

UNIT - III.

Limitations of the 1st Law thermal Reservoir.

1. state the limitations of the 1st law of T.D?

Sol: - the 1st law of T.D has it's own limitation in actual practice. Some of the situations are given below,

1. Acc to the 1st law of T.D, heat and work are mutually convertible. This is not true in real practice. There is a limitation of the conversion of one form of energy into another form.

2. Acc to the 1st law of T.D, there is no restriction on the direction of flow of work and heat, which is not true in reality.

3. Acc to the 1st law of T.D, in energy cyclic process, work and heat are exchangeable completely. But from experience, this is not true.

4. In natural way, heat is not completely converted into work, but reverse is not automatically true.

5. Heat flows from hot to cold region but the reverse is not automatically true.

6. Acc to Joule's law.

$$w = Q \text{ and } Q \geq w.$$

2. what is a thermal energy reservoir?

Sol: T.E.R:— A T.E.R. is defined as "sufficiently large system in stable equilibrium to which and from which finite amount of heat can be transferred without any change in it's temperature".

High temperature reservoir is named as "heat source" and low temperature reservoir is named as "heat sink".

Examples for Heat source:— Boiler furnace, sun nuclear reactor, combustion chamber of turbine etc.

Examples for Heat sink:— Atmospheric air, river and even ocean water may be treated as "heat sink".

A thermal reservoir is a body of infinite heat capacity which is capable of absorbing or rejecting an unlimited quantity of heat without affecting it's temperature.

3. what are the two statements of 2nd law of T.D? Explain.

Sol: The two statements of 2nd law of T.D

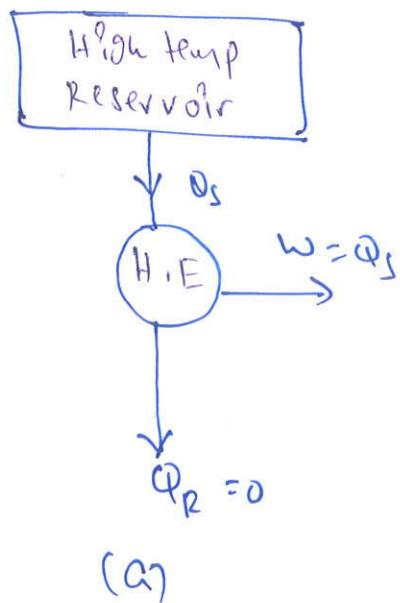
are.

1. kelvin-planck statement.

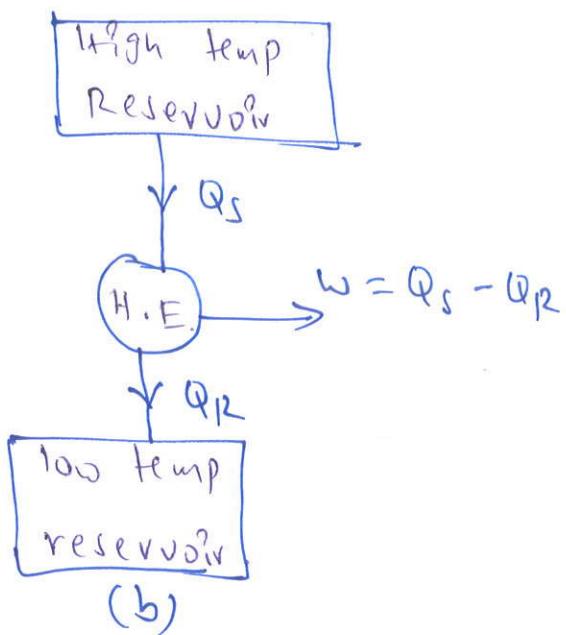
2. clausius statement.

1. Kelvin-Planck Statement:— It states that, 'it is impossible to produce work in a cycle for a heat engine, if it exchanges heat only with single thermal reservoir'.

