THE SECOND LAW OF THERMODYNAMICS

THE HEAT ENGINE

A heat engine is a thermodynamic system operating in a cycle and across the boundaries of which flows only heat and work.

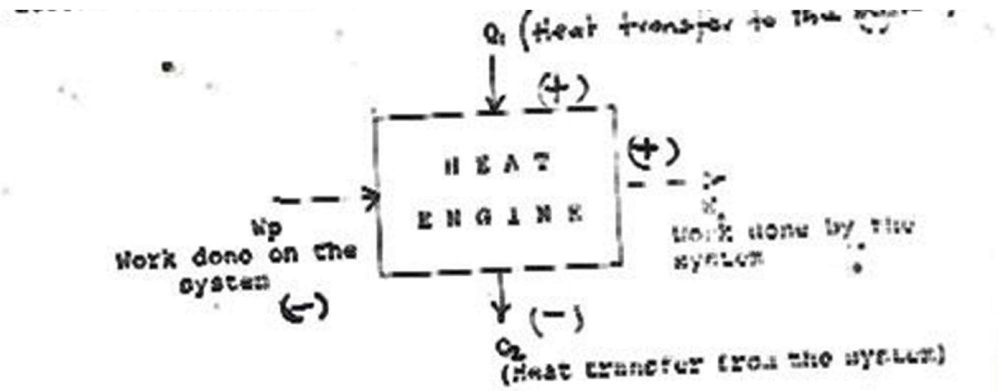


Fig. 3.1 Symbolic representation or Heat Engine

Example of Heat Engine

The Steam Turbine Plant: Represented diagrammatically in Fig. 3.2.

Applying the first law

$$dW = dQ$$

$$W_x - W_p = Q_1 - Q_2$$

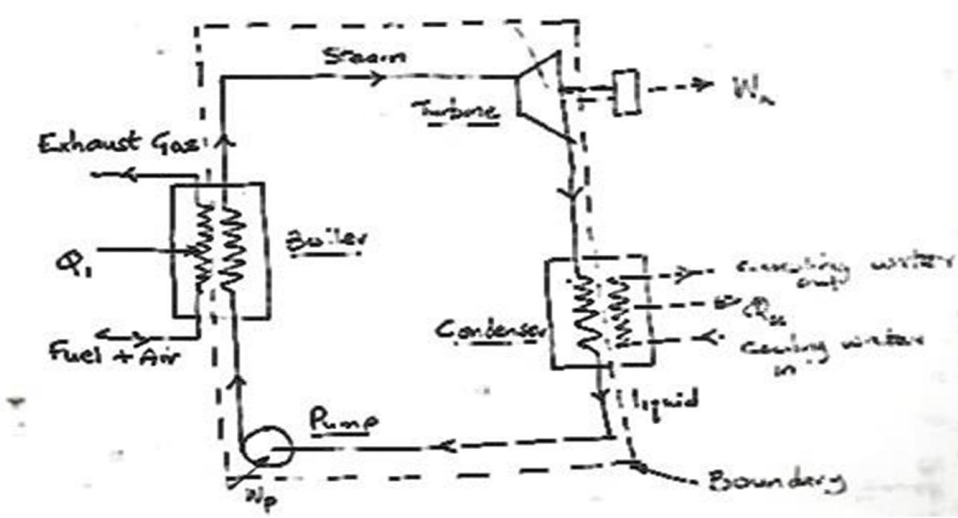


Fig. 3.2 Steam Turbine Plant

3.1.2 **Closed system gas Turbine plant:** Represented diagrammatically by Fig. 3.3.

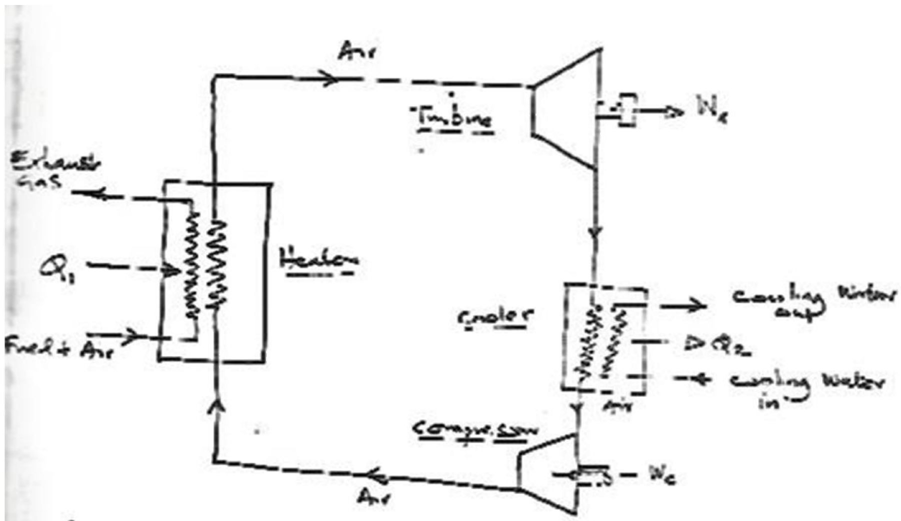


Fig 3.3 Close System Gas Turbine Plant

$$W_x - W_c = Q_1 - Q_2$$

The open system gas turbine plant and the reciprocating types of internal combustion engine have fuel and air mixture crossing their boundaries and so are not heat engine.

