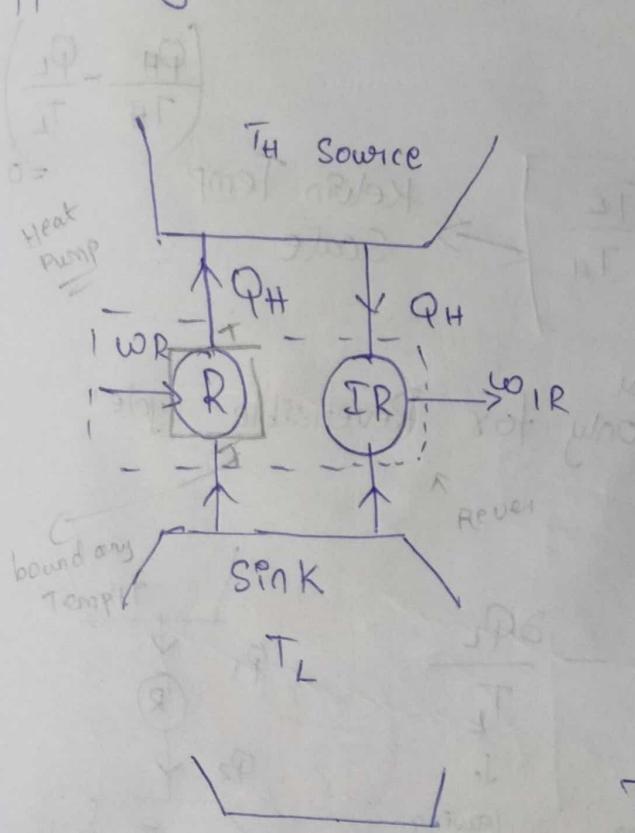


Carnot's Principle (Theorem):

1) All the reversible heat engine operating b/w two given source & sink temp have same efficiency, consequently all the heat pump & refrigerator gives same COP.
 fixed temp, not depend on intermediate

2) All the reversible heat engine operating b/w a given const temp source & const temp sink none has a higher efficiency than a reversible one.



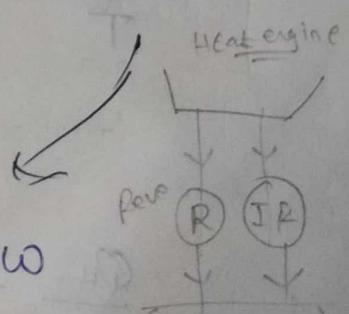
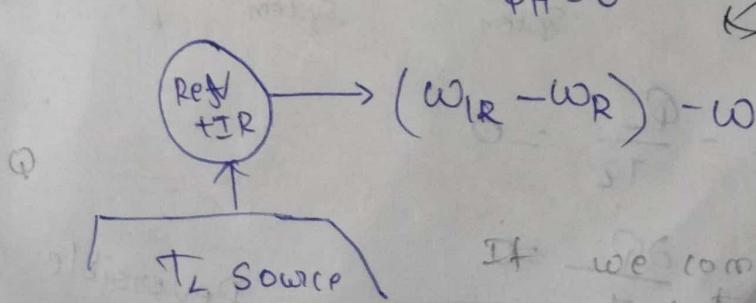
No heat Exchange

$$Q_{IR} > n_R \rightarrow \text{Assume}$$

$$w_{IR} > w_R$$

$$Q_L^R > Q_L^{IR}$$

It violates Planck's Statement



If we combine then
 No heat transfers
 it violates Kelvin-Planck's Statement
 of 2nd law

So Assumption is wrong

$$\phi(T_2, T_3) \cdot \phi(T_1, T_2) = \phi(T_1, T_3)$$

$$y = \phi(T_2, T_3)$$

$$y = \left(\frac{T_2}{T_3}\right)$$

$$\phi\left(\frac{T_1}{T_2}\right) \cdot \phi\left(\frac{T_2}{T_3}\right) = \phi(T_1, T_3)$$

$$\psi\left(\frac{T_1}{T_3}\right) = \phi(T_1, T_3)$$

$$\frac{Q_3}{Q_1} = \psi\left(\frac{T_3}{T_1}\right)$$

$$\frac{Q_3}{Q_1} = \frac{T_3}{T_1}$$

$$\left(\frac{Q_H}{T_H} - \frac{Q_L}{T_L}\right) = 0$$

$$\boxed{\frac{Q_L}{Q_H} = \frac{T_L}{T_H}}$$

Kelvin Temp Scale

$$\frac{Q_H}{T_H} = \frac{Q_L}{T_L}$$

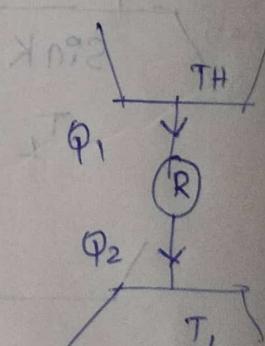
only for Reversible cycle

Claussius Inequality:

$$\frac{\partial Q}{T} = + \frac{\partial Q_H}{T_H} - \frac{\partial Q_L}{T_L}$$

Entering System

Leaving System.



$$\frac{Q_H}{T_H} - \frac{Q_L}{T_L} = 0$$

$$\frac{\partial Q}{T} = 0$$

$$\boxed{\oint \frac{\partial Q}{T} = 0}$$

Reversible cycle

Irreversible Process:

$$n_{IR} < n_R$$

$$n_R > n_{IR}$$

$$\left(1 - \frac{Q_L}{Q_H}\right)_R > \left(1 - \frac{Q_L}{Q_H}\right)_{IR}$$

$$\frac{Q_L^R}{Q_H^R} < \frac{Q_L^{IR}}{Q_H^{IR}}$$

$$\frac{T_L}{T_H} < \frac{Q_L^{IR}}{Q_H^{IR}}$$

$$\frac{Q_L^{IR}}{T_L} > \frac{Q_H^{IR}}{T_H}$$

$$-\frac{Q_L}{T_L} + \frac{Q_H}{T_H} < 0$$

$$\frac{Q_H}{T_H} - \frac{Q_L}{T_L} < 0$$

$$\left(\frac{Q_H}{T_H} - \frac{Q_L}{T_L}\right)^{IR} < 0$$

$$\left(\frac{\partial Q}{\partial T}\right)^{IR} < 0$$

$$\frac{\partial Q}{T} < 0 \text{ (for all IR)}$$

$$\boxed{\frac{\partial Q}{T} \leq 0} \rightarrow \text{for all Processes}$$

$$\frac{\partial Q}{T} = 0 \rightarrow \text{Rev}$$

$$\frac{\partial Q}{T} < 0 = \text{IR}$$

$$\oint \frac{\partial Q}{T} \leq 0$$

$$\boxed{\oint \frac{\partial Q}{T} = 0}$$

state function

$$\oint dU = 0 \quad \oint dP = 0$$

$$\oint \frac{\partial Q}{T} = \int_{\text{ST}} \frac{\partial Q}{T} + \int_{\text{P}} \frac{\partial Q}{T}$$

$$\oint dH = 0$$

$$d(S) = \frac{\partial Q}{\partial T} = 0$$

$$ds = \frac{dQ}{T} > -\frac{dP}{dT}$$

$$\boxed{\Delta S = \oint \rightarrow \text{Reversible}}$$

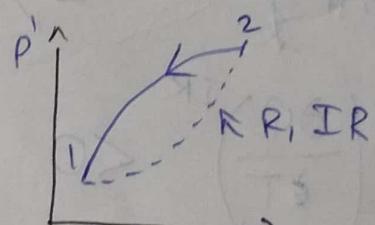
$$\Delta S = \frac{\partial Q}{\partial T}$$