Explanation:— This statement tells us that, it is impossible to convert all the heat supplied to heat engine into work. It also means that, no heat engine will have 100% efficiency. From the above statement we can understand that, a part of heat supplied to heat engine is converted to work and remaining heat is rejected to the lower temperature reservoir. Hence for a heat engine to operate, it should have at least two thermal reservoirs at different temperatures. The figures satisfying and violating Kelvin-Planck statement are shown.



(a)



(b)

a. Violating of Kelvin-Planck statement.

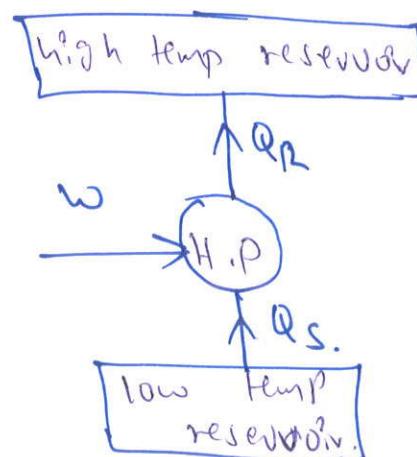
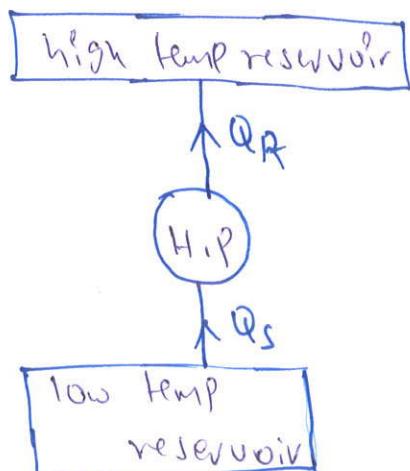
b. Satisfying Kelvin-Planck statement.

2. Clausius statement:— If states that, it is impossible for a heat pump operating in a cycle, to transfer heat from a low temperature reservoir to a high temperature reservoir without the aid of any external work.

Explanation:— we know that, heat flows from high temp body to low temp body, without any external work. but, to transfer heat from low temp reservoir to high temp. reservoir, some amount of heat must be supplied in the form of work.

w.k.t., C.O.P of the heat pump is $\frac{Q_R}{W}$. but when the work supplied is zero, the C.O.P of heat pump becomes infinity which is impossible.

so, for a heat pump to transfer heat from low temp reservoir to high temp reservoir, some amount of external work should be supplied. Figures violating and satisfying clausius statement are shown below.



4. State and prove Carnot theorem?

Sol:- Carnot theorem:-

Statement:- It states that "of all the heat engines operating between a given constant temperature source and a given constant temp sink, none has a higher efficiency than a reversible engine".

Proof:- Consider two heat engines operating between the same reservoirs. Let the source temp be T_H and sink temp be T_L . One engine is considered to be reversible and the other is considered to be irreversible.

Let each of the engine be supplied with some amount of heat Q_H .

Let the amount of work produced by reversible heat engine by w_{rev} and that by irreversible engine be w_{irr} .

In order to prove that efficiency of reversible heat engine is greater than that of irreversible heat engine, let us assume that.