HEAT ENGINE PERFORMANCE

The greater the proportion of heat supplied that is converted to work the better is the engine.

The ratio $\frac{(net\ \ work\ output)}{(heat\ \ supplied)}$ is termed the <u>cycle efficiency</u> denoted by

$$\eta = \frac{W_x - W_p}{Q_1} \quad \text{where}$$

Q_1 is heat supplied per mass of the system

W_x is work done per mass by the system

W_p is work done per mass on the system.

If Q_2 is heat rejected per mass by the system, by the first law

$$Q_1 - Q_2 = W_x - W_p$$

$$\therefore \eta = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

This shows that the cycle efficiency will be unity (i.e. 100%) if $Q_2 = 0$. That is, $Q_2 = 0$ there will be 100% conversion of heat into work.

Heat Reservoir: Heat Source and Heat Sink

The term heat reservoir (or reservoir) is used in thermodynamics to mean a heat source or heat sink of uniform temperature and of infinite capacity such that unlimited quality of heat can flow across its boundary without changing its temperature.

When heat flow is at a high temperature, it is referred to a hot reservoir and when heat flow is at a low temperature, it is referred to as a cold reservoir.

STATEMENT OF THE SECOND LAW OF THERMODYNAMTICS

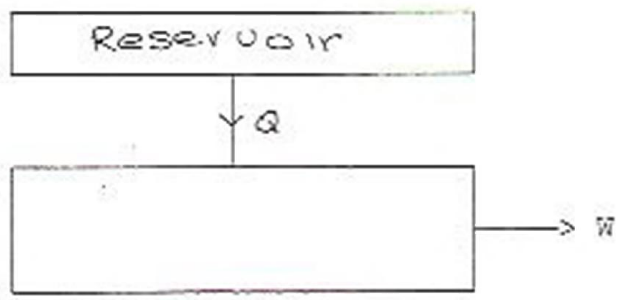
It is impossible to construct an engine which will work in a complete cycle and produce no effect, except to raise a weight and exchange heat with a single reservoir.

The first law of thermodynamics shows that net work cannot be produced during a cycle without some supply of heat. The second law emphasizes the fact that some heat must always be rejected during the cycle, i.e. the net work must be less than the heat supplied.

PERPETUAL MOTION MACHINES

Any machine which creates its own energy is called a perpetual motion machine of the first kind (PMM 1). Such a machine contradicts the first law since the first law rejects the possibility of creating or destroying energy. Similarly, any machine which produces work continuously while exchanging heat with only a single reservoir is know as perpetual motion machine of the second kind (PMM 2). This machine contradicts the second law. From the foregoing both propositions are impossible.

PMM 1
Fig. 3.4



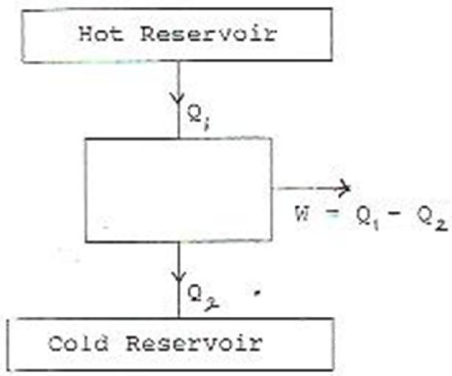
PMM 2
Fig. 3.5

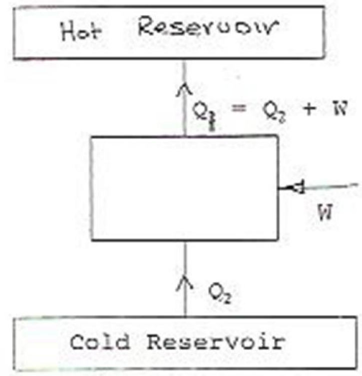
If the second law were not true it would have been possible

a. To drive a ship across the ocean by taking heat from the ocean.
b. To run a power station by extracting heat from the surrounding air.

There is nothing in the first law to say that the above projects are not possible (interchange between heat and work). The projects are, however, impossible and so the second law must be true. There is not natural sink of heat at a lower temperature than the atmosphere or ocean.