$\oint \rightarrow \text{cyclic}$ $\int \rightarrow \text{single Process}$

$$\text{Isothermal Reversible } ds = \frac{Q}{T}$$

$$ds = \int \frac{\partial Q}{T}$$

Entropy Generation:



$$\oint \frac{\partial Q}{T} = \int_1^2 \frac{\partial Q}{T} + \int_2^1 \frac{\partial Q}{T}$$

$$= \int_1^2 \frac{\partial Q}{T} + \Delta S_{2-1}$$

$$\int \frac{\partial Q}{\partial T} + \Delta S_{2-1} \leq 0$$

$$\int \frac{\partial Q}{\partial T} \leq -\Delta S_{2-1}$$

$$\int \frac{\partial Q}{\partial T} \leq S_2 - S_1$$

$$\Delta S_{1-2} \geq \int \frac{\partial Q}{\partial T}$$

$$S_{1-2} \geq \int \frac{\partial Q}{\partial T}$$

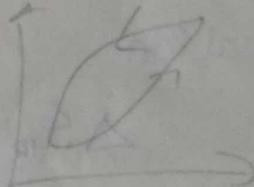
$$\Delta S > \int \frac{\partial Q}{\partial T}$$

$$\Delta S = \int \frac{\partial Q}{T} + S_{gen} \rightarrow I_{rr}$$

$$S_g = 0 \text{ (Rev)}$$

$$S_g > 0$$

$$S_{gen} \geq 0 \text{ (Irr)}$$



S_g Always +ve, (or) zero

S_{gen} \rightarrow Path function

$$\oint \frac{\partial Q}{T} \leq 0$$

$$\Delta S = \int \frac{\partial Q}{T} \text{ (Rev)}$$

$$\Delta S > \int \frac{\partial Q}{T} \text{ (Irr)}$$

\downarrow change in entropy \downarrow Entropy transfer

$$\int \frac{\partial Q}{\partial T} + \int \frac{\partial Q}{\partial T}$$

$$\int \frac{\partial Q}{\partial T} + S_{2-1} \leq 0$$

$$S_{2-1} - \int \frac{\partial Q}{\partial T}$$

$$S_1 - S_2 \geq \int \frac{\partial Q}{\partial T}$$

$$\Delta S \geq \int \frac{\partial Q}{\partial T}$$

$$\Delta S > 0$$

The entropy process during irr always greater than $\int \frac{\delta Q}{T}$ for this system.

where T is boundary δQ is differential heat b/w system & surroundings.

There has some quantity that is increased by more than what is transferred to system. This transfer of system is entropy generation (S_{gen})

$$\int \frac{\delta Q}{T} > 0 =$$

Then there is ^{must be} some S_{gen} in the generation.

$$\Delta S_{IR} = \int \frac{\delta Q}{T} + S_{gen} \quad 0 < \beta_2$$

$$\Delta S_{IR \neq}$$

Isolated System:

$$\Delta S = \int \frac{\delta Q}{T} + S_{gen} \quad w=0$$

$$\Delta S = S_{gen} \quad m=0 \quad Q=0$$

Entropy generation defines the irreversibility

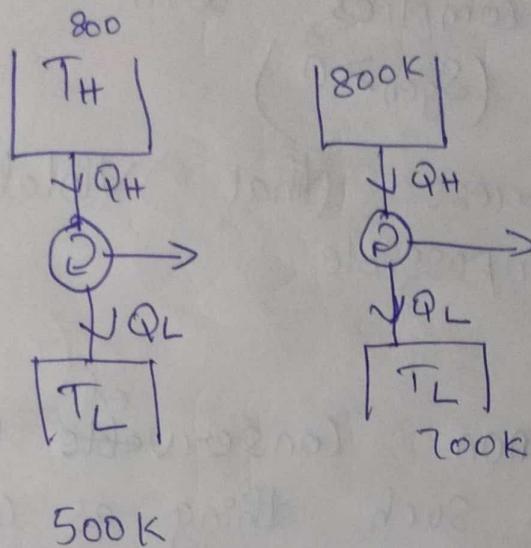
Entropy ↑ efficiency ↓

Performance ↓

diff b/w Temp ↑ Entropy ↓

- i) A heat source 800 K loss 2000 KJ of heat to a sink at
- 500 K
 - 700 K

Determine which heat transfer process is more irreversible.



$$Q_H = 2000 \text{ KJ}$$

$$\Delta S_{\text{Total}} = - \int \frac{\partial Q_H}{T} + \int \frac{\partial Q_L}{T}$$

$$\boxed{\Delta S_{\text{Total}} = \Delta S_{\text{gen}}}$$

$$= -$$

For Isolated System
no heat transfer

Proof. so $\partial Q = 0$

$$\Delta S = \int \frac{\partial Q}{T} + S_{\text{gen}}$$

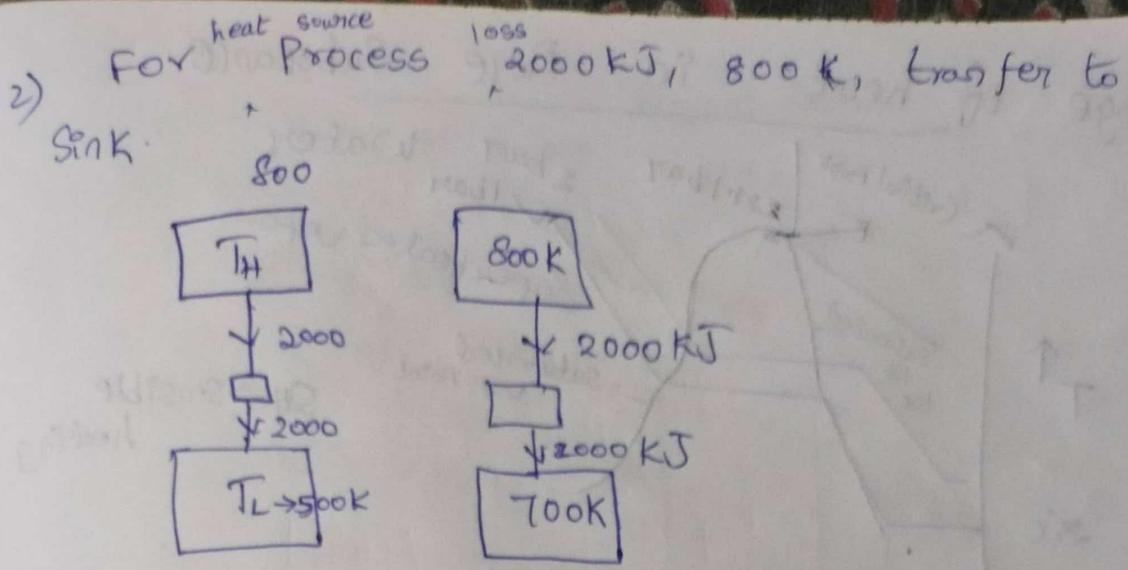
$$\Delta S = S_{\text{gen}}$$

$$\boxed{\Delta S \geq 0}$$

Entropy of Universe is isolated
if it is always ↑

Summary of Entropy Generation

- 1) The Process can occur in certain direction only not in any direction.
 - 2) The Process must Proceed in direction that complies with ↑ of entropic Principal ($S_{gen} > 0$)
 - 3) The Process that violate this Principal is impossible
-
- 2) Entropy is non ~~conservative~~ ^{ed} Property & there is no such thing as conservation of entropy Principal. Entropy is conserved during reversible Process only & ↑ during all actual process.
 - 3) The ~~poor~~ Performance of engineering System or device is degrade by presence of irreversibility; an entropy generation is a measure of magnitude of irreversibility present during that process.
 - 4) The greater extent of irreversibility, more entropy generation, Therefore entropy generation can be used as quantity measure of the irreversibility associate with Process.



$$\Delta S_{\text{Total}} (= -(\Delta S) + (\Delta S))$$

$$= - \int \frac{\partial Q}{T_H} + \int \frac{\partial Q}{T_L}$$

$$\Delta S_{\text{Total}} = - \frac{2000}{800} + \frac{2000}{700}$$

$$(\Delta S_T)_1 = 1.5$$

$$\Delta S_{\text{Total}} = - \frac{2000}{800} + \frac{2000}{700}$$

$$\Delta S_T = 0.35 \text{ kJ/k}$$

$$\Delta S \geq \int \frac{\partial Q}{T}$$

change in entropy \geq Entropy transfer to the System.