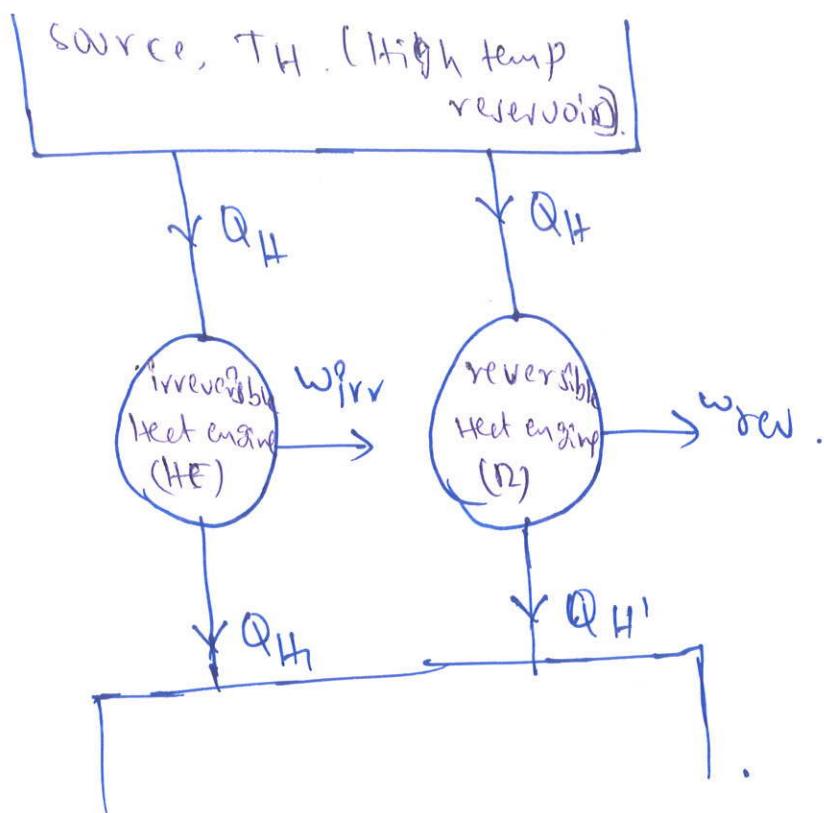
$$n_{irr} > n_{rev}$$

$$\frac{W_{irr}}{Q_{irr}} > \frac{W_{rev}}{Q_{rev}}$$

$$\frac{W_{irr}}{Q_H} > \frac{W_{rev}}{Q_H}$$

$$w_{irr} > w_{rev}$$

$$h_{irr} > h_{rev}$$



5. An engine operating on a Carnot cycle works within temp limits of 600K and 300K. If the engine receives 2000 kJ of heat, evaluate the work done and thermal efficiency of the engine?

Sol:-

Given that,

high temp, $T_1 = 600\text{K}$

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Low temp, $T_2 = 300\text{K}$

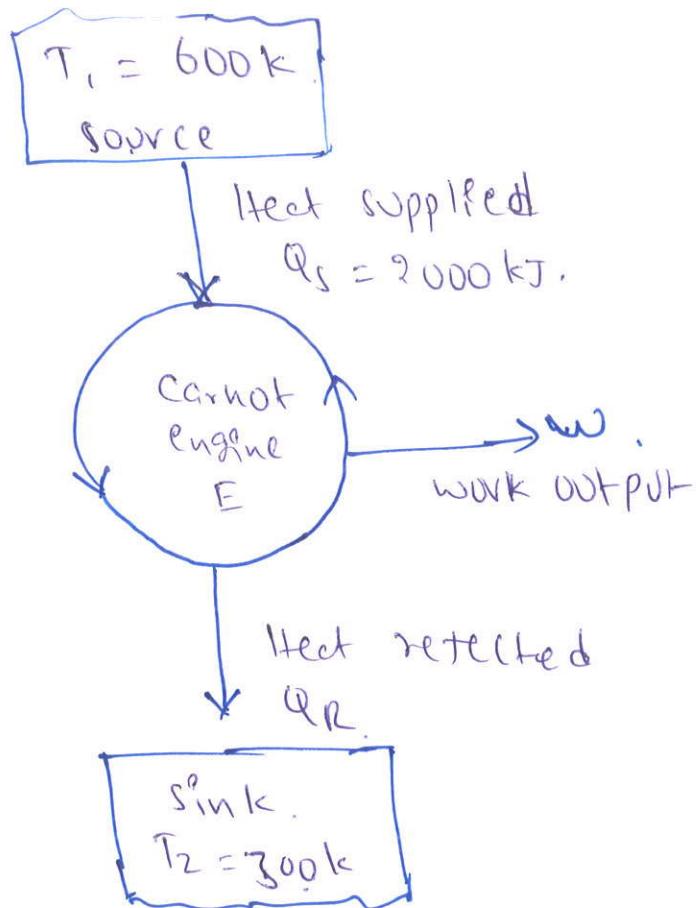
Heat supplied to engine, $Q_s = 2000\text{ kJ}$

Let,

w = work done by the engine (kJ).