DIRECT AND REVERSED HEAT ENGINES:





Direct heat engine

Produces net out-put of Work and heat from net Input of heat.

Fig. 3.6 (A)

Reversed heat engine

Directions of work and heat flow is reversed (Heat pump refrigerator)

Fig 3.6 (B)

Refrigerator withdraws heat at a lower temperature since its principal purpose is the extraction of heat from a cold space.

Heat pump. The principal purpose of the heat pump is to supply heat to the hot space.

The Coefficient o performance of Refrigerators and Heat Pumps:

The coefficient of performance of a refrigerator (known as the performance energy ratio β_{ref} is defined as

$$\frac{Heat\ \ Transfer\ \ at\ \ Lower\ \ Temperature}{Work\ \sup ply}$$

$$\beta_{ref} = \frac{Q_2}{W}$$ where Q_2 = heat extracted

The coefficient of performance of a heat pump (performance energy ratio) β_{hp} is defined as

$$\frac{Heat\ Transfer\ at\ \ Higher\,Temperature}{Work\ Supply}$$

$$\beta_{hp} = \frac{Q_1}{W}$$

The relation between these two coefficients of performance can be established by applying the first law.

$$Q_1 - Q_2 = W$$

$$Q_1 = W + Q_2$$

$$\beta_{hp} = \frac{Q_1}{W} = \frac{W + Q_2}{W} = 1 + \frac{Q_2}{W} = 1 + \beta_{\text{ref}}$$

$$\beta_{hp} = 1 + \beta_{\text{ref}}$$

PRACTICE QUESTIONS

1. The work done on a reversed heat engine is 100kg whilst the heat transfer to the engine from the low temperature is 300kJ. Determine the heat transfer to the high temperature reservoir and the COP as a refrigerator and as a heat pump.(400kJ, 3, 4)

2. A heat pump picks up 1000kJ of heat from well water at 10^0C and discharges 3000kJ of heat to a building to maintain it at 20^0C. What is the COP of the heat pump? What is the minimum required cycle net work? (1.5, 2000kJ)

4.0 **ENTROPY**

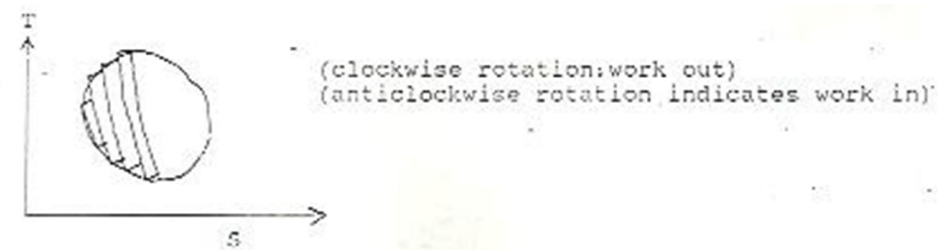
From thermo temp. Scale $\frac{q_1}{T_1} = \frac{q_2}{T_2}$ numerically

$$\frac{q_1}{T_1} = \frac{q_2}{T_2} \quad \text{Algebraically}$$

$$\therefore \quad \frac{q_1}{T_1} = \frac{q_2}{T_2} = 0$$

i.e. summation of ratio of heat transfer to absolute temp. in reversible cycle = 0

two property diagram for <u>any Reversible cycle</u> may be replaced by elemental Carnot cycle



Thus, for any reversible cycle;

Thus, for any reversible <u>cycle</u>;

$$\oint \frac{\delta q_r}{T} = 0$$

But $\frac{(q_R)}{T} = 0\, is$ a property = entropy = S

Note: $\frac{Non - property}{property}$ = property

For a reversible process,

$$\oint \frac{\delta q_r}{T} = \Delta S$$

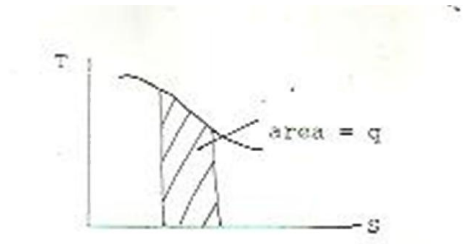
In any adiabatic process, $(\delta q)_{ad} = 0$

In any reversible adiabatic process

$$(\frac{\sigma q_R}{T})_{ad} = 0$$

$$\therefore \quad Isentroppic$$

Q_R =Tds = area under T-S curve



For an <u>irreversible</u> cycle, $\eta_1 > \eta_R$

$$\left(1 - \frac{q_2}{q_1}\right) < \left(1 - \frac{T_2}{T_1}\right)$$

Hence $\frac{q_2}{q_1} > \frac{T_2}{T_1}$ *and* $\frac{q_2}{T_1}$ *numerically*

Algebraically,

$$\frac{q_1}{T_1} + \frac{q_2}{T_2} < 0$$

$$\therefore \oint \frac{\delta_q}{T} \leq 0$$

[= 0 reversible] Clausius

[< 0 irreversible] Inequality.