$$S_{\text{gen}} \geq 0$$

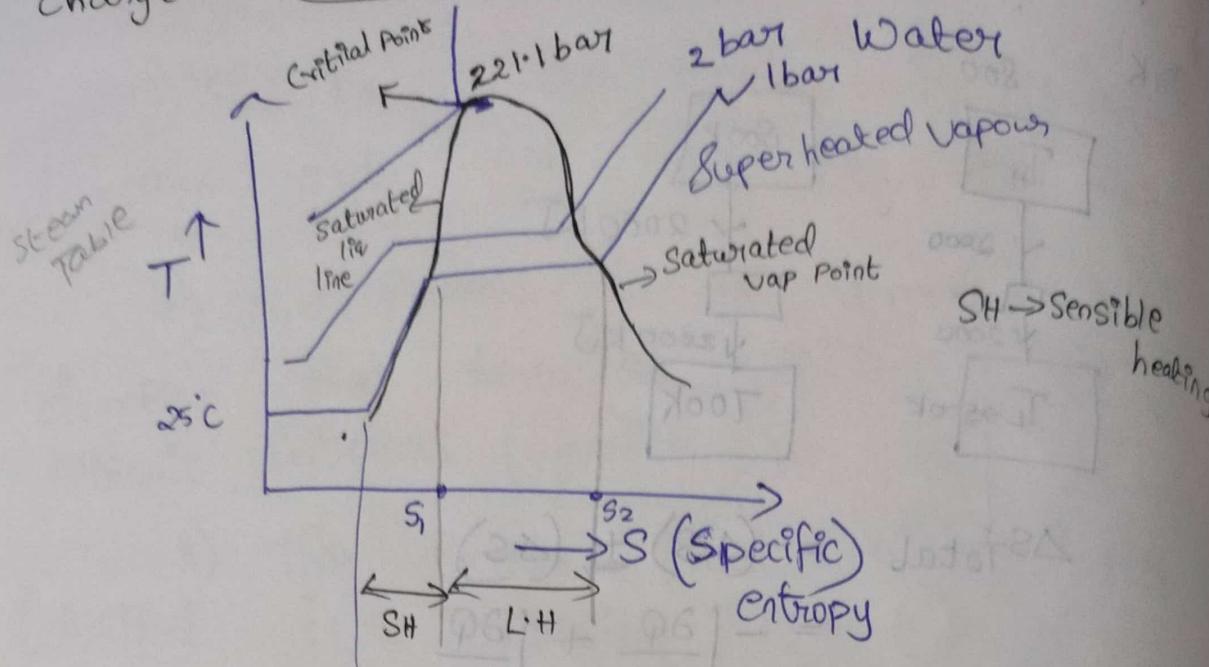
entropy generation never be \leq negative

Entropy of Universe always increases.

$$Rev = \Delta S = \int \frac{\partial Q}{T} \quad S_{\text{gen}} = 0$$

$$Irrev = \Delta S > \int \frac{\partial Q}{T} \quad S_{\text{gen}} > 0$$

Change of heat in Pure Substance

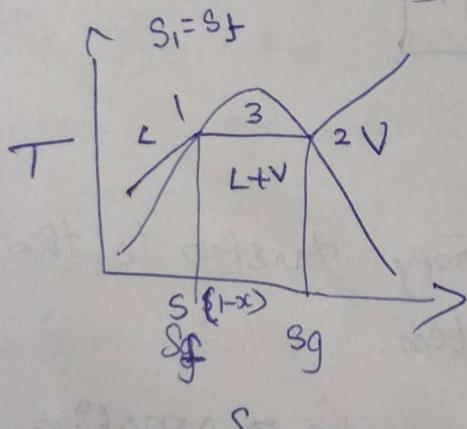


upto 221.1 bar \rightarrow Latent heat = 0 (critical point)
 221.1 bar
 $T = 374.15^\circ C$
 (liq, vapour phase coexist)

Saturated \rightarrow Change of Phase

$$\Delta S = 0 \quad (L·H = 0)$$

$$S_3 = (1-x) S_f + x S_g = \frac{M_v}{m_L + M_v}$$



$$\begin{aligned} S &= S_f - x S_{fg} + x S_g \\ &= S_f + x(S_g - S_f) \end{aligned}$$

$$S = S_f + x \bullet S_{fg}$$

$$S = S_f + x S_{fg}$$

$$S_{fg} = S_g - S_f$$

Latent heat \rightarrow Cons temp
 Change in Phase

$$x = \frac{m_v}{(m_l + m_v)} = m$$

Dryness fraction

$$V = (1-x) V_f + x \cdot V_g$$

$$V = V_f - x V_f + x \cdot V_g$$

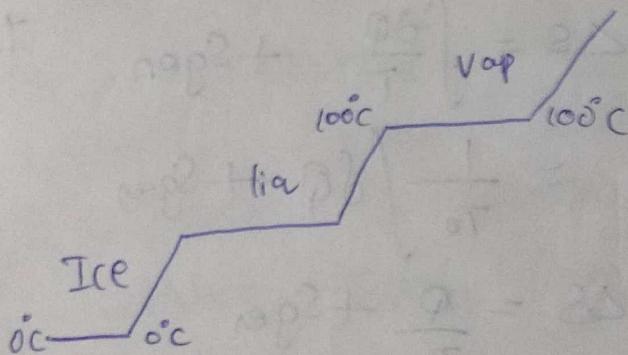
$$V = V_f + x \cdot V_{fg}$$

$$h = h_f + x \cdot h_{fg}$$

$$\mu = \mu_f + x \cdot \mu_{fg}$$

1 Tonne of Refrigeration effect:

If is capacity of refrigeration
System that can freeze 1 tonne of liquid water at 0°C into Ice in 24 hrs



Latent heat of water = 335 kJ/kg

$$Q = \frac{1 \text{ ton} \times L}{24 \text{ hr}}$$

$$1 \text{ TR} = 211.04 \text{ kJ/min}$$

$$(1 \text{ ton of RE}) = \frac{1 \text{ ton} \times 33.5}{24 \text{ hr}}$$

$$= \frac{907.5 \text{ kg} \times 335 \text{ (kJ/kg)}}{(24 \times 3600) \text{ s}}$$

$$1T = 3.5 \text{ kJ/s}$$

$$1 \text{ TR} = 3.5 \text{ K-watt}$$

Torque

Q.) A 3φ 400V star connected induction motor has a star connected phases with a stator to rotor turns ratio of 6:5. The rotor resistance & standstill reactance per phase are 0.05Ω & 0.25Ω respectively. What should be the value of external resistance per phase to be inserted in the rotor circuit to obtain max^m torque at starting & what will be rotor starting current with this resistance.

change in entropy for isothermal process

$$\Delta S = \int \frac{dQ}{T} + S_{gen} \quad \text{Temp} = \text{const}$$

$$T = T_0 = \frac{1}{T_0} \int dQ + S_{gen}$$

$$\Delta S = \frac{Q}{T_0} + S_{gen}$$

Q) A 1100 V, 50 Hz delta connection induction motor has a star connected slip ring rotor with a phase transformation ratio of 3.8. The rotor resistance & standstill leakage resistance are 0.012 & 0.95 Ω per phase respectively. Neglecting stator impedance & magnetising current. Determine the rotor current at start with slip rings are shorted.

- i) The rotor power at start with slip rings shorted.
- ii) The rotor current at 47% slip with slip rings shorted.
- iii) The rotor power factor at 47% slip with slip rings shorted.
- iv) The external ^{rotor} resistance required to obtain a starting current of 100 A in stator supply lines.

Q) A 3 ϕ 6 Pole Induction motor having a star connected rotor has an induced emf of 80V b/w slip rings at standstill as o.c. The rotor has a resistance & reactance per phase of (2 & 4 Ω respectively, calculate current (Phase & Powerfactor when slip rings are shorted.

i) S.C

ii) Slip rings are connected a star connected rheostat of 3 Ω per phase.

Entropy change: (of Pure substance)

$$V = (1-x)V_f + xV_g \rightarrow \text{specific volume}$$

$$V = V_f - xV_f + x \cdot V_g$$

$$V = [V_f + xV_{fg}]$$

$$[h = h_f + xh_{fg}]$$

$$[u = u_f + xu_{fg}]$$

$$\text{density} = \rho = \frac{1}{V}$$

$$V = mV_f$$

1 Tonne of RE-

It is a capacity of refrigeration system that can freeze 1 tonne of liquid water at 0°C into ice at 0°C in 24 hrs

$$1 \text{ tonne of RE} = \frac{1 \text{ ton} \times 335}{24}$$

$$= \frac{907.5 \times 335}{24 \times 3600/\text{s}}$$

$$= 3.5 \text{ kJ/s} = 3.5 \text{ kW}$$

$$S = S_f + xS_{fg}$$

$$S_{fg} = S_g - S_f$$

$$\delta = m \times S$$

$$h = h_f + xh_{fg}$$

$$H = h \times M$$

$$u = u_f + xu_{fg}$$

$$\delta c = 807$$

$$\text{Ans} P_{\text{sup}} = 2.1 \text{ kJ/kg}$$

$$h_{\text{sup}} = h_g + P_{\text{sup}} (T_{\text{sup}} - T_{\text{sol}} \cdot v_p)$$