η = thermal efficiency of the engine.

Q_R = Heat rejected from the engine.



we have

Carnot cycle efficiency,

$$\eta = \frac{T_1 - T_2}{T_1} = \frac{w}{Q_s}$$

1. Thermal efficiency,

$$\eta = \frac{T_1 - T_2}{T_1}$$

$$\eta = \frac{600 - 300}{600} = \frac{300}{600} = \frac{1}{2} = 0.5 (\text{W}) 50\%$$

ii. work done by engine (w)

$$\eta = \frac{w}{Q_s} \quad \cancel{\text{eqn}}$$

$$0.5 = \frac{w}{2000}$$

$$w = 0.5 \times 2000 = 1000 \text{ kJ}$$

Results:

- i. work done by the engine (w) = 1000 kJ = 1 MJ
- ii. thermal efficiency of the engine (η) = 50%.

UNIT - III.

Pure substances.

1. Show that on a Mollier diagram (H-s) the slope of a constant pressure line increases with temp in the superheated region?

Sol:- Acc to 1st and 2nd law of TP.

$$dh = Tds + Pdv.$$

It can also be written as,

$$\left(\frac{dh}{ds}\right)_P = T \quad \rightarrow \textcircled{1}$$

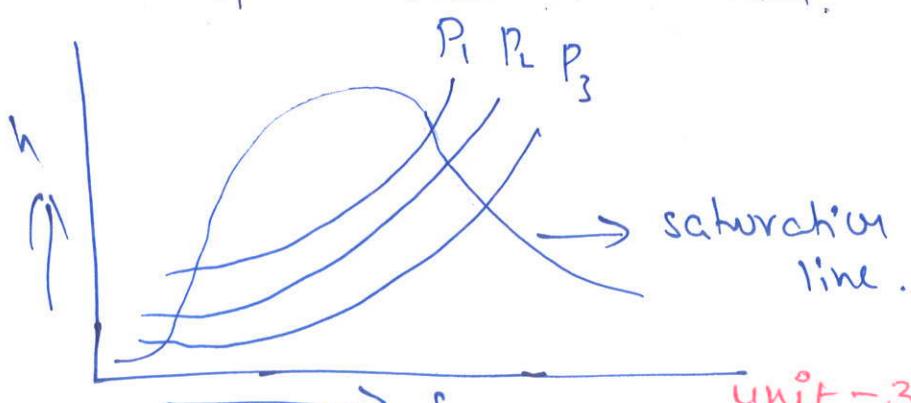
$$dh = cp(T_{\text{sup}} - T_{\text{sat}})$$

$$ds = cp \ln \left[\frac{T_{\text{sup}}}{T_{\text{sat}}} \right]$$

then, sub the above values in eqn (1)

$$\left(\frac{dh}{ds}\right)_P = \frac{cp(T_{\text{sup}} - T_{\text{sat}})}{cp \ln \left(\frac{T_{\text{sup}}}{T_{\text{sat}}} \right)} = \frac{T_{\text{sup}} - T_{\text{sat}}}{\ln \left(\frac{T_{\text{sup}}}{T_{\text{sat}}} \right)}$$

T_{sup} is greater than T_{sat} .



2. A vessel having a capacity 0.05 m³ contains a mixture of saturated water and saturated steam at a temp of 245°C. the mass of liquid present is 10 kg. Find the following.

- i. The Pressure, ii. the mass, iii. specific volume.
- iv. specific enthalphy. v. specific entropy.
- vi. specific internal energy.

