot's engine, $\eta = 1 - \frac{T_2}{T_1}$

- For 100% efficiency, either $T_2 = 0$ or $T_1 = \infty$, both cannot be possible.
- The efficiency of a heat engine depends upon temperature of source and sink, but is independent of nature of working substance.

Coefficient of performance of a refrigerator is:

$$\beta = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$$

- The coefficient of performance of refrigerator depends upon temperature of cold body (T_2) and its surrounding (T_1), but not upon the nature of working substance. [$\beta \propto \frac{1}{T_1 - T_2}$]
- [In summer, temperature of surrounding (T_1) is higher. So, $T_1 - T_2$ will be larger, and β will be smaller. Hence, more power is consumed by refrigerator in summer than in winter.]
- A refrigerator transfers heat from cold body to hot body by doing some work on the working substance. Hence, it does not violate the law of thermodynamics [conservation of energy]
- In case of a refrigerator, (heat rejected to surrounding) $Q_1 > Q_2$ (heat absorbed from cold body). So, the overall effect is that the room would get hotter and hotter.

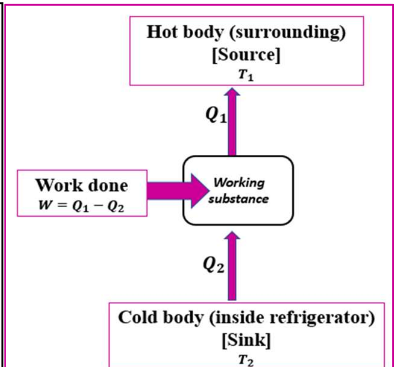

Fig: Block diagram of working of Refrigerator

Efficiency of refrigerator (η) and coefficient of refrigerator (β):

$$\beta = \frac{1 - \eta}{\eta}$$

Where, $\eta = 1 - \frac{T_2}{T_1}$

Petrol engine and Diesel engine:

- In petrol engine, after the compression of fuel in the cylinder, the temperature rises to about 600^oC, which is not sufficient for the ignition of fuel (mixture of air and petrol). Hence, spark is needed for the ignition.
  However, in case of diesel engine, due to higher compression, the temperature rises to a high value (1000ºC) that the sprayed diesel catches the fire on its own. Hence, diesel engine has no spark plug.
- The compression ratio in diesel engine is more than that in petrol engine. Hence, the efficiency of diesel engine is greater than that of petrol engine.

- The Carnot's engine (ideal engine) is free from all imperfections. But, practical (real) heat engine has many imperfections (like: friction, conduction and radiation loss etc.). Hence, efficiency of all engine is less than that of Carnot's engine.

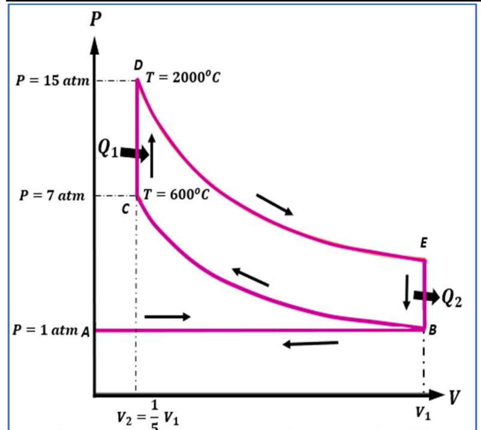

Figure: P-V diagram (indicator diagram) of Petrol Engine

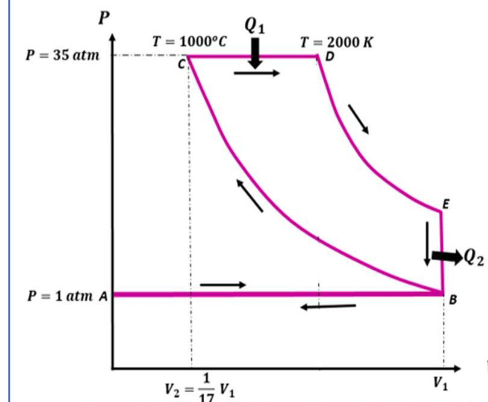

Figure: P-V diagram (indicator diagram) of Diesel Engine

AB = suction stroke
BC = compression stroke
DE = working stroke
EB = exhaust stroke

$$\eta = 1 - [1/\rho]^{\gamma - 1}$$

With $\rho = 5, \gamma = 1.4$

AB = suction stroke
BC = compression stroke
DE = working stroke
EB = exhaust stroke

$$\eta = 1 - [1/\rho]^{\gamma - 1}$$

With $\rho = 17, \gamma = 1.4$

❖ **Calorific Value:** [*also called as* ***heating value*** *or* ***heat of combustion***]

The energy contained in a fuel (or food), determined by measuring the heat produced by the complete combustion of a specified quantity of it.

$$\text{Input power } P_{input} = Calorific\ value \times \frac{mass\ of\ fuel\ consumed}{time\ of\ consumption}$$

$$1\ Cal/gram = 4.2 \times 1000 J/kg \qquad efficiency, \eta = \frac{P_{input}}{P_{input}} \times 100\%$$

Entropy: Entropy is the measure of randomness of a system.

The change in entropy is: $dS = \frac{dQ}{T} = nR\frac{dV}{V}$ [provided T is constant]

First law of thermodynamics in terms of entropy:

The first law of thermodynamics is: $dQ = dU + PdV$ where, $dU = nC_v dT$

At constant temperature ($dT = 0$), ∴ $dQ = PdV$ [$\because dU = 0$]

$\because PV = nRT$ $\quad \therefore dQ = \frac{nRT}{V}\,dV$ [$\because P = \frac{nRT}{V}$]

$$\frac{dQ}{T} = nR\frac{dV}{V}$$

$$\therefore \frac{dQ}{T} = dS \propto \frac{dV}{V}$$

Here, $\frac{dV}{V}$ represents the measure of randomness of molecules.

1. a. What is heat engine? How to you define the efficiency of a heat engine? Obtain an expression for efficiency of heat engine. 3
   b. Can the (thermal) efficiency of an engine be 100%? Explain. 2