To determine enthalpy, entropy, volume, density of 2kg Steel at 80°C
 $\& 0.85 x.$

$$T = 80^{\circ}\text{C}$$

$$V_f = 0.001029$$

$$V_g = 3.407$$

$$h_f = 334.88$$

$$u_f = 334.84$$

$$h_{fg} = 2308.8$$

$$u_{fg} = 2147.4$$

$$u_g = 2482.2$$

$$\begin{cases} \text{Interpolation } 17.5^{\circ} & \text{if not} \\ T=x & \text{there} \\ h_f=y & \end{cases}$$

$$\frac{x-x_1}{x_2-x_1} = \frac{y-y_1}{y_2-y_1}$$

Superheated stream

$$h_{sup2} = h_{sup1} + C_{ps} (T_{sup2} - T_{sup1})$$

specific
enthalpy
of
superheated
steam

mean specific heat

$$C_{ps} = \text{KJ/kg}$$

Q) 2kg of steel at 8 bar & Point 0.8.
Determine its enthalpy, entropy & volume.

$$m = 2\text{ kg}$$

$$P = 8 \text{ bar}$$

$$x = 0.8 \text{ d.}$$

$$h_f = 721.1 \text{ KJ} \quad h_{fg} = 2048.0 \text{ KJ}$$

$$S_f = 2.0461 \text{ KJ/kg} \quad S_{fg} = 4.6166 \text{ KJ/kg}$$

$$V_f = 0.001115 \text{ m}^3/\text{kg} \quad V_g = 0.2404 \text{ m}^3/\text{kg}$$

$$\text{Specific entropy } (s) = S_f + x S_{fg}$$

$$= 12.04 + 0.8 \times 4.66166 \\ = 5.72 \text{ KJ/kg}$$

$$\text{sp enthalpy } (h) = h_f + x h_{fg}$$

$$= 721.1 + 0.8 \times 2048$$

$$= 2359.5 \text{ KJ/kg}$$

some

i) find enthalpy

$\cancel{H = m h_f} \times$

$$H = m (h_f + X \times h_{fg})$$

$$= 2 (721.1 \text{ kJ} + 0.8 \times 2048.0)$$

$$= 2359.5 \text{ kJ}$$

$X \rightarrow$ Pressure
fraction,

ii) find Volume

$$V = m V_g$$

$$= 2 \times X \times V_g$$

$$= 2 \times 0.8 \times 0.2404$$

$$= 0.38464 \text{ m}^3$$

iii) Find enthalpy

$$S = m (S_f + X s_{fg})$$

$$= 2 (2.0461 + 0.8 \times 4.6166)$$

$$= 11.478 \text{ kJ/K}$$

A vessel contains volume 0.04 m^3 contains a mixture of saturated water & saturated steam at a temp of 250°C , the mass of liq present is 9kg. Find mass, specific volume enthalpy, entropy, internal energy.

$$V = 0.04$$

$$1 \text{ MPa} = 10 \text{ bar}$$

x = Dryness fraction

$$x = \frac{m_g}{m_v + m_g} = \frac{\text{mass of Vapour}}{\text{mass of liq} + \text{mass of Vapour}}$$

$$\boxed{m = m_L + m_V}$$

$$= m_L + m_V$$

\therefore mass of liq given = 9kg

$$\boxed{V = V_g + V_f}$$

$$S_f = 2.7927 \text{ kJ}$$

$$h_f = 1085.34$$

$$V_f = 0.0012512$$

$$V_g = 0.05013$$

$$h_{fg} = 1716.2$$

$$S_{fg} = 3.2802$$

$$\boxed{v = \frac{V}{m}}$$

$$\text{Specific } V_f = m_f V_f$$

volume of liq

$$= 9 \times 0.0012512$$

$$\boxed{V_f = 0.01126 \text{ m}^3}$$

$$V_g = V - V_f$$

$$= 0.04 - 0.01126$$

$$V_g = 0.02874 \text{ m}^3$$

$$Mg = \frac{V_f}{V_g}$$

$$Mg = \frac{0.02874}{0.05013} = 0.575 \text{ kg}$$

$$S_C = \frac{0.575}{9 + 0.575} = 0.06$$

$$h = h_f + x \cdot h_{fg}$$

$$= 1085.3 + 0.06(1716.2)$$

$$h = 1188.312$$

$$S = S_f + x \cdot S_{fg}$$

$$= 2.7927 + 0.06(3.2802)$$

$$S = 2.989$$

$$u_f = u_f + x \cdot u_{fg}$$

$$= 1080.3 + 0.06(1522)$$

$$u_f = 1171.62$$

$$\begin{aligned} V_f &= 0.001251 \\ V_g &= 0.05013 \end{aligned}$$

$$V = V_f + x \cdot V_{fg}$$

$$= 0.0126 - 0.06(V_g - V_f)$$

$$= 0.001251 - 0.06(0.001251)$$

$$+ 0.06(0.05013)$$

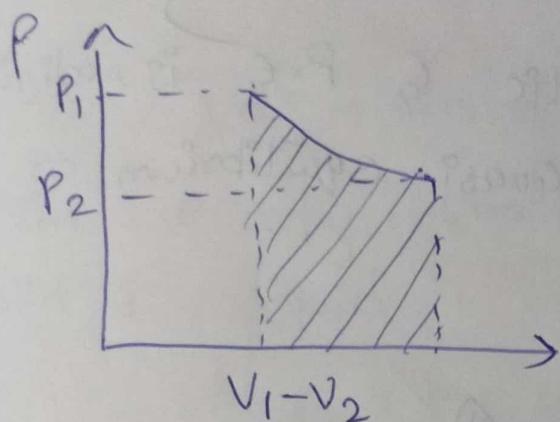
$$V = 0.00418$$

$$4.18374 \times 10^{-3}$$

Tds relation / Gibbs eqn

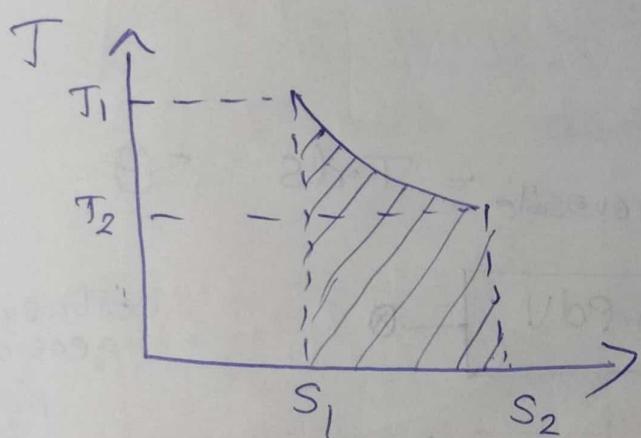
Combination of ^{1st} & ^{2nd} law of pure

Substance



$$\omega = PdV$$

$$\partial\omega = \int P dV$$



$$Q = Tds$$

$$\partial Q = \int T ds$$

Gibbs eqn: Tds :

In closed system
k.e. & p.e.
negligible

Assumption

- 1) Closed System
2) Pure substance
3) Only consider boundary or PdV work
(not other work can be considered)
4) Can ignore kinetic & P.e. is negligible.
5) Process \rightarrow Quasi-equilibrium or reversible
Internally

First law

$$(dQ)_{int \text{ reversible}} = dU + PdV \quad \text{---} ①$$

$$\text{Second law, } ds = \frac{dQ}{dT}$$

from ① & ②

$$(dQ)_{int \text{ reversible}} = T \cdot ds \quad \text{---} ②$$

$$Tds = du + PdV \quad \text{---} ③$$

Notes:

① The above eqn valid for
combine of two laws. (1 & 2 law).

② This eqn also valid for these
process where the process is in Quasi-equilibrium or
internally reversible process

③ It is relation b/w change in
State Property.

for incompressible
density

④ These eqn also tell us how entropy of system change given charge in internal energy & change in volume.