Sol: Given that,

$$V_r = 0.05 \text{ m}^3$$

$$T = 245^\circ\text{C}.$$

$$m_w = 10 \text{ kg.}$$

From steam tables, properties of steam at temp 240°C and 250°C. is,

Temp °C.	Pressure bar	specific volume m ³ /kg		enthalpy kJ/kg		entropy. kJ/kg-k	
		v _f	v _g	h _f	h _g	s _f	s _g
240		0.00123	0.05976	1037.32	1766.5	2.7015	3.4421
250		0.00125	0.05013	1085.36	1716.2	2.7927	3.2802

by interpolation, properties of steam at temp of 245°C are

$$P_{sat} = 36.589 \text{ bar.}$$

$$v_w = v_f = 0.00124 \text{ m}^3/\text{kg.}$$

$$v_s = v_g = 0.054945 \text{ m}^3/\text{kg.}$$

$$h_w = h_f = 1061.34 \text{ kJ/kg}$$

$$s_w = s_f = 2.7471 \text{ kJ/kg}$$

$$s_L = s_{fg} = 3.3612 \text{ kJ/kgk}$$

1. Pressure

$$P_{sat} = 36.589 \text{ bar}$$

$$2. \text{ Mass } = m_s = v_s / v_s$$

v_s = vol of vapour.

$$v_s = v_g = v_v - v_w = 0.05 - 0.00124$$

$$v_s = 0.04876 \text{ m}^3$$

$$\therefore m_s = \frac{v_s}{v_s} = \frac{0.04876}{0.054945} = 0.8874 \text{ kg.}$$

$$\therefore \text{Total mass of mix. } m = m_w + m_s$$

$$= 10 + 0.8874$$

$$= 10.8874 \text{ kg.}$$

3. Specific vol.

$$V = v_w + x(v_s - v_w)$$

$$x = \frac{m_s}{m} = \frac{0.8874}{10.8874} = 0.815$$

$$V = 0.00124 + 0.815(0.005494 - 0.00124)$$

$$V = 0.005617 \text{ m}^3/\text{kg}$$

4. Specific enthalpy: enthalphy:-

$$h = h_w + xL$$

$$h = 1661.34 + (0.0815 \times 741.35)$$

$$= 3.021 \text{ kJ/kg K}$$

5. Specific enthalpy.

$$s = s_w + n \cdot s_L$$

$$= 2.7471 + (0.0815 \times 3.3612)$$

$$= 3.021 \text{ kJ/kg K}$$

6. Internal energy:

$$u = h - Pv$$

$$= 1029.02 - (36.589 \times 10^3 \times 0.005617)$$

$$= 1189.068 \text{ kJ/kg}$$

3. What is principle of operation of an electrical calorimeter?

Sol:- Principle of operation:- It is used to measure the quality of wet steam. In steady flow system is allowed to flow through an electric heater. The input energy should be in adequate amount to transfer the steam into super heated region where pressure (P_2) and temp (t) are measured.

Consider I and V be the current and voltage flowing across the heater respectively. Then the electrical energy input at steady state is given as,

$$Q = VI \times 10^{-3} \text{ kW}$$

If m is the flow rate of steam, then by

applying SFEE (Steady Flow Energy Equation) to electric heater,

$$m_1 h_1 + Q = m_1 h_2$$

$$h_1 + \frac{Q}{m_1} = h_2$$

$$h_1 = h_2 - \left[\frac{Q}{m_1} \right]$$

h_1 can be computed when h_2 ,
 Q and m_1 are known.

Also,

$$h_1 = h_{f_p} + n_1 h_{fg_p}$$

From the above given n_1 can be evaluated.

4. A spherical shell of diameter 50 cm contains steam at a pressure of 40 bar and 0.85 dryness fraction. Calculate the mass of water and steam.

Sol:- Given data.

Dia of shell, $d = 50 \text{ cm} = 0.5 \text{ m}$.

$$\text{Volume of shell } V = \frac{\pi d^3}{6} = \frac{\pi \times (0.5)^3}{6} = 0.0654 \text{ m}^3$$

Pressure of steam, $P = 40 \text{ bar}$

Dryness fraction, $n = 0.85$

From steam tables

At pressure, $P = u_{\text{obar}}$

$$v_g = 0.04975 \text{ (m}^3/\text{kg})$$

$$h_f = 1087.40 \text{ (kJ/kg)}$$

$$\begin{aligned} h_g &= h_g - h_f = 2800.3 - 1087.40 \\ &= 1712.9 \text{ kJ/kg.} \end{aligned}$$

$$\begin{aligned} \text{Density} &= \frac{1}{v_g} = \frac{1}{0.85 \times 0.04975} \\ &= 23.64 \text{ kg/m}^3. \end{aligned}$$

