ESSENCE OF SECOND LAW

First law deals with conservation and conversion of energy but fails to state the conditions under which energy conversion is possible. The second law is directional law which would tell if a particular process occurs or not and how much heat energy can be converted into work.

THERMAL RESERVOIR

A thermal reservoir is the part of environment which can exchange heat energy with the system. It has sufficiently large capacity and its temperature is not affected by the quantity of heat transferred to or from it. The temperature of a heat reservoir remains constant. The changes that do take place in the thermal reservoir as heat enters or leaves are so slow and so small that processes within it are quasi-static. The reservoir at high temperature which supplies heat to the system is called HEAT SOURCE. For example: Boiler Furnace, Combustion chamber, Nuclear Reactor. The reservoir at low temperature which receives heat from the system is called HEAT SINK. For example: Atmospheric Air, Ocean, river.

HEAT ENGINE

A heat engine is a device that operates in a cycle in which heat is transferred from heat source to heat sink, for continuous production of work.

Both heat and work interaction take place across the boundary of the engine. It receives heat Q_1 from a higher temperature reservoir at T_1. It converts part of heat Q_1 into mechanical work W_1. It rejects remaining heat Q_2 to the sink at T_2. There is a working substance which continuously flow through the engine to ensure continuous/cyclic operation.

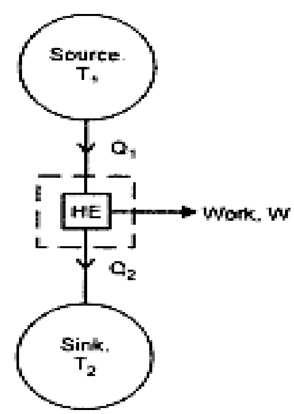


Fig 1

PERFORMANCE OF HEAT ENGINE

It is measured by thermal efficiency which is the degree of useful conversion of heat received into work.

η_{th} = Net work output/ Total Heat supplied = $W/Q_1 = (Q_1 - Q_2) / Q_1$

$$\boldsymbol{\eta_{th} = 1 - Q_2/Q_1 = 1 - T_2/T_1}; \text{ Since } Q_1/Q_2 = T_1/T_2$$

OR

Thermal efficiency is defined as the ratio of net work gained (output) from the system to the heat supplied (input) to the system.

HEAT PUMP

Heat pump is the reversed heat engine which removes heat from a body at lower temperature and transfers heat to a body at higher temperature.

It receives heat Q_2 from atmosphere at temperature T_2 equal to atmospheric temperature. It receives power in the form of work 'W' to transfer heat from low temperature to higher temperature. It supplies heat Q_1 to the space to be heated at temperature T_1.

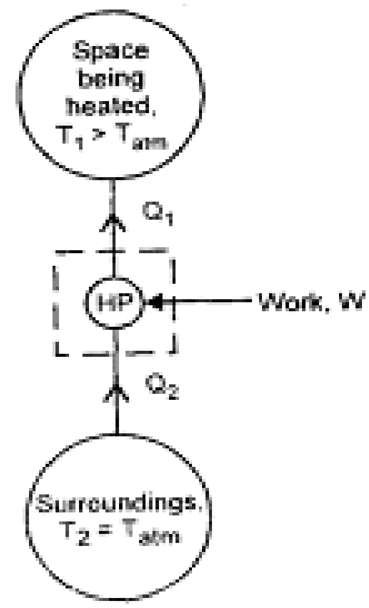


Fig 2

PERFORMANCE OF HP: It is measured by the coefficient of performance (COP). Which is the ratio of amount of heat rejected by the system to the mechanical work received by the system.

$$(COP)_{HP} = Q_1/W = Q1/ (Q_1 - Q_2) = T_1/ (T_1 - T_2)$$

REFRIGERATOR

The primary function of a heat pump is to transfer heat from a low temperature system to a high temperature system, this transfer of heat can be utilized for two different purpose, either heating a high temperature system or cooling a low temperature system. Depending upon the nature of use. The heat pump is said to be acting either as a heat pump or as a refrigerator. If its purpose is to cause heating effect it is called operating as a H.P. And if it is used to create cold effect, the HP is known to be operating as a refrigerator.

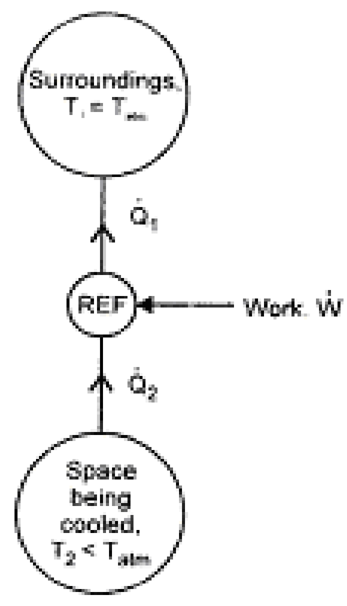


Fig 3

$(COP)_{ref}$ = Heat received/ Work Input = Q_2/W

$= Q_2/ (Q_1 - Q_2)$

$(COP)_{ref} = Q_2/ (Q_1 - Q_2) = T_2/ (T_1 - T_2)$

$$(COP)_{HP} = (COP)_{ref} + 1$$

COP is greater when heating a room than when cooling it.

KELVIN PLANK STATEMENT

It is impossible to construct such a H.E. that operates in cycle and converts all the heat supplied to it into an equivalent amount of work. The following conclusions can be made from the statement.