⑤ This eqn only depends on initial & final state. not depend on any process.

$$Tds = du + Pdv \Rightarrow \text{Gibbs eqn}$$

The entropy change of & incompressible solid & liquid

$$ds = \frac{du}{T} + \frac{Pdv}{T}$$

$$\& \boxed{h = u + PV} \rightarrow \text{flow work}$$

$$dh = du + P \cdot dv + v \cdot dP$$

$$du = dh - Pdv - v \cdot dP$$

$$Tds = dh - Pdv - vdp + P \cdot dv$$

$$\boxed{Tds = dh - vdp} \rightarrow \text{enthalpy}$$

$$Tds = du$$

$$Tds = dh - Vdp \rightarrow \text{incompressible}$$

$$Tds = C_V$$

$$C_V = \left(\frac{du}{dT} \right)_V \quad C_P = \left(\frac{dh}{dT} \right)$$

$$du = C_V \cdot dT \quad dh = C_P \cdot dT$$

$$T \cdot ds = C_V dT \quad ds = C_V \frac{dT}{T}$$

$$Tds = C_P dT - Vdp \Rightarrow ds = C_P \frac{dT}{T} - \frac{V}{T} dp$$

$$\Delta S = \int_1^2 C_V \frac{dT}{T}$$

$$\Delta S = \int_1^2 C_P \frac{dT}{T} + \int_1^2 \frac{V}{T} dP$$

$$(C_P = C_V) = C_{avg} \rightarrow \text{depend on Temp}$$

\downarrow
depend on P, V

for incompressible
not depend on P, V.

For incompressible,

$$C_{avg} = \frac{C_1(T) + C_2(T)}{2}$$

$$\Delta S = \int_1^2 C_V \frac{dT}{T}$$

$$\Delta S = \int_1^2 C_P \frac{dT}{T} - \int_1^2 \frac{V}{T} dP$$

$$\Delta S = \int_1^2 C_{avg} \frac{dT}{T}$$

$$PV = RT \quad \boxed{\frac{V}{T} = \frac{R}{P}}$$

$$\boxed{\Delta S = C_{avg} \times \ln\left(\frac{T_2}{T_1}\right)}$$

$$C_{avg} \cdot \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$$

$$\boxed{C_{avg} = \frac{(C_P(T_1) + C_P(T_2))}{2}}$$

for isotropic, $\Delta S = 0$

for incompressible, which are
isotropic then the process is also
isothermal $\boxed{C_P = C_V = C(T)}$

~~for compressible~~

Reversible + Adiabatic, \Rightarrow Isentropic
 \downarrow
 $\Delta S = 0$

$$Q = C_{avg} \ln\left(\frac{T_2}{T_1}\right)$$

$$T_1 = T_2 \quad (C_{avg} \neq 0)$$

for ideal gas,

$$\overline{T} dS = du + PdV$$

$$TdS = du - VdP$$

$$dS = \frac{du}{T} + \frac{P}{T} dV$$

$$dS = C_V \cdot \frac{dT}{T} + \frac{P}{T} dV$$

$$\Delta S = \int C_V \frac{dT}{T} + \frac{P}{T} \cdot dV$$

$$PV = RT$$

$$\frac{P}{T} = \frac{R}{V}$$

$$\Delta S = \int_1^2 C_V \frac{dT}{T} + \int_1^2 \frac{R}{V} dV$$

$$\Delta S = C_V \text{avg} \int_1^2 \frac{dT}{T} + R \int_1^2 \frac{dV}{V}$$

$$\Delta S = C_V \text{avg} \ln\left(\frac{T_2}{T_1}\right) + R \ln\left(\frac{V_2}{V_1}\right) \text{ ideal gas}$$

for Universal gas const,
 $C_P \rightarrow$
 $R_u = M \times R$

$$\bar{C}_{\text{avg}} = m \times C_{\text{avg}}$$

$$\begin{aligned}\Delta \bar{S} &= \bar{s}_2 - \bar{s}_1 \\ &= \bar{C}_{\text{v, avg}} \ln\left(\frac{T_2}{T_1}\right) + R_u \ln\left(\frac{V_2}{V_1}\right)\end{aligned}$$

ISENTROPIC Process for ideal gas:

$$\Delta S = C_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$$

$$0 = C_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$$

$$C_p \ln\left(\frac{T_2}{T_1}\right) = R \ln\left(\frac{P_2}{P_1}\right)$$

$$\Delta S = C_{\text{avg}} \ln\left(\frac{T_2}{T_1}\right) \quad C_p \ln\left(\frac{T_2}{T_1}\right) = \ln\left(\frac{P_2}{P_1}\right)^{R/C_p}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{R/C_p}$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$\boxed{\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}}$$

$$\frac{C_p}{C_v} = \gamma$$

$$C_p - C_v = R$$

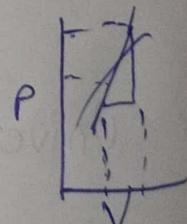
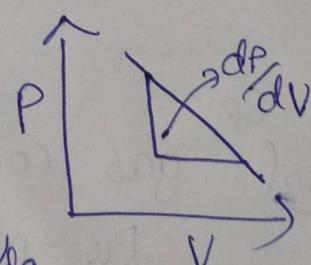
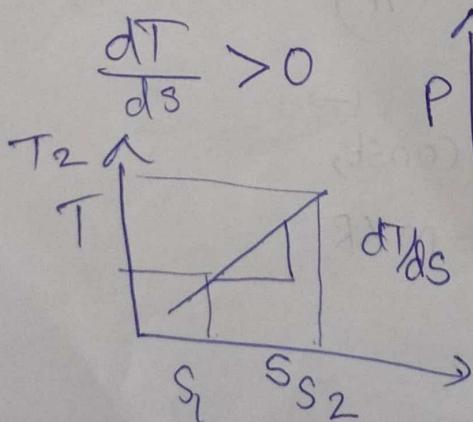
$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)$$

$$1 - \frac{C_v}{C_p} = \frac{R}{\gamma}$$

$$1 - \frac{1}{\gamma} = \frac{R}{C_p}$$

Real Process

$$\frac{dP}{dV} < 0, \quad P \uparrow, V \downarrow$$



(Q) liq methane is commonly used in various ^{const Temp 0°C} ~~critical~~ Cryogenic. The critical temp of methane is 191 K or -82°C & methane has to be maintained at 191 K to keep it in liq phase. the properties of liq methane for various temp & pressure are given in Table. Determine the entropy of liq methane as it undergoes process from 110 K to 1 MPa to 120 K & 5 MPa (Methane is a incompressible substance) what is the error in this phase.

$$110\text{K} \rightarrow 1\text{MPa}$$

$$P = 425.8 \quad C_p = 3.471$$

$$h = 209.0$$

$$S = 4.875$$

$$\Delta S = S_2 - S_1$$

$$120\text{K} \quad = 5\text{MPa} \quad = P = 415.2$$

$$h = 249.6$$

$$S = 5.145$$

$$C_p = 3.486$$

$$\Delta S_{\text{actual}} = \Delta S_{\text{ideal}} = 0.270 \text{ kJ/kg/K}$$

$$\boxed{\text{Error} = \epsilon_{\text{actual}} - \epsilon_{\text{ideal}}}$$

$$\begin{aligned}\Delta S_{\text{actual}} &= S_2 - S_1 \\ &= 5.145 - 4.875 \\ &= 0.270\end{aligned}$$

$$\begin{aligned}\Delta S_{\text{ideal}} &= 3.47 \ln \left(\frac{T_2}{T_1} \right) \\ &= 3.47 \ln \left(\frac{12\phi}{11\phi} \right) \\ &= 0.303 \text{ kJ}\end{aligned}$$

$$\begin{aligned}C_{\text{avg}} &= \frac{C_{P_1} + C_{P_2}}{2} \\ &= 3.471 + \frac{3.486}{2} \\ &= 3.4785\end{aligned}$$

$$\begin{aligned}\text{Error} &= \frac{\Delta S_A - \Delta S_I}{\Delta S_A} \\ &= 12.2\%.\end{aligned}$$

$$\Delta S_{\text{ideal}} = 3.47 \ln \left(\frac{T_2}{T_1} \right)$$

$$= 3.47 \ln \left(\frac{12\phi}{11\phi} \right)$$

$$= 0.303 \text{ kJ}$$

$$C_{\text{avg}} = \frac{C_P + C_P}{2}$$

$$= 3.471 + \frac{8.486}{2}$$

$$= 3.4785$$

$$\epsilon_{\text{corr}} = \frac{\Delta S_A - \Delta S_I}{\Delta S_A}$$

$$= 12.2 \cdot 1$$

for isentropic

$$\Delta S = 0$$

$$C_V \ln \left(\frac{T_2}{T_1} \right) + R \ln \left(\frac{V_2}{V_1} \right) = 0$$

$$\ln \left(\frac{T_2}{T_1} \right) = - \frac{R}{C_V} \ln \left(\frac{V_2}{V_1} \right)$$