Mass of 0.0654 m^3 of steam,

$$= 0.654 \times 23.64 = 1.546 \text{ kg.}$$

Mass of steam, $\approx 1.546 \text{ kg.}$

Dryness fraction
 $x =$

$$x = \frac{m_s}{m_s + m_w} = 0.85 = \frac{1.546}{1.546 + m_w}$$

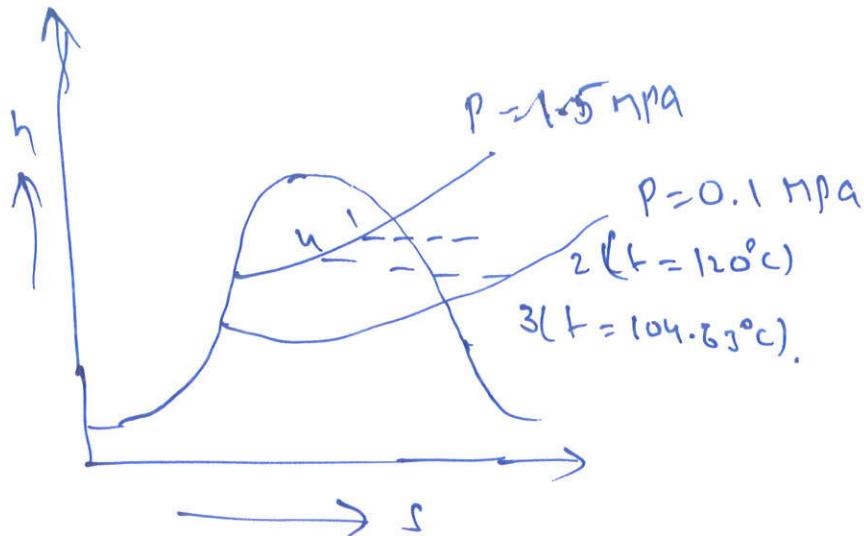
$$1.3141 + 0.85 m_w = 1.546$$

$$m_w = 0.2728 \text{ kg.}$$

Mass of water $\approx 0.2728 \text{ kg.}$

5. Steam flows in a pipe line at 1.5 MPa. After expanding to 0.1 MPa in throttling calorimeter, the temp is found to be 120°C . Find the quality of steam in the pipe line. What % of the max moisture at 1.5 MPa that can be determined with this set up if at least 5°C of super heat is required after throttling for accurate readings?

Sol:



At $P = 1.5 \text{ MPa}$, $h_f = 844.89 \text{ kJ/kg}$.

$$h_{fg} = 1947.3 \text{ kJ/kg}$$

$P = 0.1 \text{ MPa}$, & $t = 120^\circ\text{C}$

$$h_2 = 2716.2 \text{ kJ/kg}$$

$$h_1 = h_2$$

$$h_{f,1.5} + n_1 \cdot h_{fg,1.5 \text{ MPa}} = h_2$$

$$844.89 + n_1 \times 1947.3 = 2716.2$$

$$n_1 \times 1947.3 = 2716.2 - 844.89$$

$$n_1 = \frac{2716.2 - 844.89}{1947.3}$$

$$n_1 = \frac{1871.3}{1947.3}$$

$$n_1 = 0.961$$

$$P = 0.1, t = 99.63 + 5 = 104.63^\circ\text{C}$$

$$h_3 = 2685.5 \text{ kJ/kg}$$

$$h_3 = h_4$$

$$2685.5 = 844.89 + n_4 \times 1947.3$$

$$n_4 = \frac{2685.5 - 844.89}{1947.3}$$

$$n_4 = \frac{1840.61}{1947.3}$$

$$n_4 = 0.945$$

the amount of moisture absorbed is $(1 - 0.945)$

$$= 0.055 \text{ (or) } 5.5\%$$

∴ the max moisture that can be determined with this set-up is only 5.5%.