1. No cyclic engine can convert whole of heat into equivalent work.
2. There is degradation of energy in a cyclic heat engine as some heat has to be degraded or rejected. Thus second law of thermodynamics is called the law of degradation of energy.
3. For satisfactory operation of a heat engine there should be at least two heat reservoirs source and sink.

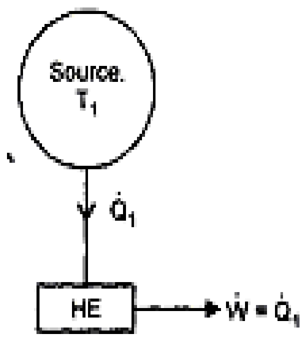


Fig 4

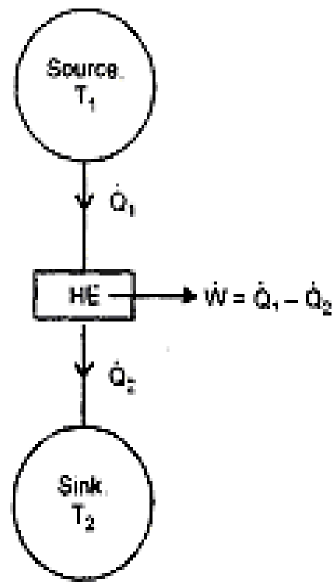
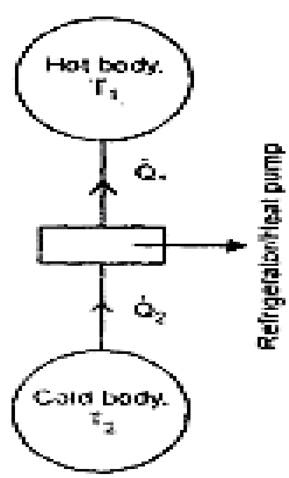


Fig 5

CLAUSIUS STATEMENT

It is impossible to construct such a H.P. that operates in a cycle and transfers heat from a colder body to a hotter body without the aid of an external agency.



CARNOT CYCLE

Carnot, showed that the temperatures of heat source and heat sink are the basis for determining the thermal efficiency of a reversible cycle. He showed that all such cycles must reject heat to the sink and efficiency is never 100%. To show a non-existing reversible cycle, Carnot invented his famous but a hypothetical cycle known as Carnot cycle.

Carnot cycle consists of two isothermal and two reversible adiabatic or isentropic operations. The cycle is shown on P-V and T-S diagrams.

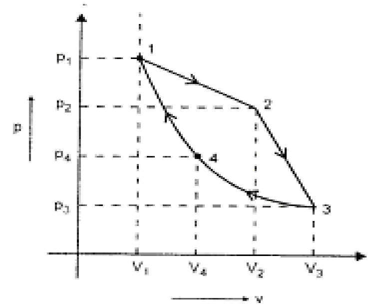


Fig 6

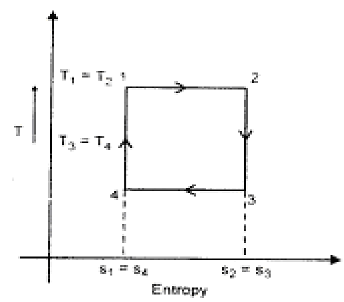


Fig 7

Operation 1-2: T = C

$Q_1 = W_{1-2} = P_1V_1 \ln V_2/V_1 = mRT_1 \ln V_2/V_1$

Operation 2-3: $PV^\gamma = C$

$Q = W = 0$

Operation 3-4: T = C

$Q_2 = W_{3-4} = P_3V_3 \ln V_4/V_3 = mRT_2 \ln V_3/V_4$

Operation 4-1: $PV^\gamma = C$

$Q = W = 0$

Net Work Done = $mRT_1 \ln V_2/V_1 – mRT_2 \ln V_3/V_4$

Since compression ratio = $V_3/V_4 = V_2/V_1$, $T_2 = T_3$

$W = mR \ln V_3/V_4 (T_1 – T_3)$

CARNOT THEOREM

No heat engine operating in a cycle between two given thermal reservoirs, with fixed temperatures can be more efficient than a reversible engine operating between the same thermal reservoirs.

- Thermal efficiency η_{th} = Work output/Heat supplied
- Thermal efficiency of a reversible engine (η_{rev})
  $\eta_{rev} = (T_1 – T_2)/T_1$
- No engine can be more efficient than a reversible Carnot engine i.e. $\eta_{rev} \geq \eta_{th}$

Condition:

1. If $T_1 = T_2$; No work, $\eta = 0$
2. Higher the temperature difference, higher the efficiency.
3. For the same degree of increase in source temperature or decrease in the sink temperature, Carnot efficiency is more sensitive to change in sink temperature.

CLAUSIUS INEQUALITY

When ever a closed system undergoes a cyclic process, the cyclic integral $\oint dQ/T$ is less than zero (i.e., negative) for an irreversible cyclic process, and equal to zero for a reversible cyclic process.

So for a cyclic process,

$$\oint dQ/T \leq 0$$

The equation for reversible cyclic process may be written as:

$$\oint dQ/T = 0$$

The equation for irreversible cyclic process may be written as:

$$\oint dQ/T + I = 0$$

I = Amount of irreversibility of a cyclic process.