$$\ln \left(\frac{T_2}{T_1} \right) = \ln \left(\frac{V_1}{V_2} \right)^{-R/C_V}$$

$$\ln \frac{T_2}{T_1} = \ln \left(\frac{V_1}{V_2} \right)^{R/C_V}$$

$$\frac{T_2}{T_1} = \frac{(V_1)^{R/C_V}}{(V_2)^{R/C_V}}$$

$$T_1 V_1^{R/C_V} = T_2 V_2^{R/C_V}$$

$$TV^{R/C_V} = \text{const}$$

$$C_P - C_V = R$$

$$\frac{C_P}{C_V} - 1 = \frac{R}{C_V}$$

$$\gamma - 1 = R/C_V$$

$$TV^{\gamma-1} = \text{const}$$

ideal gas

$$c_p \ln\left(\frac{T_2}{T_1}\right) = R \ln\left(\frac{P_2}{P_1}\right)$$

$$\ln\left(\frac{T_2}{T_1}\right) = \ln\left(\frac{P_2}{P_1}\right)^{R/c_p}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{R/c_p}$$

$$= \left(\frac{P_1}{P_2}\right)^{-R/c_p}$$

$$T_1 P_1^{-R/c_p} = T_2 P_2^{-R/c_p}$$

$$TP^{-R/c_p} = \text{const}$$

$$(P - c_V = \text{const})$$

$$1 - \frac{c_V}{c_P} = R/c_p$$

$$1 - \frac{1}{\gamma} = R/c_p$$

$$TP^{-(\gamma-1)} = \text{const}$$

$$TP^{\left(\frac{n-1}{n}\right)} = \text{const}$$

ideal gas

$$TV^{\gamma-1} = \text{const}$$

$$TP^{\frac{\gamma-1}{\gamma}} = \text{const}$$

ideal gas

Isothermal process.

$$\frac{V^{\gamma-1}}{P^{\frac{\gamma-1}{\gamma}}} = \text{const}$$

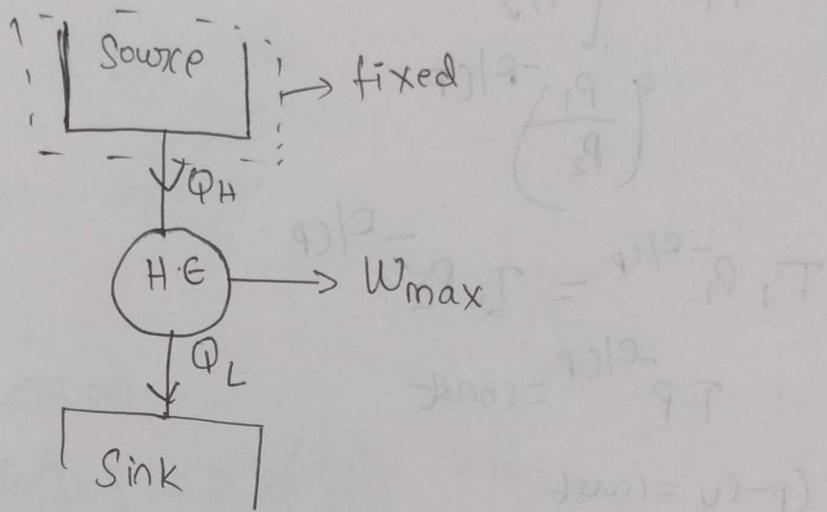
$$\left(\frac{V}{P^{\frac{1}{\gamma}}}\right)^{\gamma-1} = \text{const}$$

$$\frac{V}{P^{\frac{1}{\gamma}}} = \text{const}$$

$$PV^{\frac{1}{\gamma}} = \text{const}$$

Exergy : / Availability / Available

It is max possible useful work that can be obtained from system till it reaches the state of thermodynamic equilibrium with its surroundings.



We get max work in case of reversible

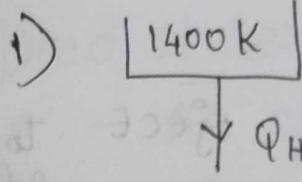
$$\eta_{rev} = \frac{W_{max}}{\Phi_H}$$

$$\eta_{rev} = \frac{T_1 - T_2}{T_1}$$

$$W_{max} = \frac{T_1 - T_2}{T_1} \times \Phi_H$$

$$W_{max} = \frac{T_H - T_L}{T_H} \times \Phi_H \quad \begin{matrix} \text{surrounding (Ambient} \\ \text{Temp)} \end{matrix}$$

$$W_{max} = \left(\frac{T_H - T_o}{T_H} \right) \times \Phi_H \quad \begin{matrix} \text{atmospheric temp} \\ + \end{matrix}$$



$$T_0 = 27^\circ\text{C}$$

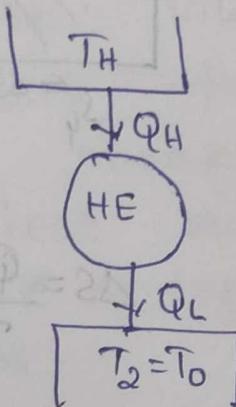
$$\frac{\frac{27}{273}}{563} \times 1000 = \frac{1400 - 543}{1400} \times 1000$$

$$W_{max} = 785 \text{ kJ}$$

more exergy, more source temp.

W_{max} — Energy / Available energy (AE)

Q_L = Unavailable energy (UAE)
(ex) Anergy



$$Q_H = A \cdot E + UAE$$

$$UAE = Q_H - A \cdot E$$

$$UAE = Q_H - \left(\frac{T_H - T_0}{T_H} \right) Q_H$$

$$UAE = Q_H - \left(1 - \frac{T_0}{T_H} \right) Q_H$$

Q1) A source of a temp of 500 K provides 1000 kJ of heat, the temp of environment 270 K then find $\frac{W_{max}}{Q}$, useful work that can be obtained ~~by~~ from its source & min energy ejected to source.

$$T_1 = 500 \text{ K}$$

$$Q = 1000 \text{ kJ}$$

$$W_{max} = 400$$

$$27 = 27 + 273 \\ = 300 \text{ K}$$

$$\text{energy} = 1 - \frac{T_0}{T_1}$$

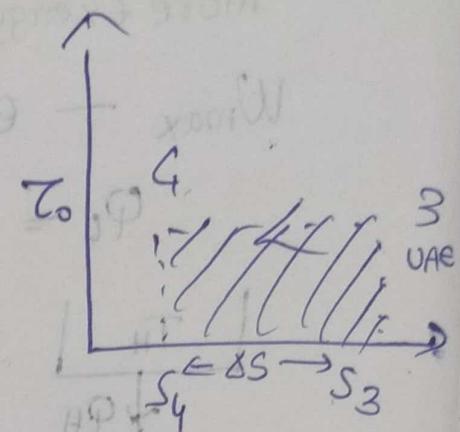
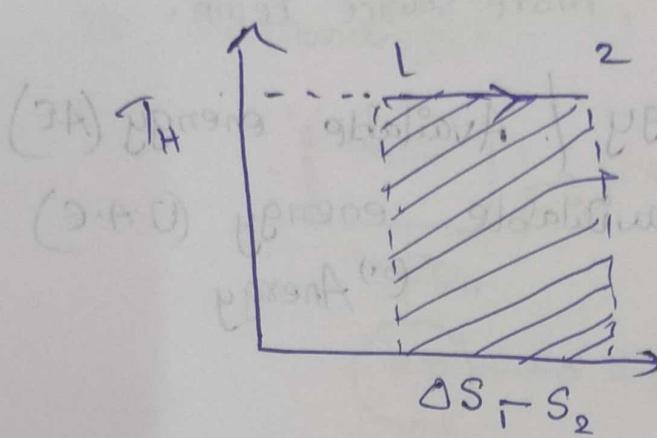
$$= 1 - \frac{270}{500} = 0.4$$

$$\eta = \frac{W_{max}}{Q} = 0.4$$

$$400 \text{ kJ} = W_{max}$$

Anergy:

Min energy that can be ejected to the sink or environment as per 2nd law of thermodynamics to achieve max work.