$$\text{Path 132} \quad \int_1^2 \frac{\delta q_1}{T} = 0$$

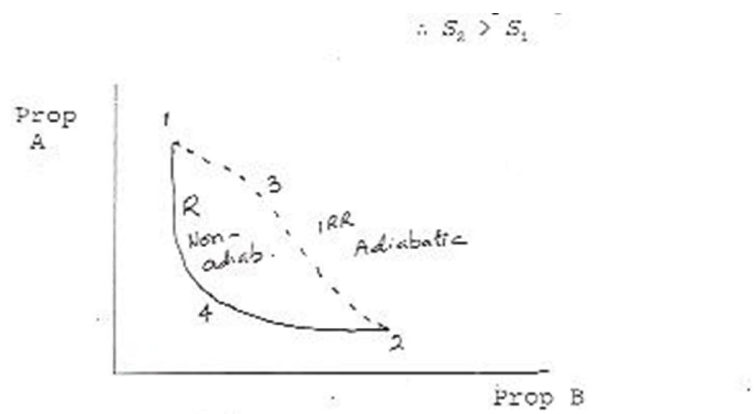
$$\text{Path 241} \quad \int_1^2 \frac{\delta q_R}{T} = S_1 - S_2$$

$$\text{Path 13241} \quad \int_1 \frac{\delta q_1}{T}$$

$$= \int_1^2 \frac{\delta q_1}{T} + \int_2^1 \frac{\delta q_R}{T}$$

$$= (0 \ + S_1 \ - S_2) < 0$$

$$\therefore \ S_2 \ > S_1$$



Note: If part of a cycle is irreversible, the whole cycle must be irreversible.

Irreversible adiabatic process incurs rise in entropy.

All Reversible adiabatic process incurs no rise in Entropy. Rise in S. if non – adiabatic, heat flow across boundary, and rise in S for system + environment e.g. heat flow q from system at T_1 to environment at lower T_o.

System: entropy loss, $= -\dfrac{q}{T_1}$

Environment entropy gain $\dfrac{+q}{T_0}$

Since $T_1 > T_o$, gain $>$ loss.

$\therefore \ \Delta s$ positive

A decrease in entropy can only be temporary and local with a greater increase elsewhere.

There is no process that cannot be reversed if we accept a greater irreversibility elsewhere.

Since entropy is a property (extensive) Δs. Same irrespective of path (rev. and irrev.) but

$$\Delta s = \int \frac{q_R}{T}$$

$$= \int \frac{q_{actual}}{T} \quad only \ \ in \ \ reversible \ \ case$$

One spontaneous tendency in nature is towards minimum energy.

Another spontaneous tendency in nature is towards <u>maximum disorder</u> (of motion or position) as in changes from solid to liquid, to gas, to gas at lower pressure to a larger number of molecules, mixing of different fluids, dissipation of energy by friction or viscosity

<u>Entropy is a measure of disorder</u>

In an adiabatic device, reversible (Reversible adiabatic) process is most efficient. Hence, isentropic efficiency η_s can be devised.

(N.B. a process efficiency not cycle effy.)

For work absorber (compressor or pump)

Isentropic Efficiency (η_s) $= \dfrac{isentropic \ \ work}{actual \ work} = \dfrac{W_s}{W}$

For work producer (turbine)

$$\eta_s = \frac{W}{W_S}$$

For a flow device (nozzle)

$$\eta_s = \frac{actual \ \ outlet \ E_k}{isentropic \ \ \ outlet \, E_k}$$

$$\left(E_2 = \quad Kinetic \ Energy\right)$$

c.f. in a slow moving device (large piston compressor) time for heat transfer

$\therefore$ *isothermal ideal*

$$\eta_T = \frac{W_T}{W}$$

4.1 Third law states that "the entropy of a pure substance in its most stable/state approaches zero as the temperature approaches zero i.e. lim S = 0

Practice Questions

1. A system consists of a pure dissipative element and a pure thermal element with a heat capacity of 50kJ/K. It experiences an irreversible work transfer interaction which takes the system from state 1 at a temperature of 300K to state 2 at a temperature of 310K. If no heat is transferred during this irreversible process, calculate the change in entropy of the system for this process (1.6395kJ/kgK).

2. A carnot heat engine rejects 230kJ of heat at 25^0C. The net cycle work is 375kJ. Determine the thermal efficiency and the cycle high temperature.