$$\Delta E = Q_H - \left(1 - \frac{T_0}{T_H} \right) Q_H$$

$$= Q_H - \left(Q_H - \frac{T_0}{T_H} Q_H \right)$$

$$\Delta E = Q_H - \left(Q_H - T_0 \left(\frac{Q_H}{T_H} \right) \right)$$

$$= Q_H - (Q_H - T_0 \Delta S)$$

$$= Q_H - Q_H + T_0 \Delta S$$

$$UAE = Q_H - Q_H + T_0 \Delta S_H$$

$$\boxed{UAE = T_0 \Delta S}$$

$$\boxed{\Delta E = Q_H - T_0 \Delta S}$$

$$\omega_{max} \left\{ \begin{array}{l} \text{Exergy} \\ \text{A.E} \end{array} \right\}$$

$$\left. \begin{array}{l} \text{Emax} \\ \text{UAG} \end{array} \right\} \begin{array}{l} \text{UAE} \\ \text{Anergy} \end{array}$$

$$Q_H = \Delta S T_H$$

Dead state:

A system is said to dead state when system is in thermodynamic equilibrium with environment.

mechanical eqn, with Exergy = 0 → Surrounding temp same

Q1) A heat reservoir at 900K is brought into contact with ambient at 300K for short time during this time 9000 KJ of heat is lost by the heat reservoir. The total loss of available energy exergy due to this process.

$$T_b \left(\frac{\partial P}{\partial T} \right)_{\text{sum}} = w_b$$

$$\text{HEX} = \left(1 - \frac{T_o}{T_h} \right) Q_{H0}$$

$$T_b \left(\frac{\partial P}{\partial T} \right)_{\text{sum}} = \left(1 - \frac{300}{900} \right) 9000$$

$$T_b \left(\frac{\partial P}{\partial T} \right)_{\text{sum}} = \left(1 - \frac{1}{3} \right) 9000 = 6000$$

Dead state:

When a system comes in equilibrium to its surroundings, which means that the availability of system is zero it is called dead state. No useful work can be obtained from a system is in dead state.

for a finite body,

$\Delta t \rightarrow$ very small,

$$\Delta Q = mc\Delta T$$

$$= mc(T - T + \Delta T)$$

$$= mc(0) = 0$$

if $\Delta Q = 0$ then $mc\Delta T = 0$ from (1)

therefore

$$\Delta W = \left(1 - \frac{T_0}{T_H}\right) \times \Delta Q$$

$$\Delta W = \left(1 - \frac{T_0}{T_H}\right) (mc\Delta T)$$

$$\boxed{\frac{mc}{T_H - T_0}}$$

$$\Delta W = -mc\left(\frac{T_0}{T_H}\right) dT$$

$$W = \int_{T_1}^{T_2} -mc\left(\frac{T_0}{T}\right) dT$$

$$= -mc \left[\frac{T_0}{T_2} - \frac{T_0}{T_1} \right]$$

$$W = -mc \int_{T_1}^{T_2} \left(1 - \frac{T_0}{T}\right) dT$$

$$W = -mc \left\{ (T_2 - T_1) - T_0 \ln \left(\frac{T_2}{T_1} \right) \right\}$$

$$W = mc \left\{ T_0 + mc \left(\frac{T_2 - T_1}{T_1} \right) \right\}$$

$$W = mc \left\{ T_0 \ln \left(\frac{T_2}{T_1} \right) - (T_2 - T_1) \right\}$$

$$= mc \left[T_0 \ln \left(\frac{T_2}{T_1} \right) + (T_1 - T_2) \right]$$

$$= mc \cdot T_0 \left[\ln \left(\frac{T_2}{T_1} \right) + \frac{1}{T_0} (T_1 - T_2) \right]$$

* $w = T_0 \left\{ mc \ln \left(\frac{T_2}{T_1} \right) + mc \frac{(T_1 - T_2)}{T_0} \right\}$

↓
Incompressible

↓
surrounding

$$= T_0 [\Delta S_{\text{Substance}} + \Delta S_{\text{surrounding}}]$$

$$w = T_0 (\Delta S_{\text{sys}} + \Delta S_{\text{env}})$$

$$w = T_0 \Delta S_{\text{env}}$$

$$A-E = T_0 \Delta S_{\text{env}}$$

Q) A steel billet 2000 kg/m is to be cooled from 1250 K \rightarrow 450 K,

The heat released during this process is to be used as source of energy, the ambient temp is 303 K & specific heat of steel is $0.5 \text{ kg}/\text{kJ K}$ find out the available energy for this billet.

Sol

$$T_0 = 303 \text{ K}$$

$$A-E =$$

$$A-E =$$

$$A-E T_0 = T_0 \left[mc \ln \left(\frac{T_2}{T_1} \right) + \frac{mc}{T_0} (T_1 - T_2) \right]$$

$$\frac{1250}{450}$$

$$= 303 \left[2000 \ln \left(\frac{450}{1250} \right) + \frac{2000}{303} (1250 - 450) \right]$$

$$= 980 \quad 490.439 \text{ MJ}$$

$$\Delta A \cdot E = (A \cdot E)_1 - (A \cdot E)_2$$

$$\frac{S(T_1, T_2)}{\text{of}} = \left(1 - \frac{T_0}{T_1}\right) Q - \left(1 - \frac{T_0}{T_2}\right) Q$$

$$= \left(Q - \frac{T_0}{T_1} Q - Q + \frac{T_0}{T_2} Q\right)$$

$$\Delta E = \frac{T_0}{T_2} Q - \frac{T_0}{T_1} Q$$

$$= T_0 Q \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$

$$= T_0 Q \left(\frac{T_1 - T_2}{T_1 T_2} \right)$$

diff Temp
two diff Sources

Irreversibility:

$$I \cdot R = W_{\max} - W_A \quad (W_A = \text{Actual})$$

(Energy of Rev) (Energy of Proc)

$$I \cdot R = A \cdot E + W_{IR}$$

I · R = loss of A · E

* quog. Stoddard \rightarrow I · R \propto charge is Entropy generation

* I · R $\propto \Delta S_{gen}$

I > 0

The irreversibility is directly proportional to entropy generation in Universe.

$$I_R = T_0 S_{gen}$$

$$T_R = T_0 S_g \text{ Universe}$$

$$= T_0 \cdot S_g \text{ Universe}$$

$$= T_0 (S_g \text{ system} + S_g \text{ surrounding})$$

$$I_R = T_0 \Delta S \text{ Universe}$$

$$\Delta E = T_0 \Delta S$$

2) A rate of heat received by heat engine from source of 9000 K is 6000 kJ/s the engine rejects heat to sink of 300 K the heat engine produce a power of 200 kW ^{Actual work} Determine irreversible rate of this process.

$$\begin{array}{r} 9000 \\ - 300 \\ \hline 8700 \end{array}$$

$$9000 \text{ K} - 300$$

$$W_{max} = \left(1 - \frac{T_0}{T_1}\right) Q = \frac{58 \text{ kJ}}{5800 \text{ kW}}$$

$$W_A = 200 \text{ kW}$$

$$I_R = W_{max} - W_A$$

$$\left(1 - \frac{300}{9000}\right) 6000$$

Summary & Exergy

$$\textcircled{1} \text{ Heat energy} = \text{Exergy} + \text{Aenergy}$$

\Rightarrow low grade energy = High grade energy + waste or losses.

$$\Rightarrow \text{low grade energy} = A \cdot E + U_A E$$

Dead state

{ Hot 70°C } $\Delta T = 93^\circ\text{C}$ → immediate Surrounding
 Potato 27°C . Dead state Environment (27°C) Dead state

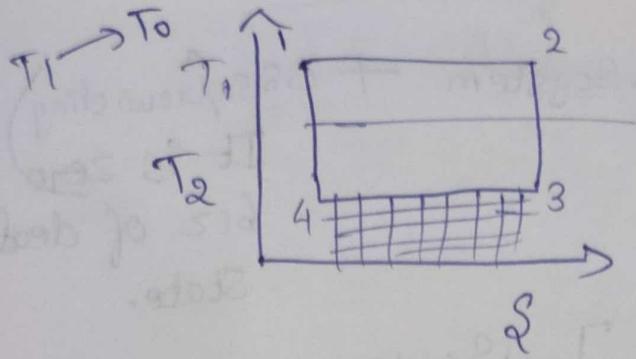
$$\Delta A \cdot E = (A \cdot E)_{\text{system}} - (A \cdot E)_{\text{dead state}}$$

$$\Delta A \cdot E = T_0 \left(\frac{T_1 - T_2}{T_1 T_2} \right)$$

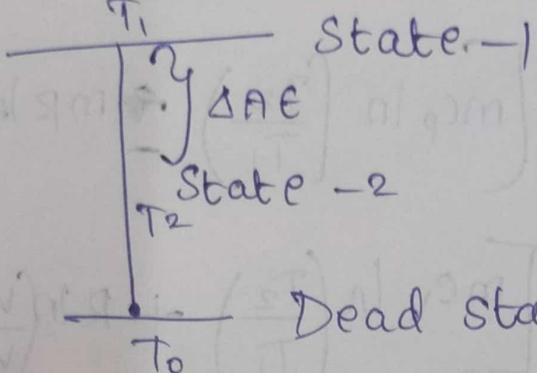
$$\Delta A \cdot E = T_0 \Delta \text{Surrounding}$$

State-1

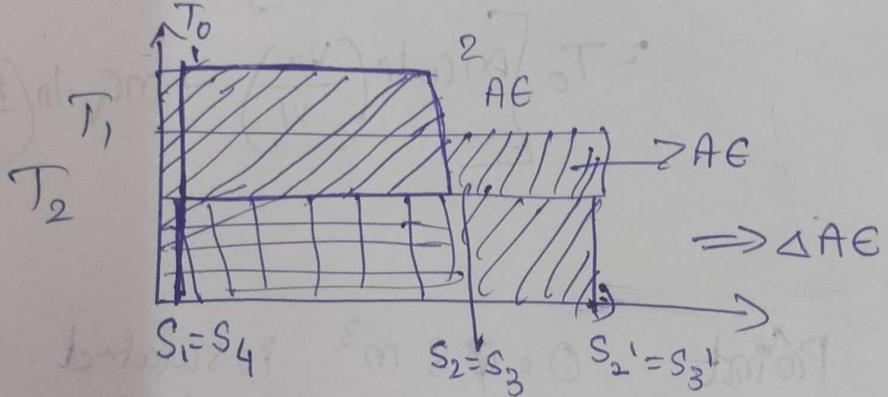
State-2 T, S diagram,
Dead state



$$T_1 > T_2 > T_0$$



Dead state



$$(VAE)_1 + \Delta AE$$

$$\Delta S = \frac{Q}{T}$$

$$T_0 \Delta S - T_0 \Delta S' \\ = T_0 (S_2 - S_1) - T_0 (S_2' - S_1)$$

for Irreversibility:

$$I \cdot R = w_{max} - w_A$$

$$I \cdot R = T_0 S_{gen \text{ Universe}}$$

$$= T_0 (S_{gen \text{ System}} + S_{gen \text{ Sur}})$$

$$I \cdot R = T_0 \Delta \cancel{S} S_{univ}$$

$$I \cdot R = T_0 (\Delta S_{\text{System}} + \Delta S_{\text{Surrounding}})$$

It is zero
bcz of dead state.

$$IR = T_0 \Delta S_{\text{System}}$$

For ideal gas,

$$\begin{aligned} IR &= T_0 \left[m c_p \ln \left(\frac{T_2}{T_1} \right) - m R \ln \left(\frac{P_2}{P_1} \right) \right] \\ &= T_0 \left[m c_v \ln \left(\frac{T_2}{T_1} \right) + R \ln \left(\frac{V_1}{V_2} \right) \right] \\ &= T_0 \left[m c_p \ln \left(\frac{V_2}{V_1} \right) + m c_v \ln \left(\frac{P_2}{P_1} \right) \right] \end{aligned}$$

Q1) A Point 0.08 m³ insulated resin tank contains 1.5 kg of ideal gas at 100 kPa. Electric work is done on the until the pressure in tank rise to 135 kPa. The loss in availability associate with process is? $\frac{\text{Energy}}{\text{Availability}}$

$$R = 188.9 \text{ J/kg K} \quad C_V = 680 \text{ J/kg K}$$

i) Specific heat of const volume = $C_V = 680 \text{ J/kg K}$
 temp of dead state = 298 K.

$$T_0 = 298 \text{ K}$$

$$IR = \Delta AL$$

$$IR = T_0 [m c_p \ln \left(\frac{V_2}{V_1} \right) + m c_v \ln \left(\frac{P_2}{P_1} \right)]$$

$$\left(\frac{V_2}{V_1} \right) = 1$$

$$\text{loss in A.E} = I \cdot R = 298 (1.08 (680) \ln \left(\frac{135}{100} \right))$$

$$IR = T_0 m c_v \ln \left(\frac{P_2}{P_1} \right)$$

$$IR = 91.219 \text{ KJ}$$

$$91.219 \text{ KJ}$$

$$\text{loss in A.E} = \underline{T} = T_0 \Delta S_{\text{gen}}$$

$$= T_0 (\Delta S_{\text{gas}} + \Delta S_{\text{water}})$$

$$\Delta S_{\text{gas}} = m c_p \ln \left(\frac{T_2}{T_1} \right)$$

$$\Delta S_{\text{water}} = \frac{Q}{T_1} = \frac{m L_V}{260 + 273}$$

$$m L_V = m g c_p (T_2 - T_1)$$

$$= 1662.5 (1) = m g \times 1.08$$

$$= 1662.5 \times 1.08 = 1800 \text{ J}$$

$$= 1800 \text{ J}$$

1) Exhaust gases leave an internal combustion engine at 800°C & 1 atm after having done 1050 kJ work per kg of gas in engine ($P_{\text{of gas}} = 1.1$) the temp of the surroundings is 30°C

- How much available energy per kg of gas is lost by throwing away the exhaust gases?
- What is the ratio of lost available energy to engine work?

$$\text{i) } A \cdot \epsilon_{800} = M C_p \left[(T - T_0) + T_0 \ln \frac{T_0}{T} \right]$$

$$= 1 \times 1.0 \ln (800 - 30) + (73 + 30)$$

$$= 425.55 \ln \left(\frac{303}{800 + 273} \right)$$

$$\text{lost} = \frac{425.55}{60} = 0.405$$

$$= 40.52 \text{ J}$$

2) A hot spring produces water at a temp of 56°C . The water flows into a large tank with a mean temp of 14°C at rate of 0.1 m^3 of water per min. What is rate of working of ideal heat engine which uses all the available energy?

$$V = 0.1 = \frac{0.1}{60} =$$

$$A \cdot \epsilon_{56^{\circ}\text{C}} = M C_p \left[(T - T_0) + T_0 \ln \frac{T_0}{T} \right]$$

$$\dot{m} = \rho X V$$

$$= 1000 \times \frac{0.1}{60}$$

$$A \cdot c = 1000 \times \frac{0.1}{60} \times 4.2 \left[\frac{(56 - 14) + 273 + 14}{\ln \frac{273 + 14}{273 + 56}} \right]$$

$$= 19.35 \text{ kW}$$

- 2) Air at 6 bar & 77°C through a turbine adiabatically with velocity of 90 m/sec & leaves the turbine at 1.2 bar & 7°C with velocity 150 m/sec. Determine per kg of air a) maximum work b) irreversibility c) Actual work. Assume surroundings at 25°C & 1 bar.

$$W_{\max} = h_1 - h_2 - T_0(s_1 - s_2) + \frac{c_1^2 - c_2^2}{2000}$$

$$W_{\max} = C_p(T_1 - T_2) - T_0(s_1 - s_2) + \frac{c_1^2 - c_2^2}{2000}$$

$$s_2 - s_1 = C_p \ln \left(\frac{T_2}{T_1} \right) - R \ln \left(\frac{P_2}{P_1} \right)$$

- 3) In a counter flow heat exchanger, 12 kg/sec air at 1000K is cooled to 600K using cooling water which enters the exchanger at 283K & leaves at 366K. If ambient conditions are 300K & 0.1 MPa. Determine a) water flow rate b) change in availability of air c) change in availability of water d) loss in availability.

$$Q_{air} = Q_{water}$$

$$m_a c_a (\Delta T)_{air} = m_w c_w (\Delta T)_w$$

$$12 \times 1.005 (1000 - 400) = m_a \times 4.187 (366 - 28)$$

$$m_a = 20.86 \text{ kg}$$

water flow rate

$$C_p \ln \frac{T_2}{T_1} = R \ln \left(\frac{P_2}{P_1} \right)$$

$$S_2 - S_1 = 1.005 \times \ln \left(\frac{400}{100} \right)$$

$$S_2 - S_1 = -0.9208$$

$$S_1 - S_2 = 0.9208$$

$$h_1 + h_2 + f(S_1, S_2)$$

$$\phi_1 - \phi_2 = 1.005 (1000 - 400) - 300 (0.9208)$$

$$\left(\frac{\partial P}{\partial T} \right)_{\text{sat}} = \left(\frac{\partial P}{\partial T} \right)_{\text{dew}} = 27.0$$